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NEW OPPORTUNITIES OF NUTRIENT RECYCLING IN WATER SERVICES

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Ravinteiden kierrätyksen uudet mahdollisuudet vesihuollossa

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EXECUTIVE SUMMARY

The KEHÄ project is funded by the European Regional Development Fund and this report is one part of the project invested into the research of new cutting-edge technologies for nutrient recycling in the water services.

The harmful discharge of nutrients such as phosphorus and nitrogen into surface water is known to deteriorate water quality and cause eutrophication. The most visible example of such deterioration for Finland is the Baltic Sea. Therefore, the European legislation such as the EU Urban Wastewater Treatment Directive 91/271/EEC and the Government of Finland Decree on Urban Wastewater Treatment 888/2006 demand an efficient removal of phosphorus and nitrogen from the wastewater treatment plants. This then leads to one important question: What should be done with the removed nutrients? The first European Sustainable Phosphorus Conference, which took place in Brussels on March 6-7, 2013 highlighted that the annual import of phosphorus to the European Union costs many billions of Euros every year. Not only this, the scientific community has recently warned that the planet is going to run out of phosphorus reserves in the coming 80 years. Thus, the answer to what should be done with the removed nutrients turns out to be simple yet profound - “nutrients recycling”.

This report, therefore, has analyzed the existing nutrient removal technologies based on mechanical, biological, chemical, combined and advanced models. Chapter 9, deals with the Limit of Technology concerning nutrient removal, and highlights the efficiencies of different models. The significant part of the report focuses on nutrient recovery, and the existing technologies that provide efficient recovery methods. It was observed that the recovered nutrient products could be used as magnesium ammonium phosphate or struvite, stabilized sludge, ash, nitrate products or simply applied to irrigation. To provide an overview of the applied science of nutrient recovery technologies, examples from countries such as Finland, Germany, Japan, the Netherlands, Norway, Switzerland and Sweden are discussed in Chapter 14. The report has also investigated into the emerging ideas and technologies in the field of nutrient recycling. Due to the scattered nature of such information both online and offline, some of the latest ideas might have been missed. Despite this, Chapter 15 shows that nutrient recycling technologies are constantly emerging, and that, the future is full of new and bold ideas. Overall, this research report highlights the existing as well as emerging technologies that play a very vital role of recovering nutrients. As such, a framework can be developed in the future about the new opportunities of nutrient recycling in water services.

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SYKLI
Suomen ympäristöopisto

CONTENTS

KEY DEFINITIONS

Aerobic / Oxic Oxygen available

Anaerobic No oxygen available

Anoxic No oxygen available but the oxygen can be taken from the nitrates. So, denitrification is possible in this stage, resulting in nitrogen removal

Effluent The water that is discharged after treatment

Influent The water that needs to be treated

Population Equivalent (PE) The pollution load of a household sewage produced by one individual in 24 hours

Total Nitrogen The sum of all types of nitrogen compounds that occur in various forms

Total Phosphorus The sum of all types of phosphorus compounds that occur in various forms

Volatile Fatty Acids (VFA) The group of fatty acid produced when microorganisms ferment carbohydrates

ABBREVIATIONS

A/O	Anaerobic/ Oxic
A^2O	Anaerobic Anoxic Oxic
BOD	Biochemical Oxygen Demand
EC	European Commission
ECA	European Court of Auditors
EEC	European Economic Community
EU	European Union
EUSBSR	European Union Strategy for Baltic Sea Region
HELCOM	Helsinki Commission
HSY	Helsinki Region Environmental Services Authority
mg/l	milligram per liter
m^3	Cubic meters
MUCT	Modified University of Capetown
N-P-K	Nitrogen- Phosphorus-Potassium
N	Nitrogen
P	Phosphorus
PE	Population Equivalent
PAO	Phosphorus Accumulating Organism
SITRA	Suomen Itsenäisyyden Juhlarahasto (The Finnish Innovation Fund)
TN	Total Nitrogen
TP	Total Phosphorus
UCT	University of Cape Town
VFA	Volatile Fatty Acid
WWTP	Wastewater Treatment Plant

WORDS IN FINNISH

Eutrophication	Rehevöityminen
Nitrogen	Typpi
Phosphorus	Fosfori
Potassium	Kalium
Sludge	Liete
Wastewater	Jätevesi

1. INTRODUCTION

When discharged into surface waters, nutrients such as phosphorus and nitrogen can adversely affect the water quality through the loss of dissolved oxygen and algae blooms. The harmful impacts of the nutrients' discharge into the surface waters have led to many strict regulations regarding the discharge limits from the Wastewater Treatment Plants (WWTPs). Therefore, in Finland, all wastewater utilities are required to remove phosphorus and nitrogen as per the legal limits. The numerical figures from the Finnish Environmental Institute show that the Finnish rivers have carried an annual average of 3400 tons of phosphorus and 74,000 tons of nitrogen into the Baltic Sea, which is an approximate 10% of the total nutrient loading (Finnish Environmental Institute 2015).

The European Union Urban Wastewater Directive of 1991 set a minimum level of nutrient discharge limits for the sensitive territories whereby 15 member states designated the entire territory as sensitive, Finland being one of them. The sensitive areas are directed to have at least 70-80 % of nitrogen removal and at least 80 % of phosphorus removal from the WWTPs. Finland has made significant developments in this field as for instance, Helsinki´s Viikinmäki WWTP achieves over 90% of nitrogen removal and over 95% of phosphorus removal (HSY 2017). The Government of Finland's Decree on Urban Wastewater Treatment 888/2006 directs the level of nutrient removal in municipal and urban areas inside Finland.

The legislative aspect of the nutrient recovery depends upon the proportional development of emerging technologies that can provide the desired level of performance. From the beginning of this century, there have been numerous remarkable achievements throughout the world that have improved the traditional and conventional processes for nutrient removal. The development of new technologies has increased the possibilities of effective nutrient removal with the least amount of nutrient discharge into the surface waters. Along with this, the strict discharge limits set by the governments and the municipalities have pushed the WWTPs to invest in effective new technologies. Therefore, this is the field where legislations and directives of the nutrient removal must collaborate with the latest research and development activities.

At the end of 2015, the European Commission presented a Circular Economy Package. Among the action plans, the package includes the initiatives for new regulations so that the organic and waste based fertilizers can move freely inside the Union like the synthetic and mine-based fertilizers. For this reason, the nutrients available in the wastewater could be recovered as high-quality fertilizers. The good news is that the European Commission´s circular economy proposes the revision of the Fertilizer Regulation 2003/2003 EC inside the European community.

Long-term sustainability of the circular economy is possible if the nutrients present in the wastewater are reused in society, so that the agricultural sector becomes self-sufficient in plant nutrients. As a result, the significant annual demand for phosphate-rock fertilizer could be mitigated. The scholarly statistics claim that at the current rate of consumption, the planet will run out of known phosphorus reserves in the next 80 years (Massachusetts Institute of Technology 2016). This can be a positive incentive for WWTPs to utilize the nutrients present in the wastewater to produce high quality fertilizers. The financial gain from the production of fertilizers can be further utilized in the renewal of the nutrient recovery technologies in the treatment plants. In this way, a circular flow of nutrients from agriculture, and, to agriculture could be achieved.

The first European Sustainable Phosphorus Conference took place in Brussels on the 6th and 7th of March, 2013. The conference highlighted that the annual import of phosphorus to the European Union is more than 2 billion Euros per year. Therefore, more than 66,000 new jobs could be created if the nutrients were recycled inside the European Union. For Finland, the Finnish Innovation Fund (SITRA) projects that the annual added value of recycling the nutrients could be up to 510 million Euros. (SITRA 2015.)

To rightfully serve this purpose, the report focuses mostly on research and development of the new technologies in nutrient removal and recycling. Therefore, the author has made a detailed survey into the cutting-edge technologies in the field of nutrient removal, recovery and reuse. The report provides a framework for the future development of the nutrient recovery processes which could be implemented at the national Finnish level to achieve the state-of-the-art technology with the highest level of efficiency in water services.

2. OBJECTIVES

The concept of circular economy and the concept of circulating nutrients inside the European Union is a positive development. This has led to the European-level research into the future provisions of the fertilizer acts that will encourage the recovery and reuse of nutrients from the municipal wastewater. There is a need to outline the role of Finland in this aspect, both economically and technologically. Therefore, the KEHÄ project aims to highlight the new opportunities for energy and nutrient recycling in the water services.

2.1 The KEHÄ Project

As a project, KEHÄ, or CIRCLE, focuses on the recycling and re-use of energy and nutrients in the municipal wastewater treatment and consequently reduce the use of imported nutrients and energy in relation to the volume of production. The project is run in a collateral cooperation with Häme University of Applied Sciences, Laurea University of Applied Sciences, Aalto University, Association for Water and the Environment of Western Uusimaa and Environmental School of Finland. The project is funded by the Regional Councils of Helsinki-Uusimaa and Häme Region. The primary objectives of the project are:

- ✓ To accelerate and support the transition into blue energy and bio-economy
- ✓ To enhance the implementation of resource wise solutions in water services
- ✓ To improve the cost efficiency of using nutrients and energy in water services
- ✓ To improve the wastewater treatment ratio
- ✓ To provide comparable data for the process, environmental effects and spatial data of water services

The project aims at bringing about real changes in the energy efficient and nutrient recovery technologies through the following methods

- ✓ Development of water treatment process control
- ✓ Implementation of appropriate spatial data management and sophisticated digital information on water solutions
- ✓ Focus on environmental approach to water treatment
- ✓ Developing instrument clusters and networked operating models.

2.2 This Report

This report is one branch of the KEHÄ project carried out by the Häme University of Applied Sciences and the School of Technology in Hämeenlinna, Finland. Therefore, most of the information relates to the technological development of nutrient recycling processes in municipal wastewater treatment. The main objectives of this report are:

- ✓ To analyze the existing technologies in nutrient removal, recovery and reuse that have the highest level of observed efficiency
- ✓ To enhance the technologies for nutrient recycling and reuse in the municipal wastewater treatment
- ✓ To develop a framework for the future development of the nutrient recovery processes that could be applied to Finland in the near future.

3. LEGISLATION

Since the formation of the European Union, there have been many directives and collateral agreements between the member countries to promote the quality of the surface waters inside the European continent. The EU sets the standard, which the member states must maintain as their minimum standard for nutrient removal in various fields. At the national level, Finland has brought forward numerous acts and decrees that clearly state the restrictions on certain discharges such as nitrates from agriculture into waters. At the European level, the Urban Wastewater Treatment Directive (91/271/EEC) authorizes the requirements for the European communities. It is, therefore, beneficial to make a brief legislative review of the European and the Finnish directives that relate to the nutrient removal from WWTPs as well as the laws on the free movement of fertilizers inside the community. This knowledge is vital because without the permission of the European laws, the high-quality fertilizers recovered from the wastewater nutrients cannot have the legal rights to be applied in agriculture. The upcoming subsections are summarized from the online legislative platforms Finlex (http://www.finlex.fi/en/) and EUR-Lex (http://eur-lex.europa.eu).

3.1 EU Urban Wastewater Treatment Directive 91/271/EEC

The EU Urban Wastewater Treatment Directive 91/271/EEC clearly encourages the recycling of the sludge from the wastewater treatment, and discourages the disposal of sludge into the surface waters. Therefore, to ensure total natural protection, the monitoring of the treatment plants is suggested, and the member states have to present their national programs to the European Commission.

Article 4 of the directive mentions that wastewater of a treatment plant before discharge should be processed through no less than secondary treatment which involves biological treatment or some similar processes so that the treated water complies with the quality standards. The amount of nitrogen and phosphorus in the discharged or treated water in the sensitive areas should be as mentioned in the following table 1.

Table 1. Nutrient discharge limit and reduction under the EU Ur ban Wastewater Treatment Directive 91/271/EEC

Parameters	**Value (Concentration)**	**Value (Reduction)**
Total Nitrogen (TN)		70–80 %
Plants of 10,000–100,000 PE*	15 mg/l	
Plants > 100,000 PE	10 mg/l	
Total Phosphorus (TP)		80 %
Plants of 10,000–100,000 PE	2 mg/l	
Plants > 100,000 PE	1 mg/l	

(PE*, or population equivalent- refers to the pollution load of household sewage produced by one individual in 24 hours)

Table 1 shows that the amount of TN and TP in the discharged water (or effluent) should not exceed a certain value in the sensitive areas. Therefore, all WWTPs are obligated to follow this directive to prevent the accumulation of phosphorus and nitrogen in the water bodies which results in eutrophication. The key points of this directive are:

- ✓ Article 4 mentions the requirement for a secondary wastewater treatment for agglomeration with more than 10,000 PE and for all discharges to the freshwaters and estuaries from agglomerations with more than 2,000 PE.
- ✓ Article 5 lays out a more stringent treatment for discharges into the catchments of those areas designated as sensitive, thus requiring nutrient removal from wastewater prior to discharge.

3.2 The EU Fertilizer Regulation 2003/2003/EC

The massive amount of nutrients that are present in wastewater can be recovered to produce fertilizers. Therefore, it is important to look into the legislative aspects of the quality of fertilizers that are circulated inside the European Union. According to the Fertilizer regulation 2003/2003/ EC, fertilizers in each member state must display certain technical characteristics as laid down by the provisions. After that, they can be designated by the letters “EC”. Some of the key points of this regulation are mentioned below:

- ✓ Since ammonium nitrate products could be used both as fertilizers and explosives, it is important to have tough regulations on ammonia based fertilizers.
- ✓ It is essential for the manufacturers of nitrate fertilizers to perform detonation - resistance tests before placing on the market.

- ✓ Fertilizers can be contaminated by substances that can potentially harm humans, animals and plants. Therefore, some provisions are required to test the public safety factor of these fertilizers.

3.3 The EU Council Directive 91/676/ EEC (Nitrate Dire2ctive)

This directive implemented the legislation of reducing nitrates from the agricultural sources. As a consequence, land application of biosolids was banned in some countries such as Switzerland, the Netherlands and Sweden (Oleszkiewicz & Barnard 2006).

The directive aims to reduce water pollution from nitrates that are used in agriculture. The key points of the legislation are:

- ✓ Designation of vulnerable zones for all the draining that are or could be affected by high level of nitrates and eutrophication.
- ✓ Establishment of mandatory action programs for these areas, taking into account the scientific and environmental data.
- ✓ A code for good agricultural practice concerning fertilizer use.

3.4 The EU Sewage Sludge Directive 86/278/EEC

The directive relates to the soil protection when sludge is used in the agriculture. It has set the rules and regulations on how farmers can use sewage sludge as fertilizer without causing pollution to soil, surface and ground water. The limits have been set on the concentration of the following heavy metals:

- ✓ Cadmium
- ✓ Copper
- ✓ Nickel
- ✓ Lead
- ✓ Zinc
- ✓ Mercury
- ✓ Chromium

And subsequently, the application of sludge that exceeds the limit of these heavy metals is banned inside the European Union. The key points of the directive are mentioned below:

- ✓ In normal situations, the sludge has to be treated before being used in farming. However, in some EU countries it may be allowed if it is worked or injected into the soil.

- ✓ However, sludge may not be used at all on grasslands or crops that are going to be grazed by animals and for a minimum of 3 weeks before harvesting. Similarly, sludge application is not allowed on fruits and vegetable crops during the growing season (except fruit trees). In addition, the sludge is prohibited on soil that is used to grow fruit and vegetables which are in direct contact with soil and eaten raw. This ban applies for 10 months before the harvest as well as during the harvest.

3.5 Government of Finland Decree on Limiting Certain Emissions from Agriculture and Horticulture (1250/2014, amendments up to 1261/2015 included)

The Government of Finland Decree on the Discharge of Nitrates from Agriculture concerns the protection of water against the pollution caused by nitrates from agricultural sources. It sets out the instruction for good agricultural practices, and the decree is followed across the country. The following are the key points of the legislation:

- ✓ Manure storages and manure gutters must be watertight such that no leakage occurs.
- ✓ Nitrogen fertilizers must not be applied on snow-covered, frozen or water saturated ground.
- ✓ Use of nitrogen fertilizer is prohibited on areas closer than 5 meters from a water course.
- ✓ The scale and use of nitrogen fertilizer is based on the average crop yield, cultivation zone and crop rotation.

3.6 Fertiliser Product Act 539/2006 of Finland

The Fertiliser Product Act of Finland aims to ensure the quality of plant protection, foodstuffs and the environment and to promote the supply of safe fertilizer products that are of good quality and suitable for plant production. Hence, this legislation also accounts for the marketing of new fertilizers that are manufactured, and their transport, import, export and use. The key points of the Act are mentioned below:

- ✓ Fertilizer product must be uniform and should comply with the legislative requirements.
- ✓ Only the fertilizers that have national designation or EC designation can be imported, placed on the market, or manufactured for marketing.

- ✓ A new type designation may be added to the national type designation of fertilizer product if it contains the nutrients in quantities that are beneficial to the plants and their growth.

- ✓ The approval of a new fertilizer product is decided by the Finnish Food Safety Authority.

3.7 Government of Finland Decree on Treating Domestic Wastewater in Areas Outside Sewer Networks (157/2017)

This decree concerns the regulations regarding the properties that produce wastewater less than 100 PE and do not need an environmental permit. According to the section 2 of the decree, the nutrient load in these properties is defined by person – equivalent load, i.e., TP load of 2.2 g/person/day and TN load of 14 g/person/day. Section 3 of the decree sets the general requirements for nutrient removal of 80% of BOD, 70% of TP and 30% of TN.

4. THE FINNISH ROLE IN BALTIC SEA PROTECTION

This chapter highlights the utmost importance of nutrient removal in the Finnish context from the environmental point of view. The capital city of Finland is one of the leading forces in the European Union to ensure environmental protection of the European Community, and bears name to the two important stages of mutual cooperation- the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area and the Helsinki Commission (HELCOM).

The high amount of nutrients such as phosphorus, ammonia and nitrate in the discharged water (effluent) of the WWTPs can stimulate the growth of microorganisms in the receiving water body. This can lead to the undesired growth of aquatic algae and the reduction of dissolved oxygen. In some cases, the high amount of Nitrate such as over 30 parts per million (ppm) can inhibit the growth and immune system of aquatic species (Petrucio & Esteves 2000).

The ratios by weight for an average community of algae are approximately measured as 1 P (Phosphorus) : 7 N (Nitrogen) : 40 C (Carbon) : 100 dry weight : 500 fresh weight. Hence, if one of the elements is growth limiting in the water body, phosphorus can theoretically generate 500 times its weight in living algae, nitrogen 71 times and carbon 12 times. (Vallentyne 1974.) Therefore, the clear impact of these nutrients in the water can be easily seen in seas or lakes where eutrophication has occurred. The 2016 report of the European Court of Auditors (ECA) has defined eutrophication as the process that occurs when excess nutrients generated mostly by human activity, mainly nitrogen and phosphorus, enter a body of water. Thereby, causing intense and potentially toxic algal blooms. The most visible example of eutrophication for Finland is the Baltic Sea catchment area, where nutrient over-enrichment has produced significant algal bloom. The Baltic Sea has become one of the world´s most polluted seas and eutrophication is its greatest challenge (ECA 2016).

To prevent further eutrophication in the Baltic Sea, Finland has its own stricter regulations than the requirement of the EU Urban Wastewater Directive (91/271/EEC). As one of the eight EU member countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden) to border the Baltic Sea, Finland has a common role in minimizing the nutrient load to the sea. A regional convention was signed in 1974 known as the Helsinki Convention on the Protection of the Marine Environment of the

Baltic Sea Area. Similarly, HELCOM proposed the Baltic Sea Action plan to restore the Baltic Sea environmental status to the good by 2021.

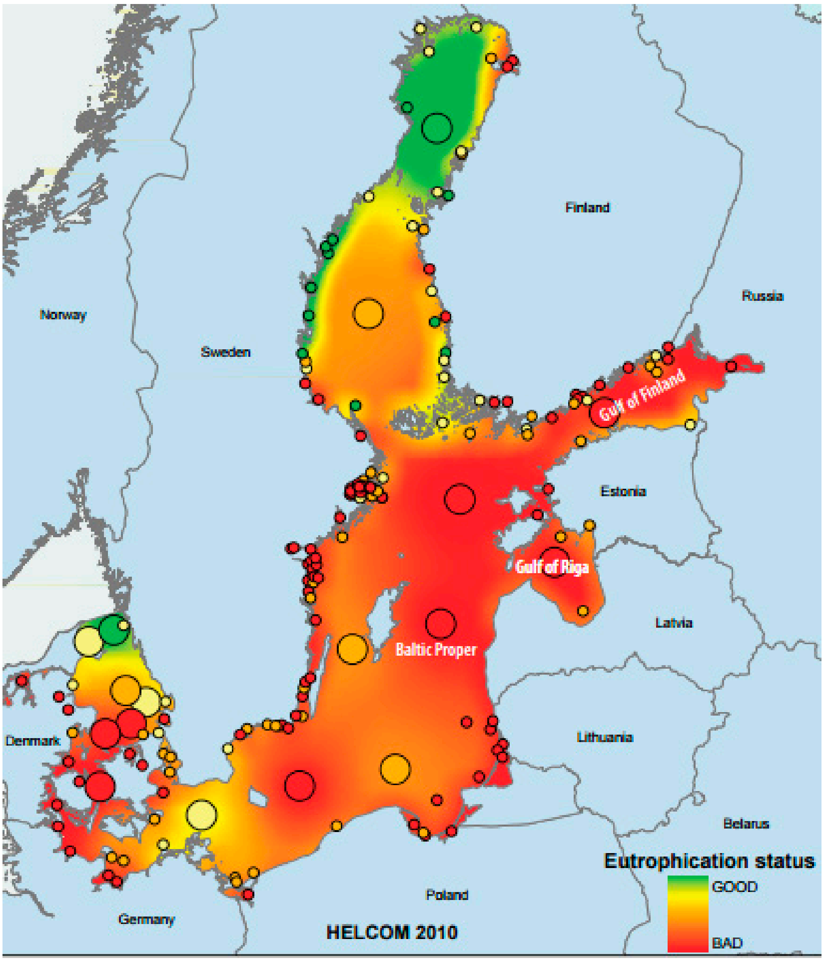


Figure 1. Eutrophication of the Baltic Sea as investigated by the Helsinki Commission (HELCOM 2010)

The eutrophication status of the Baltic Sea, is shown in Figure 1 and provided by HELCOM. The Baltic Proper, the Gulf of Riga and the eastern part of the Gulf of Finland show the highest levels of eutrophication. The western coast of Finland in the Gulf of Bothnia has performed well, with a very low level of eutrophication. The member states of the European Union that share the Baltic Sea, along with Russia, have a common responsibility to minimize this trend in the sea.

Not all the Baltic Sea member states which were required to comply with the Urban Wastewater directive 91/271/EEC were able to fulfill their obligations by 2012. Only Finland and Germany were very close to full compliance with Articles 4 and 5 of the directive setting out secondary and more stringent treatment requirements from the WWTPs. (ECA 2016.)

In 2013, the signatory countries of the HELCOM agreed to reduce the annual input of phosphorus to the sea by 41% and nitrogen by 13% (ECA 2016).

5. WASTEWATER TREATMENT OVERVIEW

The wastewater is full of resources which, if properly channeled, could fulfil important nutritional demands of our planet. Technologies to recover essential nutrients from the wastewater have become highly essential due to the increase in fertilizer prices and strict discharge limits on these nutrients. There are also significant worries about the long-term depletion of potassium and phosphorus which are extracted from the mineral deposits. Phosphate rock is non-renewable and with the current rate of extraction the planet will run out of deposits in the future. The overall sustainability of WWTPs can be improved by reducing the use of non-renewable resources, minimizing waste generation and implementing resource recycling approaches (Ahmed et al. 2015).

Wastewater has significant amount of nitrogen and phosphorus. In domestic wastewater, almost 70–80 % of nitrogen and 50 % of phosphorus are contained in the urine. (Jönsson 2001; Larsen and Gujer 1996). Therefore, wastewater can be a good source of Phosphate fertilizer after efficient recovery processes. There is an opportunity to produce Struvite ($MgNH_4PO_4 \cdot 6H_2O$), which in itself is a Phosphate Fertilizer and a perfect alternative to the rock-Phosphate deposits which are depleting at an alarming rate (Rahman et al. 2013).

Wastewater treatment normally involves mechanical, biological, chemical and physical processes to remove organic matters and nutrients. The following are the typical stages of the wastewater treatment:

Preliminary treatment:

> This is the initial phase of the wastewater treatment in which the incoming wastewater passes through screen.

Primary treatment:

> In primary treatment phase, wastewater is held in settling tanks. The heavier solids settle at the bottom and the lighter solids float on the surface, which are then pumped out of the tank and scrapped away.

Secondary treatment:

> This phase is also called activated sludge process in which incoming wastewater is mixed with seed sludge full of decomposing microorganisms in aeration tanks. The process produces heavy particles that settle at the bottom of the tank which are separated as secondary sludge.

Tertiary or advanced treatment:

> Tertiary or advanced treatment is a final treatment phase which ensures that the treated wastewater is environmentally safe for discharge. This process includes filtration, disinfection, nutrients removal etc.

Fourth treatment:

> Even after primary, secondary and tertiary treatments; wastewater can still contain pharmaceuticals, hormones, industrial chemicals, micro-pollutants and other toxic compounds which are removed in the fourth treatment phase. One such example of quaternary treatment is the addition of activated carbon. Fourth treatment phase has been recently practiced in Germany and Switzerland and is forecasted to be widely popular in future.

Figure 2 shows different processes of WWTPs.

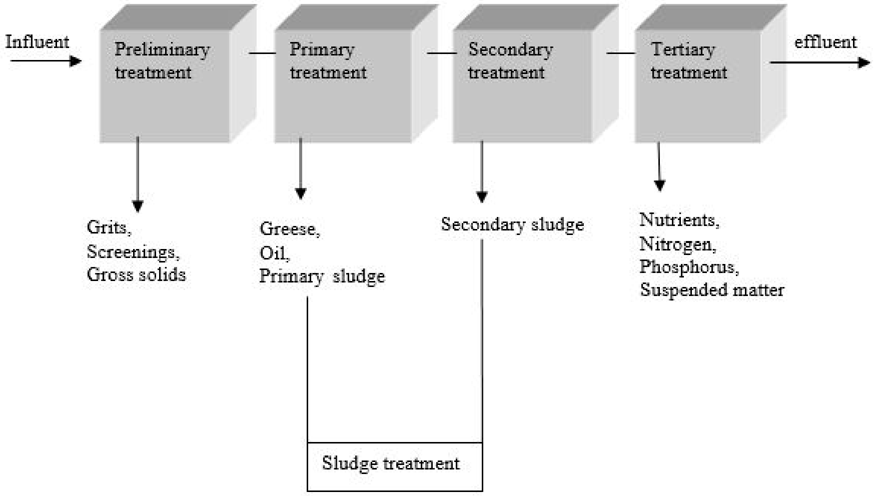


Figure 2. Typical processes of WWTPs excluding the fourth treatment (designed after the literature review of Ruotsalainen 2011; Metcalf & Eddy 2003)

6. NITROGEN REMOVAL TECHNOLOGIES

The European Union Directive for Urban Wastewater Treatment demands 70%–80% of nitrogen removal from the incoming influent. The following table 2 shows the directive for effluent concentration standard.

Table 1. Effluent standard according to the European Union Urban Wastewater Treatment Directive for sensitive areas prone to eutrophication

Parameters	**Value (Concentration)**	**Value (Reduction)**
TN		70–80%
Plants of 10,000–100,000 PE	15 mg/l	
Plants > 100,000 PE	10 mg/l	

Nitrogen, as mentioned in the previous chapters, is a significant contributor of eutrophication in the aquatic bodies. Algae and plankton growth require nitrogen as the nutrient. Thus, it is responsible for the decreased levels of dissolved oxygen, increased level of toxins, reduced water clarity and bad odor (Oleszkiewicz et al., 2015). Therefore, it is vital to remove nitrogen from wastewater.

The biological nutrient removal occurs in the phases of nitrification and denitrification. During nitrification, the ammonia (NH_4^+) is first converted to nitrite (NO_2^-) and then to nitrate nitrogen (NO_3^-). And subsequently, during denitrification, the nitrate nitrogen is converted to nitrogen gas (N_2) as shown in figure 3.

The chemical reactions for biological nitrogen removal are:

Nitrification:

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Denitrification:

$$2NO_3^- + 10_e^- + 12H^+ \rightarrow N_2 + 5CO_2 + 6H_2O$$

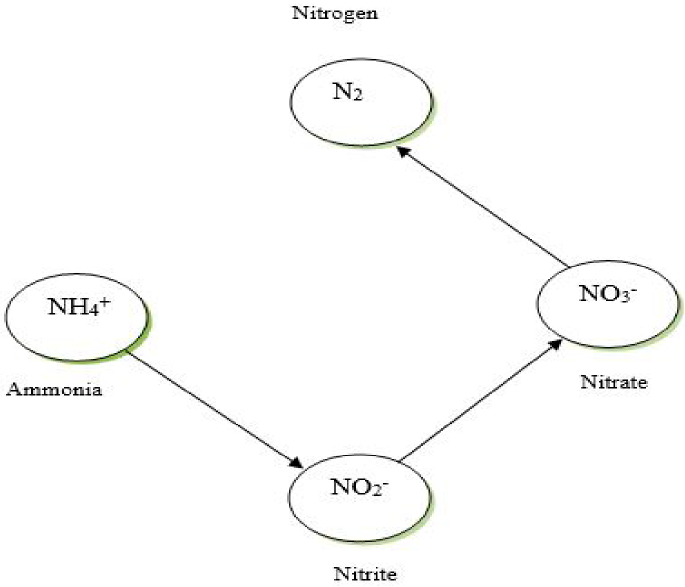


Figure 3. Nitrification- denitrification in wastewater treatment process

During nitrification, aerobic autotrophic bacteria *Nitrosomonas* and *Nitrobacter* are responsible for oxidizing ammonium nitrogen to nitrate nitrogen. These bacteria require oxygen for their growth. Therefore, nitrification is an aerobic process.

Denitrification involves heterotrophic organisms that reduce nitrate to nitrogen gas. These bacteria need organic carbon source as their food under anoxic conditions. As these bacteria break down nitrate, nitrogen gas is released which is then trapped in the filter media. The highest denitrification rate occurs at the pH range of 7-7.5 (Wiesmann et al. 2002).

6.1 Suspended Growth Process

In the suspended growth process, microorganisms treating the waste suspend in the wastewater. Commonly, in the activated sludge process, microorganisms actively degrade the organic matter under aerobic conditions. Subsequently, the settled biomass is returned to the aeration tank or removed. Biological nutrient removal, hence, is realized in the activated sludge process with suspended growth. The following diagram in figure 4 shows the suspended growth process.

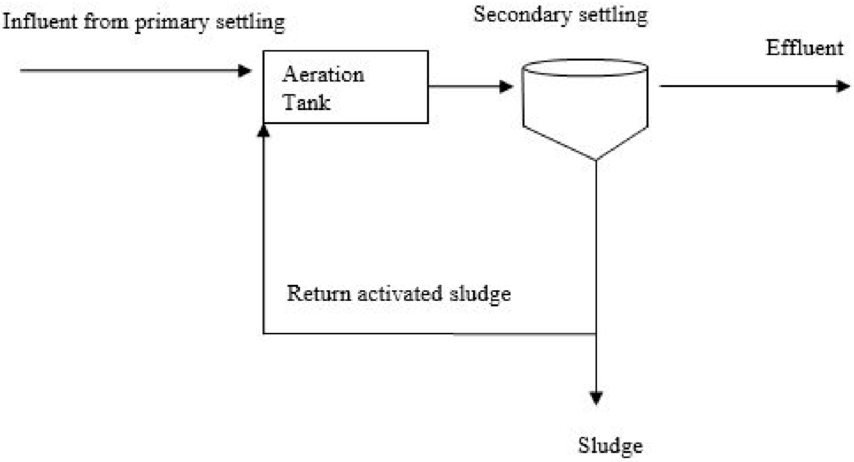


Figure 4. Biological nitrogen removal with suspended growth in the activated sludge process

6.2 Attached Growth Process

In attached growth process, the microorganisms treating the waste are attached to an inert material or medium. As a result, the wastewater flows over the media. The medium can be rock, slag, or special plastic or ceramics material. Subsequently, there is a formation of a biofilm on the material. Biofilm is an aggregate of microorganisms often attached to a surface and embedded in a self-produced matrix of extracellular polymeric substances that make the cells stick to each other. Attached growth process depends on the oxygen amount and the transfer of substrate mass from liquid stream to the biofilm.

One of the most conventional aerobic attached growth processes is called a trickling filter. In a trickling filter, the wastewater is trickled over a medium The sewage or waste stream flow over the medium thus causing a layer of biofilm to grow. Biological Aerated Filters (BAF) are another form of attached growth process which provide better filtration (Oleszkiewicz et al. 2015).

7. PHOSPHORUS REMOVAL TECHNOLOGIES

This chapter is the technical review of the phosphorus removal technologies currently applied to most WWTPs. As explained in the previous chapters, one of the leading causes of eutrophication is phosphorus. Therefore, municipal WWTPs have to remove phosphorus from the incoming untreated water (known as influent) below the legal limits. According to the EU Urban Wastewater Treatment Directive (91/271/EEC), the amount of phosphorus in the discharged water (known as effluent) should be less than 1 mg/l for the treatment plants greater than 100,000 PE. The directive for phosphorus in the European Union is presented in table 3.

Table 1. EU Council Directive, (91 /271 /EEC) for TP in the Effluent

Population Equivalent	**Value Concentration**	**Reduction %**
10,000 – 100,000	2 mg/l	70 – 80%
>100,000	1 mg/l	80%

The minimum effluent nutrient levels as directed by the European Council Directive as shown in table 3 aim to protect the sensitive areas of the Europe prone to eutrophication. However, Finland has its own stricter environmental permits, and so, the nutrient treatment is stringent (Ruotsalainen 2011). The best practices to remove nutrients from the wastewater include biological and/or chemical processes. The concept of removal is the biological uptake by microorganism, and the chemical precipitation with the help of metal cation. The individual treatment plants have individual targets, therefore, either one of them or both removal methods are applied.

With the large diversity of nutrient removal in Europe, the most widely and dominantly used process is the biological phosphorus removal (Oleszkiewicz & Barnard 2006).

7.1 Enhanced Biological Phosphorus Removal (EBPR)

Within the biological nutrient removal technologies, Enhanced Biological Phosphorus Removal (EBPR) is well established because of its capacity to achieve effluent TP of 0.5 mg/l. (Wu et al. 2011; Liu et al. 2009). But, it is also possible to increase the nutrient removal rate of TP up to 0.1 mg/l with an adequate supply of Volatile Fatty Acids (VFA) and granular filtration (Barnard et al. 2012; Subramanian et al. 2012).

The primary objective of this process is to decrease the amount of phosphorus in the activated sludge system with the aid of specific organisms. Therefore, there are aerobic Phosphorus Accumulating Organisms (PAO). The stimulation of the growth of the organism can be achieved if the anaerobic (without oxygen) and aerobic (with oxygen) conditions alternate in turn and VFA are added or formed in the anaerobic condition by the fermenting bacteria (Ruotsalainen 2011).

The removal capacity of this process depends upon the uptake and storage of phosphorus by the PAOs, and so a competitive advantage should be provided for their survival. As the phosphorus is accumulated by the PAOs, the phosphorus load increases in the solid stream and hence it can be ideally removed from there. When bacteria consume the substrate, they remove phosphorus from the liquid stream which is ingested into their biomass. This removal is enhanced by selecting PAOs that not only consume phosphorus for their cellular functions, but also accumulate large quantities of polyphosphate within their cell. (Oleszkiewicz et al. 2015.)

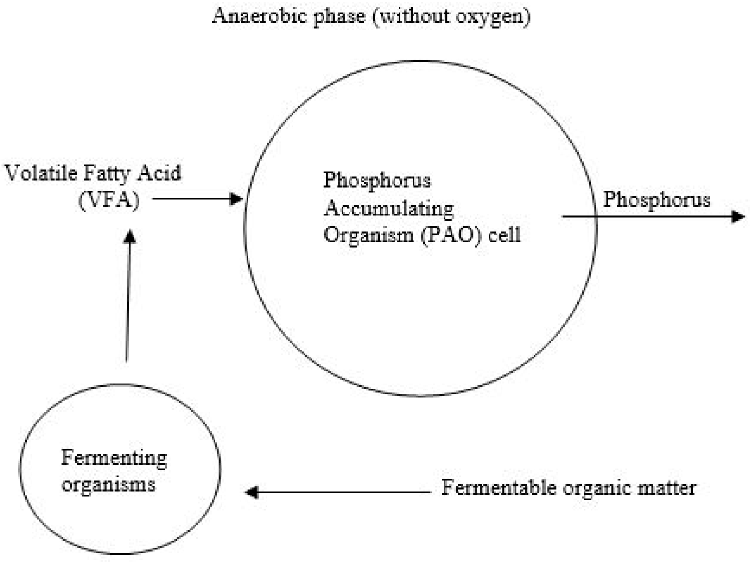


Figure 5. PAOs in the anaerobic phase. (designed after the literature review of Wentzel et al. 2008)

As shown in Figure 5, in the anaerobic phase of the EBPR, phosphorus is released by the PAOs after they consume VFA supplied by the fermenting organisms.

After being subjected to oxygen, as shown in figure 6, these PAOs accumulate more phosphorus into their cells than what they initially released during the anaerobic phase. With a sufficient supply of oxygen, a net removal of phosphorus from the liquid stream is achieved (Oleszkiewicz et al., 2015).

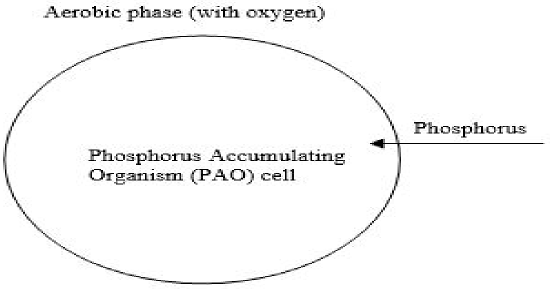


Figure 6. PAOs in the presence of oxygen. (designed after the literature review of Wentzel et al. 2008)

To achieve the effluent TP below 0.1 mg/l in the discharged water, EBPR requires a sufficient supply of VFA and tertiary filtration (Barnard et al. 2012).

The upcoming subsections highlight the most common configurations for EBPR processes.

7.1.1 Phoredox (A/O Process)

A/O refers to Anaerobic (no oxygen) / Oxic (with oxygen) phases. This process configuration ensures that a competitive advantage is provided to the PAOs so they are enriched in biomass. The system has two tanks, an anaerobic tank followed by an aerobic tank. Ruotsalainen (2011) mentions that this process does not provide conditions for nitrogen removal, however, in high temperatures it is difficult to prevent the oxidation of ammonia into nitrate, known as nitrification. The following diagram shows the A/O Phoredox process configuration:

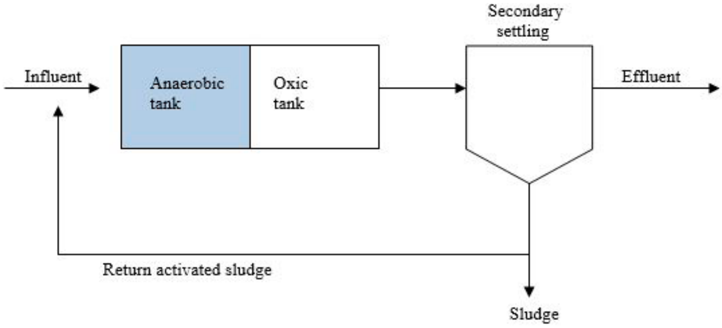


Figure 7. The A/O Phoredox process (adapted from Metcalf & Eddy 2003)

7.1.2 3-Stage Modified Bardenpho (A^2/ O)

The A^2/ O process is modified from A/O process in that it offers an anoxic tank for denitrification. The total configuration is of Anaerobic- Anoxic-Oxic phases. So, this process is beneficial in the removal of both phosphorus and nitrogen. Figure 8 shows the configuration for the A^2/O process:

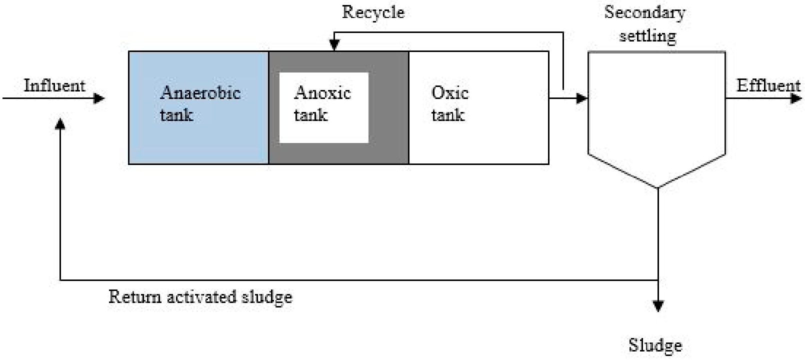


Figure 8. 3-stage modified Bardenpho process (adapted from Metcalf & Eddy 2003; Ruotsalainen 2011)

The three phases are:

- ✓ Anaerobic phase: no oxygen available
- ✓ Anoxic: no oxygen available, but presence of bound oxygen in e.g. nitrates. So denitrification is possible in this stage, resulting in nitrogen removal
- ✓ Aerobic: oxygen available

In the 3rd Stage, the Bardenpho Process, nitrified mixed liquor from the aerobic zone is introduced to the anoxic zone, thus providing chemically bound oxygen as nitrate or nitrite. Due to denitrification, the return activated sludge, as shown in the figure, receives less nitrate (Ruotsalainen 2011).

7.1.3 Modified Bardenpho (5-Stage Process)

The 5-Stage Modified Bardenpho process has 5 phases of anaerobic, anoxic and aerobic tanks to remove phosphorus, nitrogen, and carbon. Figure 9 shows the system configuration for this process.

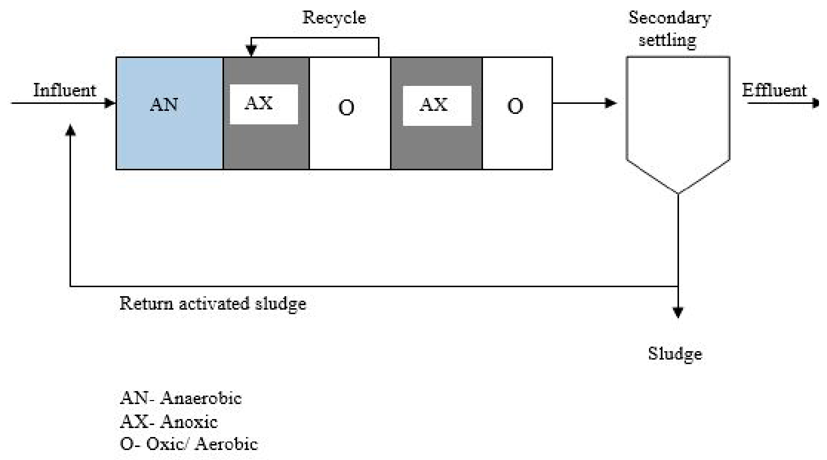


Figure 9. Modified 5 Stage Bardenpho Process (designed after the literature review of Metcalf & Eddy 2003)

The denitrification occurs in the Anoxic tanks (marked as AX in the figure), and the minimization of phosphorus is realized in the secondary settling (Ruotsalainen 2011).

7.1.4 UCT- University of Cape Town Process

In the weaker wastewaters, it is essential to lower the amount of nitrates in the anaerobic zone of the treatment plant. Therefore, this process discharges the return activated sludge to the anoxic tank which leads to the reduction of nitrates in the anaerobic tank. Figure 10, below, shows the UCT configuration.

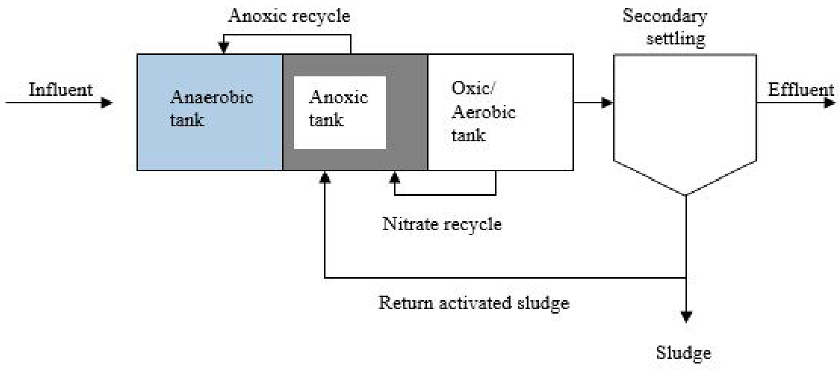


Figure 10. University of Cape Town-UCT process (adapted from Metcalf & Eddy2003; Ruotsalainen 2011)

With this arrangement, the effluent concentration of 0.18 mg/l total-phosphorus is achieved (Nordvästra Skånes Vatten och Avlopp 2010; cited by Ruotsalainen 2011).

7.1.5 Modified University of Cape Town (MUCT) Process

The modified version of University of Cape Town Process (UCT) is called the MUCT process, and it differs from the UCT in that the Anoxic Tank is divided into two zones. The configuration of this process is shown in figure 11.

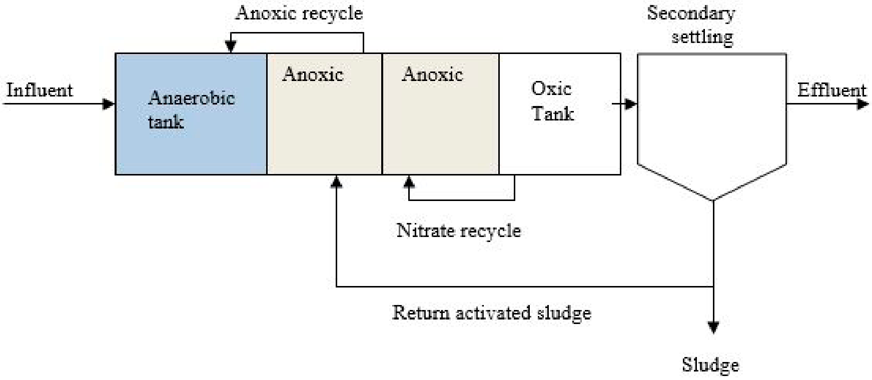


Figure 11. Modified University of Cape Town (MUCT) process (adapted from Metcalf & Eddy 2003)

The dynamics of the splitting tank is to convey the return activated sludge to the first anoxic tank, and internal recycle from the oxic tank to the second anoxic tank where denitrification occurs. The anoxic recycle from the first anoxic tank is further sent to the anaerobic tank.

7.1.6 Virginia Initiative Plant (VIP)

The Virginia Initiative Plant, or VIP process has many similarities with the A^2O and UCT processes, but differs in the recycling methods and the phases. The configuration for this process is shown in figure 12.

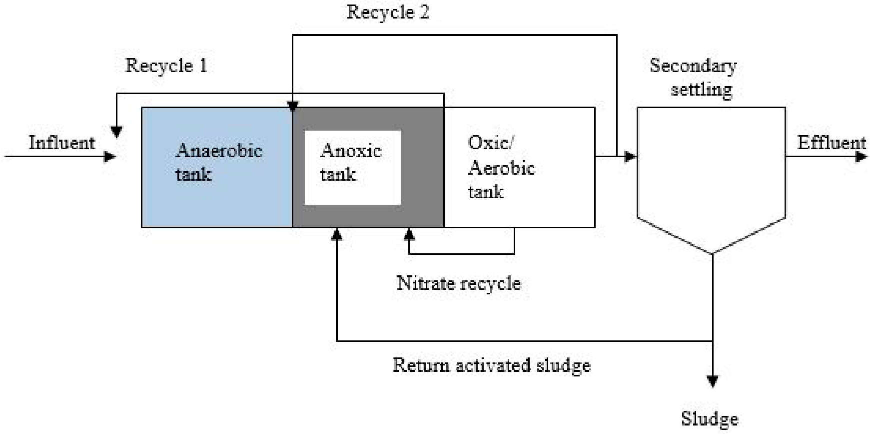


Figure 12. VIP process (adapted from Metcalf & Eddy 2003)

7.1.7 Johannesburg (JHB)

JHB is the modified version of the 5-stage Bardenpho process. The design configuration is shown in figure 13.

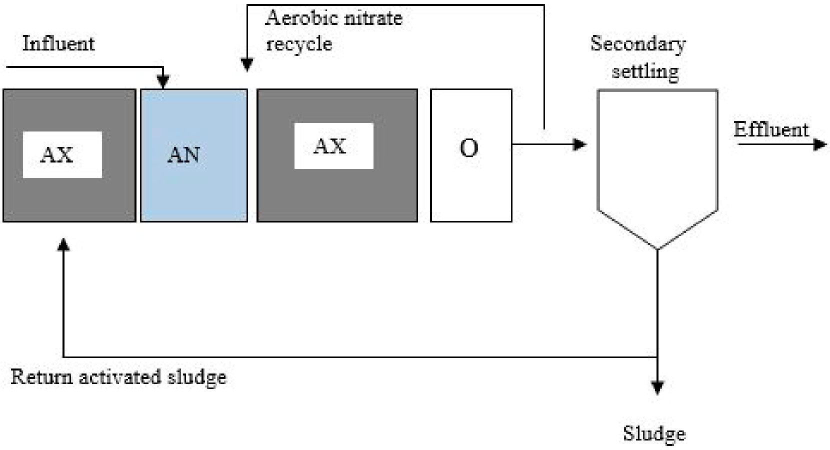


Figure 13. Johannesburg Process (Adapted from Metcalf & Eddy 2003)

7.1.8 PhoStrip

This process utilizes biological as well as chemical phosphorus removal. The configuration of the PhoStrip system is shown in figure 14.

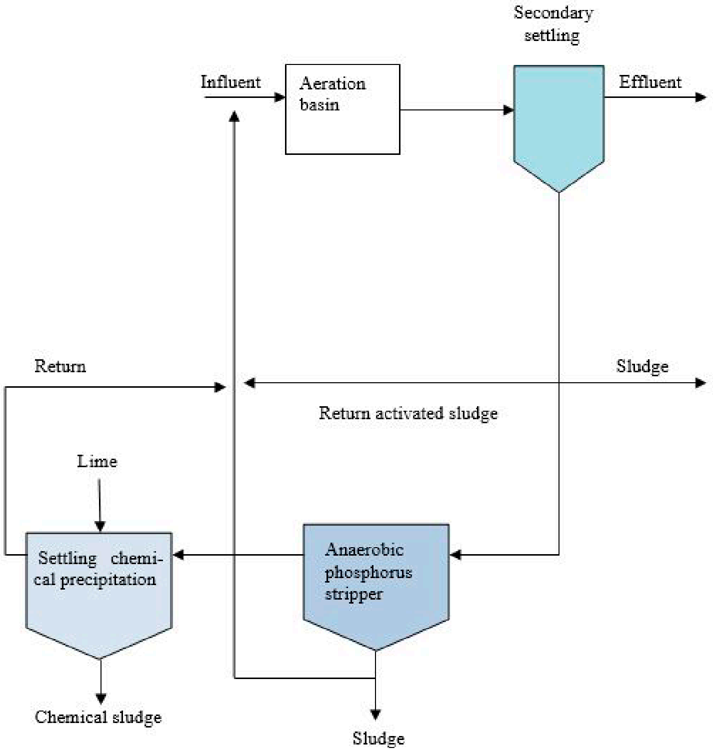


Figure 14. PhoStrip process configuration (adapted from Metcalf & Eddy 2003)

In the PhoStrip process, 10–30 % of the influent wastewater is pumped to the anaerobic phosphorus stripper. In this tank, phosphorus is released thus making it easy to be removed chemically in the next precipitating tank. Ruotsalainen (2011) mentions that if the precipitant is lime, the dose or concentration of the precipitant is dependent on the alkalinity of the wastewater. In other cases, if alum or iron salts are the precipitator, the dose is dependent on the amount of phosphorus released.

7.1.9 Bio-denipho

This Danish system removes both nitrogen and phosphorus with biological treatment. The process has been in practice in the existing large WWTPs of Denmark such as Lynetten and Damhusåen. The following figure 15 shows the configuration for Bio-denipho.

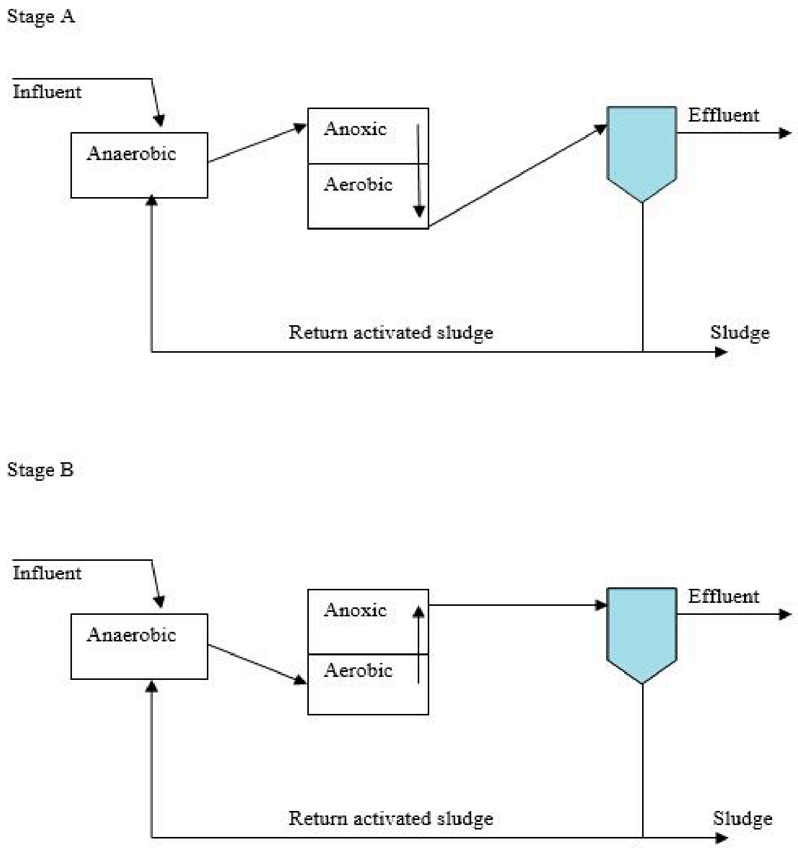


Figure 15. Bio-Denipho Configuration (based on Veoliawatertechnolgies, 2017)

In the first phase, the system directs the mixed liquor from anaerobic tank to the anoxic tank, and then to the aerobic tank. In the second phase, the conditions alter as shown in figure 15.

7.2 Chemical Phosphorus Removal

Chemical systems for phosphorus removal have a higher operational price tag than the biological systems. (Kresge et al. 2009). Precipitation is the prevailing method, and aluminum or iron salts are the widely applied chemicals. In the secondary or tertiary clarifiers, aluminum sulfate or ferric chloride can be added. In those cases where the effluent TP of less than 0.5 mg/l TP is required, WWTPs use granular filtration with chemical additions directly to the filters (Oleszkiewicz et al. 2015). Granular filtration is a process where water is allowed to pass through granular surfaces such as a layer of sand, and suspended solids and pathogens are blocked or retained.

Some of the most common chemicals used for the precipitation of phosphorus are mentioned below (Karttunen 2004; cited by Ruotsalainen 2011):

- ✓ ferrous Sulphate ($FeSO_4 * 7H_2O$)
- ✓ Aluminium Sulphate ($AlSO_4 *14\ H_2O$)
- ✓ AVR (Aluminium Sulphate with 13 % of Al_2O_3 and 0.4–4.3% of Fe_2O_3)
- ✓ ANSU (Aluminium Sulphate with 15.3% of Al_2O_3 and 6–8% of siliceous solids)
- ✓ ferric chloride ($FeCl_3 * 6H_2O$)
- ✓ lime ($Ca(OH)_2$)

This process is capable of achieving an effluent TP of 0.3 mg/l with gravity settling, and can go below 0.1 mg/l with additional post filtration (Whalley et al. 2013; Hart et al. 2012).

7.2.1 Process Configuration

The most common practice in the chemical nutrient removal process is to add chemicals either directly to the activated sludge reactor or to the effluent channel out of the primary clarifier (Oleszkiewicz et al. 2015). The precipitants can be introduced during different phases of the treatment process. They are:

- ✓ before primary treatment (known as pre-precipitation)
- ✓ after secondary treatment (known as post-precipitation)
- ✓ simultaneously with biological treatment in the activated sludge process (known as simultaneous precipitation)
- ✓ precipitation without biological treatment (known as direct precipitation)

Diagram 16 shows the locations where precipitating chemicals are commonly introduced into the WWTPs.

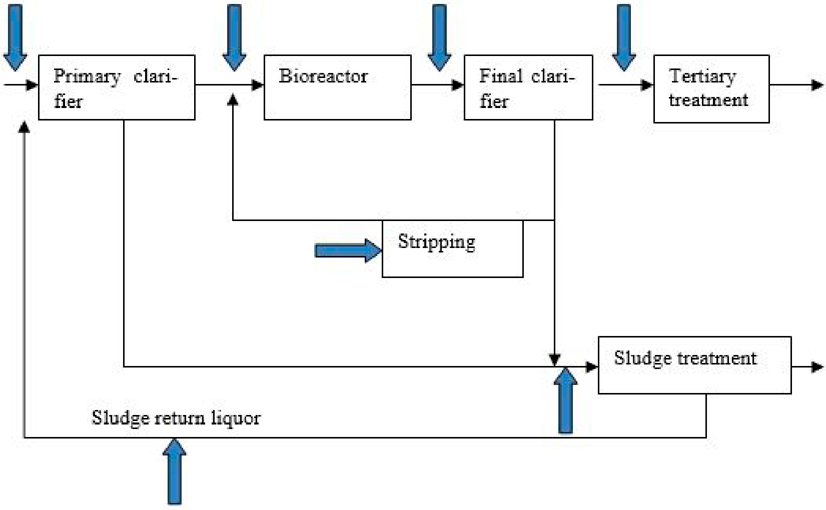


Figure 16. Common locations for chemical precipitation in a WWTPs (edited after Oleszkiewicz et al. 2015)

Karttunen (2004) highlights the reduction rates for phosphorus by chemical methods as presented in table 4:

Table 4. Reduction level for Phosphorus in Chemical Phosphorus Removal by precipitation

Treatment	**Phosphorus Reduction %**
Pre-precipitation	85–95
Post precipitation	90–98
Simultaneous precipitation	75–90
Direct precipitation	75–90

Phosphorus can be removed biologically, and then enhanced with the addition of chemicals. In this case, the required amount of chemicals is less. Supplementary chemical dosing is commonly utilized if the phosphorus concentration in the effluent is higher than desired (Janssen et al. 2002).

Post precipitation is being widely practiced as more municipalities are regulated to levels below 0.3 mg/l of TP. A tertiary ballasted flocculation is reported to achieve effluent TP of 0.05 mg/l when practiced with co-precipitation (Oleszkiewicz et al. 2015).

7.3 Combined Phosphorus Removal

The selection between biological and chemical processes is a real issue for facilities either in design or upgrade since both have advantages that make them appealing for the nutrient removal processes. The Enhanced Biological Phosphorus Removal technology has lower waste activated sludge production, better control of filamentous growth, improved biomass settling, low oxygen requirements for organic matters and improved nitrification rates in the aeration basin. Furthermore, effluent of 0.1 mg/l TP is achievable biologically (Oleszkiewicz et al. 2015).

If the regulations demand very high effluent standards such as TP less than 0.05 mg/l, then the treatment plants require chemical post treatment such as flocculation in addition to the biological Phosphorus removal (Takacs et al. 2011; O'Shaughnessy et al. 2009).

Chemical treatments can be reliable and less complex than the biological removal processes. For most of the highly regulated facilities, the combination of both biological and chemical Phosphorus removal is reliable to achieve low effluent TP (Benisch et al. 2013; cited by Oleszkiewicz et al. 2015).

8. ADVANCED TREATMENTS

If the effluent discharge limit is very high, advanced treatment is required after secondary treatment. Removal of nutrients in the advanced treatment is achieved by the filtration, precipitation, floatation, biofiltration and ion-exchange (Ruotsalainen 2011). Along with these removal processes, membrane bio-reactor processes have achieved high effluent standards along with the possibility of displacing secondary settling in the conventional treatment (Kim et al. 2010; Annaka et al. 2006; Kimura & Watanabe 2005; Kimura et al. 2008).

8.1 Sand Filtration

Sand filters are helpful in polishing the effluents and thereby removing the suspended solids. Sand is used as a filtering medium, and rapid mixing should occur before the sand filtration to ensure that the liquor is evenly distributed (U.S EPA 2008). Figure 17 shows the sand filtration process:

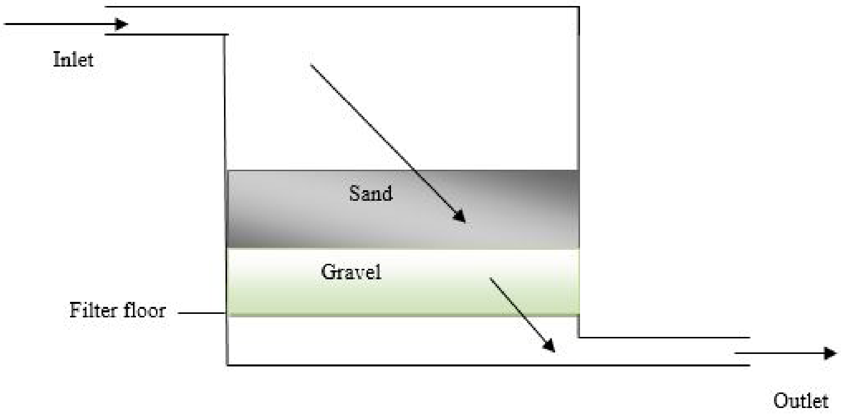


Figure 17. Basic design of Sand Filter (Modified from Tchobanoglous & Schroeder 1985)

It is reported that the best effluent standard is met when sand filtration is used with chemical precipitation. In cases where aluminum salt is used as a precipitant, the effluent phosphorus level of 0.05 mg/l is achievable. (Rajala et. al. 2003.)

8.2 Biofiltration

Biofiltration utilizes the growth of microorganism in a bed to remove both nitrogen and phosphorus. The water to be treated is applied either intermittently with some time intervals, or continuously.

There are various applications of biofiltration technologies. The leading technologies are Biocarbone, Biofor, Biostyr and Dynasand filters which differ in the weight of the material and the continuous or intermittent application (Niemelä 2009; cited by Ruotsalainen 2011).

8.3 Floatation

In this process, the solids and liquid particles are separated from the liquid phase with aeration of fine air bubbles. Therefore, it is also known as the Dissolved Air Floatation process (DAF). Figure 18 shows the basic idea of the Dissolved Air Floatation Process.

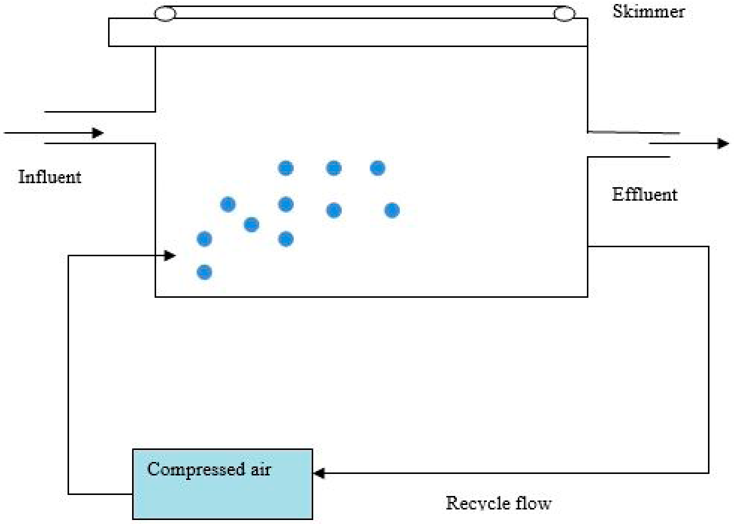


Figure 18. Floatation system with Dissolved Air Floatation process (designed after literatures review)

According to Koivunen (2007; cited by Ruotsalainen 2011), the tertiary dissolved air floatation process can remove phosphorus from wastewater very efficiently, with 50–80% of phosphorus removed and effluent concentration of 0.1 mg/l phosphorus.

8.4 Ion Exchange

Ion exchange is a simple technological process that removes nitrates and ammonia in the WWTP. Nitrogen is removed when the ammonium and nitrate ions are displaced. Ammonia removal is enhanced by zeolite exchange, which removes nitrogen. A Zeolite has a porous structure, so it contains many different types of cations. A schematic of the Ion-Exchange system is shown in figure 19.

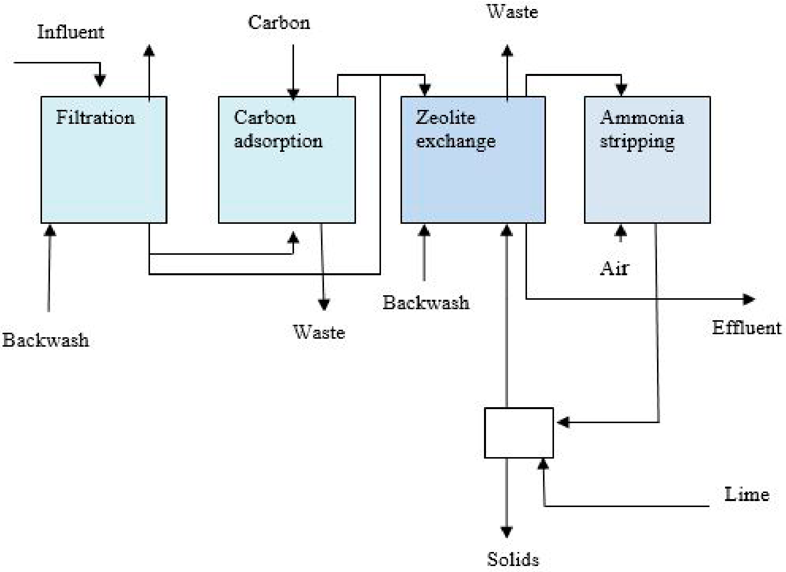


Figure 19. Ion Exchange system for nutrient removal (adapted from Metcalf & Eddy 2003)

9. THE LIMIT OF NUTRIENT REMOVAL TECHNOLOGY

The selection of the process for nutrient removal is dependent on local conditions like existing tankage, wastewater characteristics, availability of chemicals, solid waste management and long-term carbon footprint. With many new innovations in tertiary treatments and the best available solid separation techniques, the current limit that can be achieved in nutrient removal for phosphorus is 0.01 mg/l and for nitrogen is 3 mg/l in the effluent water (Oleszkiewicz et al. 2015). The following table shows the attainable nutrient removal in mg/l as reported by Oleszkiewicz et al.

Table 5. The current Limit of Technology (LOT) for effluent limits in mg/l

Process	**Total Phosphorus (mg/l)**	**Total Ammonia Nitrogen (mg/l)**	**Total Nitrogen (mg/l)**
Conventional Activated Sludge with Extended Aeration	5	<3	25
Conventional Activated Sludge with Extended Aeration + Simultaneous Nitrification Denitrification + Chemical Phosphorus Re-moval	0.3	<1	<7
Biological Nutrient Re-moval	<0.5	<1	<7
Conventional Activated Sludge with Extended Aeration + Simultaneous Nitrification Denitrification + Chemical Precipitation + Filter	<0.1	<1	<7
Biological Nutrient Re-moval + Post Denitrification + Chemical Precipitation + Ultra Filtration Membrane	0.01	<1	<3

With the large diversity of nutrient removal processes in Europe, the dominant process is a one-sludge biological nutrient removal, consisting of a sequence of anaerobic, anoxic and aerated zones. Commonly used biological nutrient removal processes in Northern Europe and the U.K. include the modified Bardenpho process and the Johannesburg process (Oleszkiewicz & Barnard 2006).

The biological phosphorus removal is dependent on the amount of bio-degradable Chemical Oxygen Demand (COD) and VFA. If it is high, the process is simple; but if the COD is very low, the system needs to be designed with caution (Pitman 1991).

Since the characteristics of the influent wastewater also play a very significant role in the nutrient removal, it is best to see the different features of the incoming wastewater, and their effect on the phosphorus removal processes as presented in table 6. The ratios of dissolved oxygen in the wastewater, i.e., Biochemical Oxygen Demand (BOD, BOD7), COD, and nutrients Phosphorus and Nitrogen in the incoming influent determine the efficiency of the processes.

Table 6. Wastewater characteristics and its relevance to the type of nutrient removal processes (Metcalf & Eddy 2003; Janssen et al. 2002; Pitman 1991; cited by Ruotsalainen 2011)

Ratio	**Value**	**Features**
BOD:COD	>0.5	Easy biological treatment
BOD: Phosphorus	>15 – 20	Guarantee of biological phos-phorus removal
	>40	Effluent phosphorus of less than 1 mg/l possible
	25 – 35	Chemical Precipitant required for effluent polishing
	<25	Chemical addition is the best option
BOD7/ TP after mechan-ical treatment	>15	Phosphorus effectively re-moved below 1 mg/l
BOD: Nitrogen	>4 – 5	Well-functioning phosphorus and nitrogen removal
Phosphorus: COD	>1:50	Supplementary chemical pre-cipitation required

Both the removal of phosphorus by biological and chemical methods have some advantages and disadvantages. For instance, 0.1 mg/l of effluent phosphorus can be realized with biological means, and chemical precipitations can also achieve similar standards when improved solid separation techniques are applied.

The following table 7 shows the effluent standard achievable with different processes. In most cases, the combined processes achieve better results.

Table 7. Phosphorus removal by different processes. (Developed after Whalley et al. 2013; Barnard et al. 2012; Hart et al. 2012; Hazlett and Kalmes 2012; Sherif 2012; Subramanian et al. 2012; Kang et al. 2008; cited by Oleszkiewicz et al. 2015)

Treatment	Average Soluble Reactive Phosphorus (Phosphate Phosphorus) mg/l in effluent	Average Total Phosphorus (mg/l) in effluent
Biological phosphorus removal with adequate VFA	0.1	0.5
Biological phosphorus removal with adequate VFA and cloth filter	0.1	0.2
Biological phosphorus removal with adequate VFA, chemical post-treatment and ultrafiltration	0.01	0.03
Conventional activated sludge with co-precipitation and post- filtration	0.08	0.1
Conventional activated sludge with dedicated chemical post-precipitation and ultrafiltration	0.02	0.03

10. THE FINNISH EXAMPLE: VIIKINMÄKI WWTP

The Viikinmäki WWTP is the largest treatment plant in the Nordic countries operating completely underground. The plant receives 270,000 m^3 of daily flow and almost 100 million m^3 of yearly flow of wastewater. Around 85% of the wastewater is domestic and the remaining is industrial.

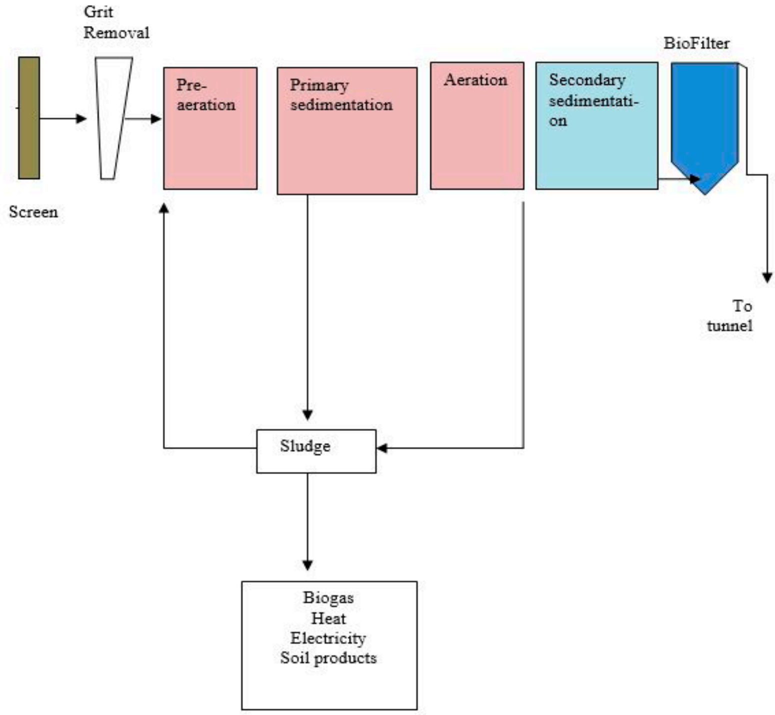
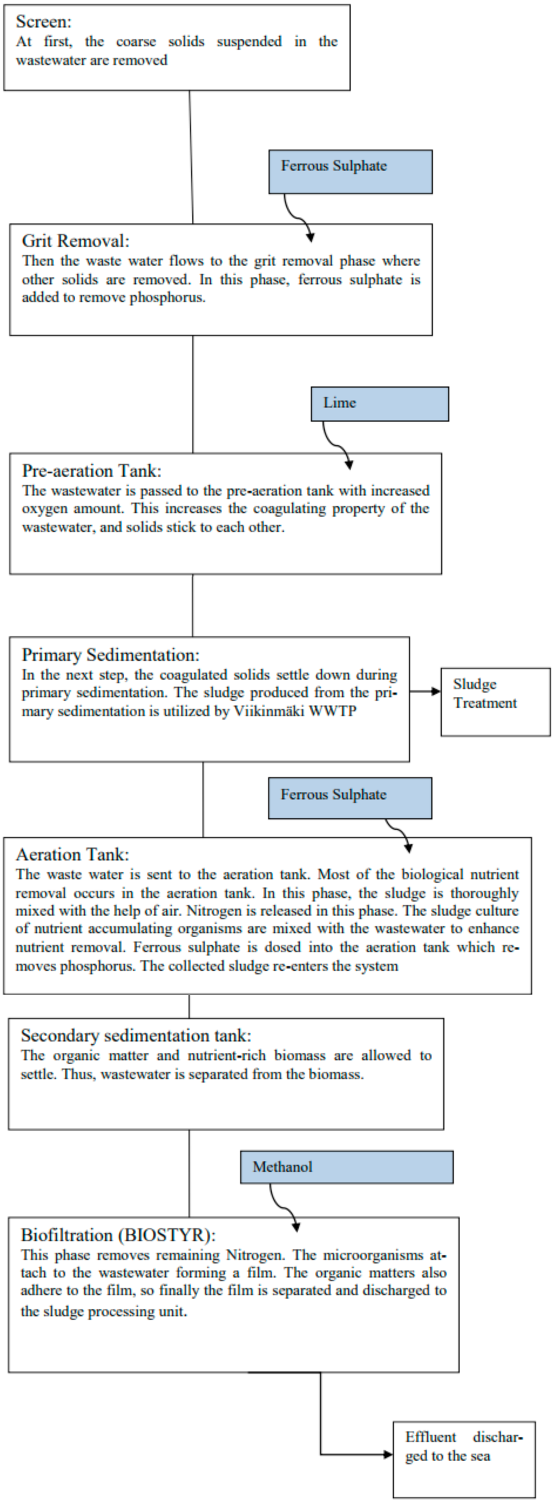


Figure 20. A schematic of the Viikinmäki WWTP, Finland

As shown in figure 20, the wastewater treatment process in Viikinmäki WWTP goes through different phases. The process is based on the activated sludge method, with mechanical, biological and chemical treatment.



Screen:
At first, the coarse solids suspended in the wastewater are removed

Grit Removal:
Then the waste water flows to the grit removal phase where other solids are removed. In this phase, ferrous sulphate is added to remove phosphorus.

Pre-aeration Tank:
The wastewater is passed to the pre-aeration tank with increased oxygen amount. This increases the coagulating property of the wastewater, and solids stick to each other.

Primary Sedimentation:
In the next step, the coagulated solids settle down during primary sedimentation. The sludge produced from the primary sedimentation is utilized by Viikinmäki WWTP

Aeration Tank:
The waste water is sent to the aeration tank. Most of the biological nutrient removal occurs in the aeration tank. In this phase, the sludge is thoroughly mixed with the help of air. Nitrogen is released in this phase. The sludge culture of nutrient accumulating organisms are mixed with the wastewater to enhance nutrient removal. Ferrous sulphate is dosed into the aeration tank which removes phosphorus. The collected sludge re-enters the system

Secondary sedimentation tank:
The organic matter and nutrient-rich biomass are allowed to settle. Thus, wastewater is separated from the biomass.

Biofiltration (BIOSTYR):
This phase removes remaining Nitrogen. The microorganisms attach to the wastewater forming a film. The organic matters also adhere to the film, so finally the film is separated and discharged to the sludge processing unit.

Figure 21. Processes of Viikinmäki WWTP

As can be seen from the diagram, simultaneous precipitation with Ferrous Sulfate has been applied as a chemical process for nutrient removal along with biological process. The advantage of simultaneous precipitation is that the existing treatment plants can adjust to it with low capital cost and easy operation methods.

The treatment is done with the traditional activated sludge method and the removal of phosphorus is carried out at the same time in two-phase simultaneous precipitation. Ferrous sulfate ($FeSO_4$) is the chemical precipitant, and the phosphorus is bound to the sludge, which is then sent for the treatment. The first phase of nitrogen removal is done during the activated sludge process with the principle of denitrification. The second phase of the nitrogen removal occurs at the biological nitrogen filters. During the aeration phase, the ammonium nitrogen contained in the wastewater is oxidized into nitrate nitrogen (NO_3). Later this is reduced to nitrogen gas. The basic principle of denitrification is to utilize denitrifying bacteria which reduce nitrate nitrogen into free nitrogen gas. In advanced treatment at Biofilters, the remaining nitrogen is removed, and methanol is added to accelerate the process (HSY, 2017).

10.1 BIOSTYR Biofiltration

In Viikinmäki WWTP, after the advanced treatment with BIOSTYR filtration technology, the following effluent concentration is achieved.

Table 8. Effluent standard achieved at Viikinmäki WWTP

Nutrient	**Effluent Concentration**	**Reduction Rate**
Nitrogen	4.3 mg/l	91%
Phosphorus	0.3 mg/l	97%

Biostyr is capable of reducing the nitrogen in the wastewater as well as filtering the sludge and fine particles.

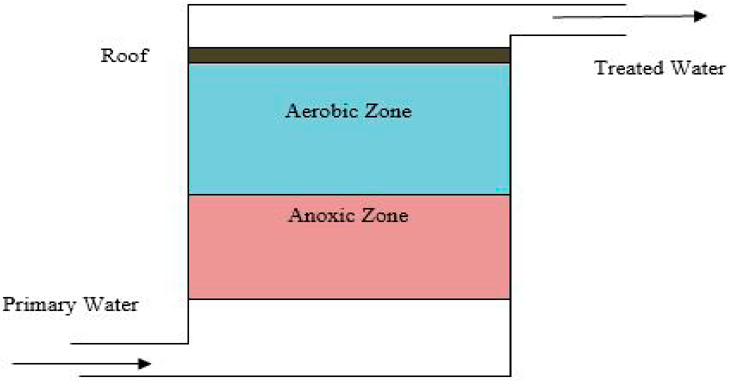


Figure 22. A basic schematic of the BIOSTYR Biofilter

As shown in figure 22, the wastewater is passed upward through anoxic and aerobic zones. In the anoxic zone, denitrification as well as the retention of suspended solids takes place. In the aerobic zone, the ammonium is converted to nitrites and then to nitrates which is again recirculated to the raw wastewater.

In the anoxic zone, carbon is essential. Therefore, methanol is added to accelerate the process.

10.2 Sludge Treatment

The sludge generated in the Viikinmäki WWTP is processed in the bioreactor. During the digestion process, methane gas is generated which is utilized to produce electricity and heat. As a result, almost 60% of the plant´s electrical needs are met.

The sludge is dried using a centrifuge, and the process is accelerated with polymer. Then the dry sludge is taken away for further processing into soil products at the Metsäpirtti composting field in Sipoo (HSY, 2017).

10.3 Treatment Results and Control

The plant has been successful in removing 95% of solid and oxygen consuming matter and phosphorus as well as 90% of nitrogen. The minimum level of nutrient removal is defined in EU water frame directive. However, Finnish has its own strict regulations which are based on the national legislation of Water Act: license to conduct wastewaters by Water Court 264/1961. The treatment requirements for Viikinmäki WWTP is defined by plant-specific environmental license which also sets boundary conditions for the waste conducted to air and solid waste. In addition to these requirements, the plant is also obligated to meet the quality goals set by the City of Helsinki Council according to its Baltic Sea strategy (HSY 2017).

11. NUTRIENT RECOVERY

For optimum growth plants need essential nutrients such as phosphorus and nitrogen. Plants can absorb phosphorus in the form of phosphate ions, and nitrogen in the form of nitrate and ammonium ions. Nitrogen can be synthesized by the Haber-Bosch process in which the free atmospheric nitrogen can be converted to ammonia. As a result, ammonia can be produced as a fertilizer with the aid of this process. In contrast to nitrogen, phosphorus is obtained from phosphate rock reserves which are forecast to become depleted within this century. Some 80% of mined phosphorus is used in agriculture (Oleszkiewicz et al. 2015). The wastewater discharge contains phosphorus. For instance, the incoming wastewater in the Viikinmäki WWTP in Helsinki contains 1815 kg/day of phosphorus derived from some 800 000 residents (HSY 2017). This phosphorus could be recovered as phosphate. In a WWTP, there are many potential points of nutrient recovery.

The following diagram 23 shows the potential for nitrogen recovery in the WWTPs.

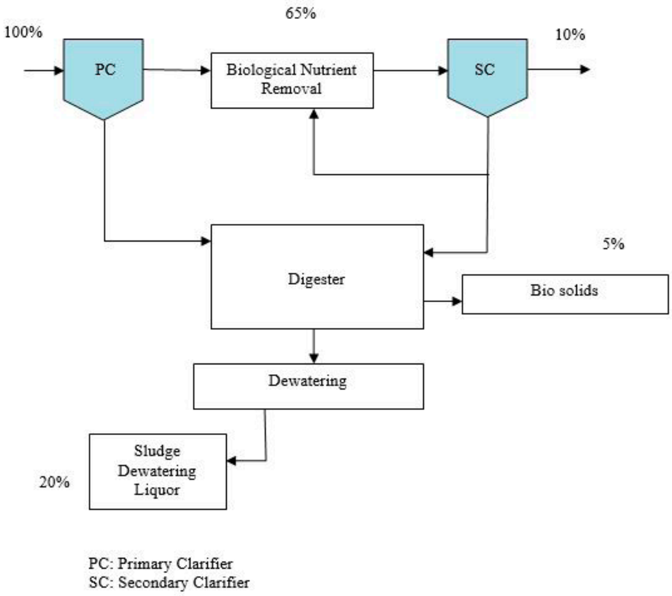


Figure 23. Nitrogen recovery potential at various points in a WWTP (diagram modified from Oleszkiewicz et al. 2015)

Parallel to the nitrogen recovery potential, the following diagram 24 shows the potential for phosphorus recovery in the WWTPs.

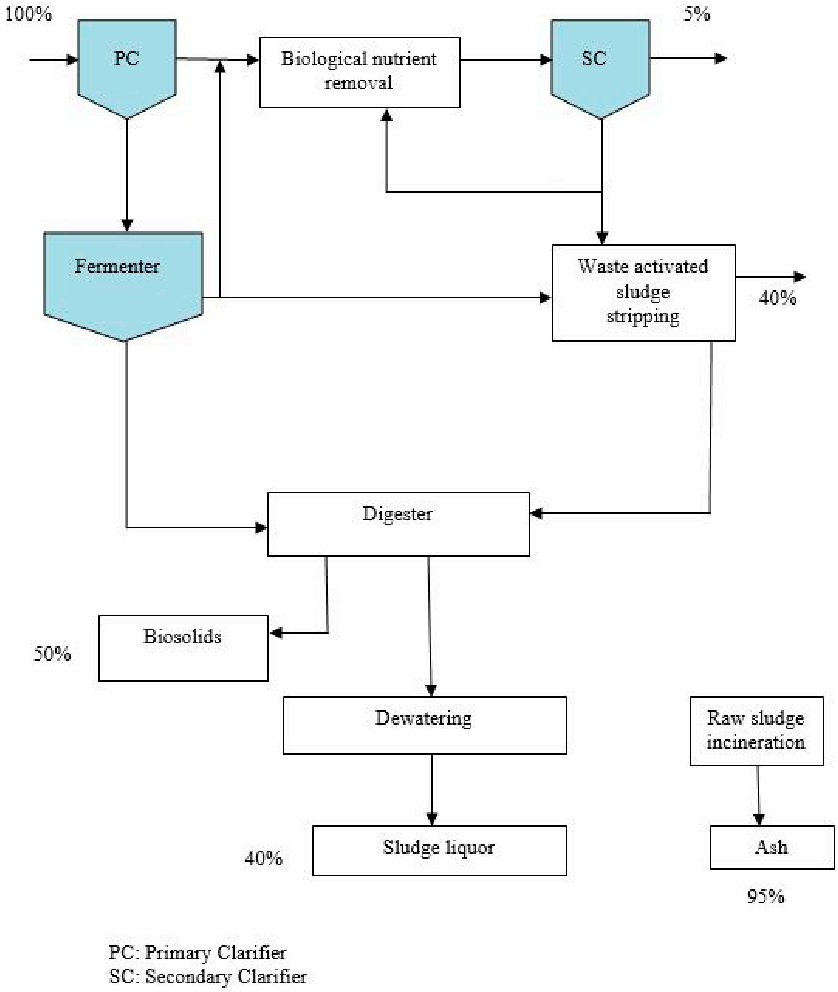


Figure 24. Phosphorus recovery potential at various points in a WWTP (diagram modified from Oleszkiewicz et al., 2015)

Figure 24 shows the potential points from where phosphorus could be recovered from the WWTPs. Wastewater treatment is capable of removing almost 95% of phosphorus from the incoming influent and discharging it into the sewage sludge. From the sewage sludge, phosphorus can be recovered after treatment and can be applied to land as fertilizer or can be recovered in the side stream using chemicals (Khunjar et al. 2013). Nutrients can be recovered from the nutrient rich side streams, sewage sludge, and sewage sludge ash (Oleszkiewicz 2014). Almost 90% of the influent phosphorus could be recovered from sewage sludge or sludge ash (Cornel & Schaum 2009).

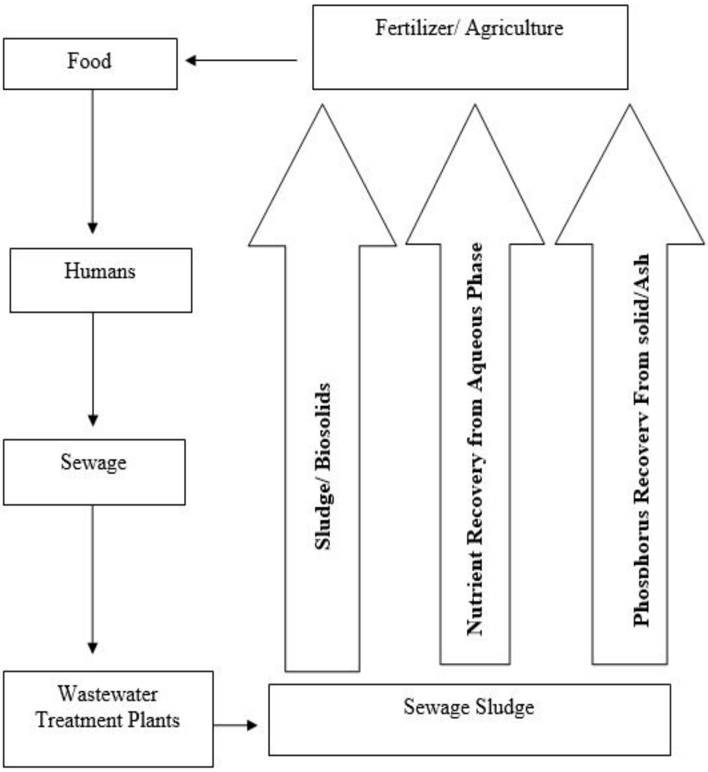


Figure 25. Nutrient recovery cycle (WWI 2016)

11.1 Final Products After Recovery

Phosphorus can be recovered from biosolids, sidestreams sludge dewatering liquor, chemical sludge, ash, and from the mainstream (Oleszkiewicz et al. 2015). It is considered that the crystallization process can recover phosphorus from the liquid phase either as calcium phosphate that is similar to phosphate rock, or as magnesium ammonium phosphate hexahydrate known as struvite. Another possibility is the recovery from sludge or sludge ash in the form of struvite or calcinated phosphate. Yet another possibility is to recover phosphorus from sewage sludge ash, producing white phosphorus. (Desmidt et al. 2015.)

11.1.1 Calcium Phosphate

Calcium Phosphate is directly comparable to the phosphate rock, so it can be used as a secondary material in the phosphate fertilizer industry (Roeleveld et al. 2004).

11.1.2 Struvite

Struvite is chemically known as magnesium ammonium phosphate hexahydrate ($MgNH_4PO_4 \cdot 6H_2O$). As struvite contains phosphorus and nitrogen, struvite is a potential raw material for the fertilizer industry. It is reported that struvite has very low concentration of heavy metals and other pollutants. Furthermore, the nutrients in struvite are plant available. This makes struvite highly suitable for agricultural use as a slow release fertilizer (Nawa 2009).

Figure 26. Struvite (http://www.phosphorusplatform.eu/)

11.1.3 Ash

After thermal decontamination in the incinerator, calcined phosphate fertilizers can be obtained from sludge ash. The composition of the ash, however, depends on the type of incinerated sludge.

11.2 Phosphorus Recovery from Biosolids

PAOs play a vital role in the biological removal of phosphorus. The biosolids are enriched with phosphorus as a result. When the biosolids are removed from the wastewater including PAOs as waste activated sludge, phosphorus is removed as well. This waste activated sludge is a form of recovered phosphorus which can be applied to land as fertilizer. However, biosolids need to be disinfected and stabilized before land application (Oleszkiewicz et al. 2015).

The available treatment technologies for phosphorus recovery from biosolids are described in the following subsections.

11.2.1 Lystek

The Lystek process is an effective advanced biosolids processing method developed by Lystek international in Canada. The process generates a liquid product called LysteGro™ after the high temperature treatment of biosolids with a high pH alkali. This resulting liquefied material can be used in agriculture, farming and horticulture; with high concentrations of Nitrogen- Phosphorus-Potassium (N-P-K) of 4.5-7-2.5. The low viscosity biofertilizer that is obtained has a solid concentration in the range of 14–17%. (Lystek.com). It is reported that LysteGro™ has no pathogen regrowth even when stored for over a year (Singh et al. 2006).

The schematic of the Lystek process is shown in figure 27.

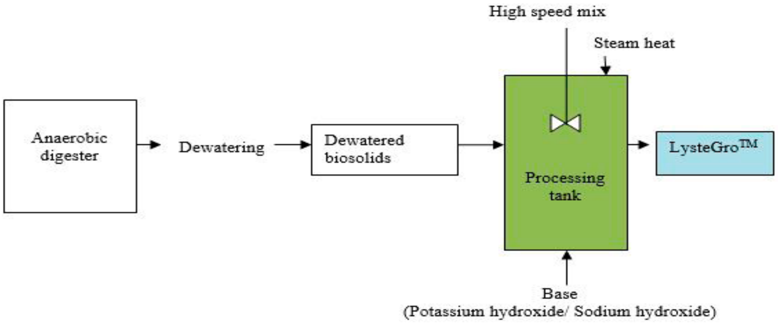


Figure 27. Schematic diagram of Lystek process (Oleszkiewicz et al. 2015; Singh et al. 2006; Janssens 2014)

The pH, temperature and processing time are the control parameters of Lystek technology. The dewatered solids are pumped to the processing tank where alkaline hydroxides of potassium or sodium are applied along with heat from the steam boilers.

The process operates within the temperature range of 60–80 °C and the pH range of 8–10. The purpose of the high speed mixing is to release more water from the bacterial cells, and the purpose of high temperature is to kill pathogens. Ultimately, when base is added, the nutrient value of the product is enhanced (Dennis Consultants, 2008).

11.2.2 N-Viro

The N-Viro process adds a large dose of alkaline lime/kiln dust to the dewatered sludge. Then the mixture is mixed, dried and heated. Due to the addition of 35–70% by dry weight of alkaline admixtures, the end product has a similar physical structure to that of soil (Oleszkiewicz et al. 2015). The schematic of the N-Viro process is shown in figure 28.

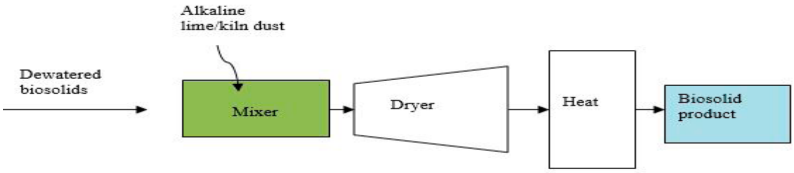


Figure 28. Schematic representation of N-Viro process (Oleszkiewicz et al. 2015)

The N-Viro process is a form of alkaline stabilization. The dewatered solids are mixed thoroughly in the mixer where lime kiln dust is added. In the dryer, the biosolids are dried to remove the moisture and then passed through the heat chamber where they undergo a curing process. Ultimately, a biosolid product is produced which has the physical similarities of dry soil.

11.2.3 VitAG

VitAG is an emerging technology for nutrient recovery. The supporters of VitAG solution for nutrient recovery claim that it consumes 31% less energy and produces 40% less greenhouse gas in comparison to inorganic fertilizers, and provides the same amount of plant available nutrient (Gould et al. 2011).

In this process, the dewatered biosolids are converted to a commercial ammonium sulfate granular fertilizer. The final product has the Nitrogen-Phosphorus-Potassium-Sulfur ratio (N-P-K-S) of 16-2-0-16. (Oleszkiewicz et al. 2015.) The sludge stream serves the role of quenching the acid-ammonia reaction. The following figure 29 shows the schematic of the process.

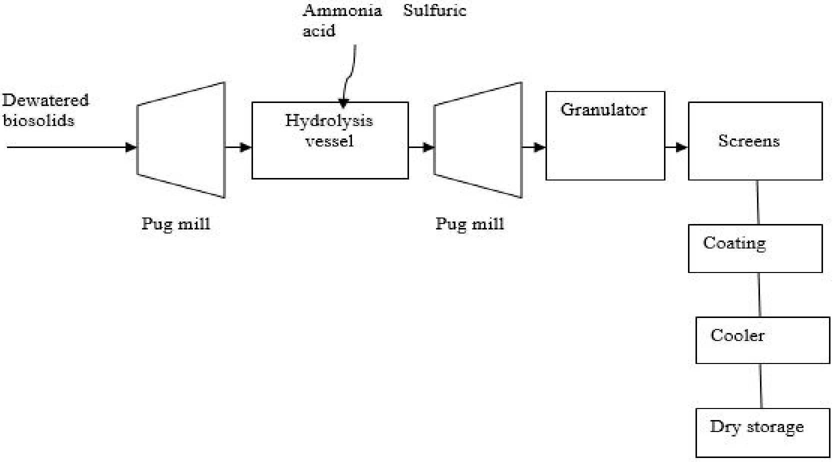


Figure 29. Schematic representation of VitAG process, producing ammonium sulfate (Oleszkiewicz et al., 2015; developed after Gould et al., 2011)

11.2.4 Neutralizer®

Neutralizer is also an emerging technology consisting of chemical treatment processes with chlorine dioxide and nitrous acid in two different batches. In the first stage, chlorine dioxide is added to the waste activated sludge for disinfection. In the second stage, further disinfection of sludge is performed with the addition of Nitrous Acid. After disinfection, ferric sulfate is added to precipitate phosphorus. The process does not increase the volume of the sludge, and takes very less real state (Oleszkiewicz et al. 2015).

The schematic of the process is shown in figure 30.

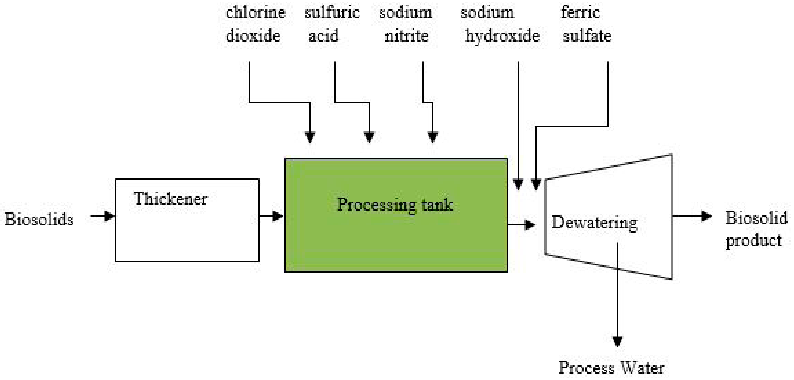


Figure 30. Schematic representation of Neutralizer process (Oleszkiewicz et al. 2015)

11.2.5 Schwing-Bioset

Schwing-Bioset is also an emerging technology that uses alkaline treatment. The sludge cake is mixed with lime and sulfamic acid. As an outcome of the chemical reactions, ammonia is released. High pH and temperature is maintained to disinfect and stabilize the biosolids. In addition, iron salt is dosed to improve the product quality (Oleszkiewicz 2015). The schematic of the process is shown in figure 31.

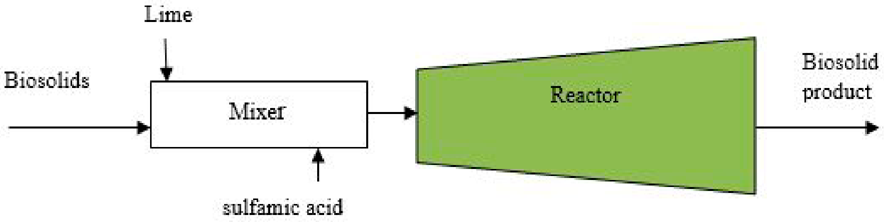


Figure 31. Schematic of Schwing-Bioset process (modified from Oleszkiewicz et al. 2015)

11.3 Phosphorus Recovery from Sidestream Sludge Dewatering Liquor

The recovery of phosphorus can be done in such a way that the phosphate is precipitated. Magnesium is one of the chemicals that can be used which produces Magnesium Phosphate and Struvite (Oleszkiewicz et al. 2015). Wastewaters contain a high amount of phosphorus and nitrogen, and hence is a good source of struvite ($MgNH_4PO_4 \cdot 6H_2O$), which is a phosphate fertilizer and an alternative source of phosphate rock fertilizers in agricultural production (Rahman et al. 2013).

Struvite precipitation is preferable as the recovery process is simple, effective and removes ammonium which can be utilized as fertilizers (Woods et al. 1999). The widely applied struvite recovery technologies are mentioned in following subsections.

11.3.1 Ostara™ - PEARL and WASSTRIP

Ostara technology is in full scale operation with 14 commercial installations worldwide and one is under construction as of now in Spain

(Ostara 2017). The process is able to achieve phosphorus removal rates greater than 80% from the treated liquid (WEF 2010) with average phosphorus and ammonium recovery reported to be 80–90% and 14–42% respectively (cited by Oleszkiewicz et al. 2015). The technology has two batches, the PEARL™ fluidized bed reactor and WASSTRIP™. The following diagram in figure 32 shows the schematic of the Ostara Technology.

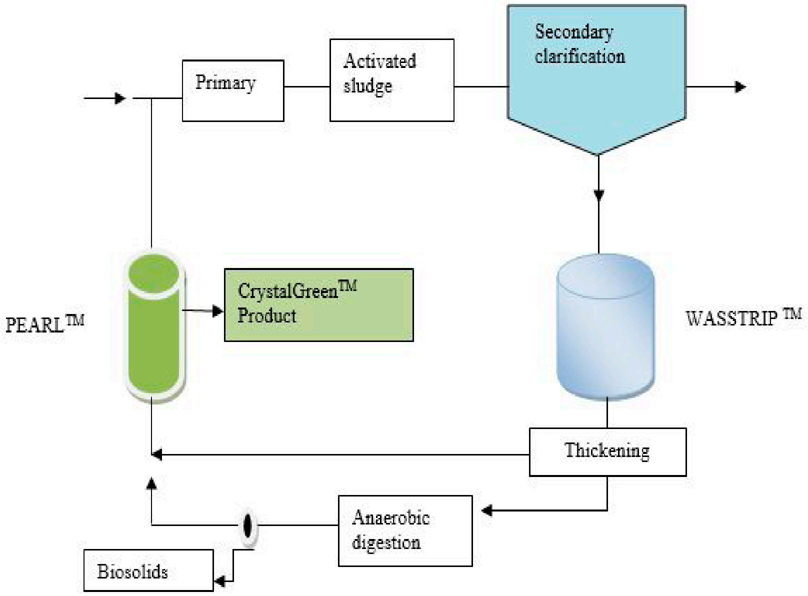


Figure 32. Ostara PEARL and WASSTRIP technologies (designed after Ostara 2017)

Figure 33. Ostara PEARL technology for recovering phosphorus (Ostara 2017)

Figure 34. Ostara WASSTRIP technology (Ostara, 2017)

In biological nutrient removal systems, PEARL™ removes up to 50% of the total influent phosphorus before it accumulates as struvite. In a controlled setting, magnesium is added and the nutrients crystallize into fertilizer granules which grow in diameter. Finally, the granules are harvested, dried and bagged with a brand name of Crystal Green ™ (Ostara 2017).

Figure 35. Ostara Crystal Green struvite fertilizer (Ostara, 2017)

Ostara's other technology, WASSTRIP™ (Waste Activated Sludge Stripping To Remove Internal Phosphorus), is complementary to the Pearl process. It releases phosphorus from the stream before it reaches the anaerobic digester, thereby, providing maximum phosphorus to the PEARL reactor.

11.3.2 Multiform Harvest™

The Multiform Harvest technology is utilized for overall phosphorus removal and it is concerned more with the lower operating cost than the appearance and purity of struvite fertilizer (Oleszkiewicz et al. 2015). The system is able to convert phosphorus and ammonia into struvite. The following figure 36 shows the schematic of the Multiform Harvest process technology.

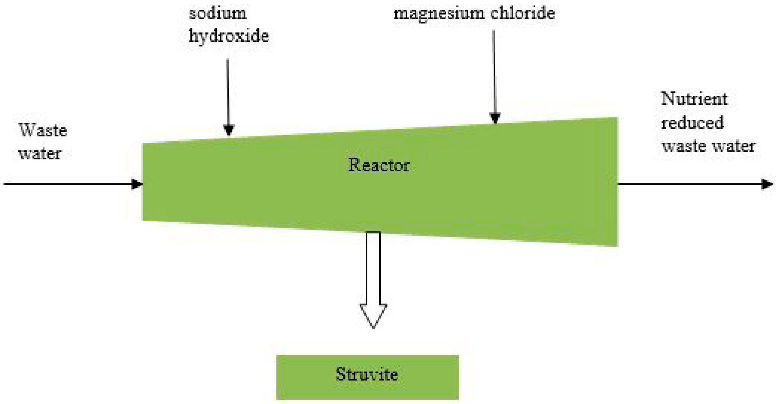


Figure 36. Multiform Harvest Technology for Struvite Recovery (Designed after Multiform Harvest, 2017)

11.3.3 PHOSNIX

PHOSNIX is a struvite recovery technology with a side stream process and it enables effective phosphate removal and recovery from the digester wastewater of the sludge treatment process as granulated struvite (Ueno & Fuji 2001; Nawa 2009). The process was developed by Unitika Ltd in Japan. The chemicals added are magnesium hydroxide and sodium hydroxide. The schematic of the Phosnix process is described in figure 37.

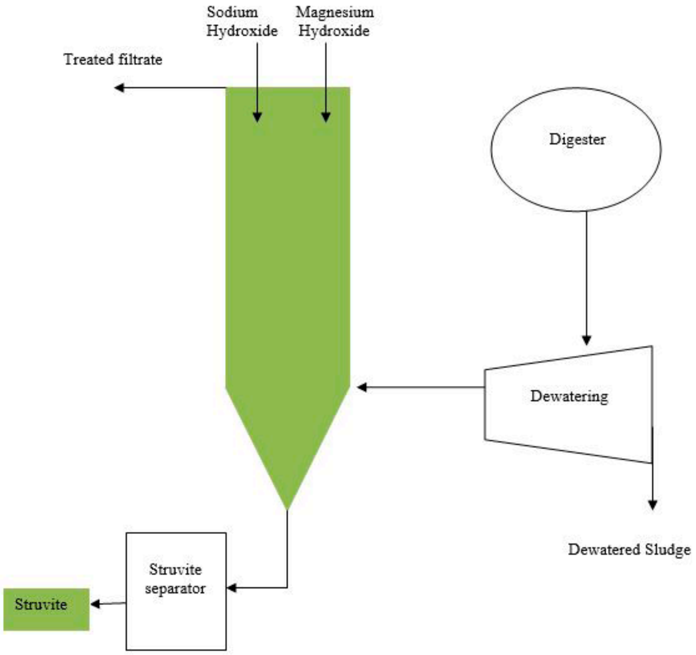


Figure 37. A schematic diagram of the PHOSNIX Technology for Struvite recovery (modified from Oleszkiewicz et al. 2015)

After the recovery of the struvite, it is sold to the fertilizer company as a source of raw materials. The fertilizer that is produced is widely applied to paddy rice, vegetables and flowers. Ueno and Fiji (2001) reported that the application of this struvite fertilizer increased the taste of the paddy rice.

PHOSNIX technology has been used in the Lake Shinji WWTP, Japan to recover phosphorus.

11.3.4 Crystalactor®

Crystalactor is a phosphorus recovery technology developed by DHV in the Netherlands. The process utilizes crystallization technology whereby phosphorus is precipitated on a nucleus such as sand or anthracite in the form of calcium phosphate, magnesium ammonium phosphate or potassium magnesium phosphate. The full scale operation of this technology in Geestmerambacht WWTP, Netherlands has reported that the TP decreased from 6.7 mg/l in the influent to 0.3 mg/l in the effluent. (Oleszkiewicz et al. 2015.) The schematic diagram of the Crystalactor process is shown in figure 38.

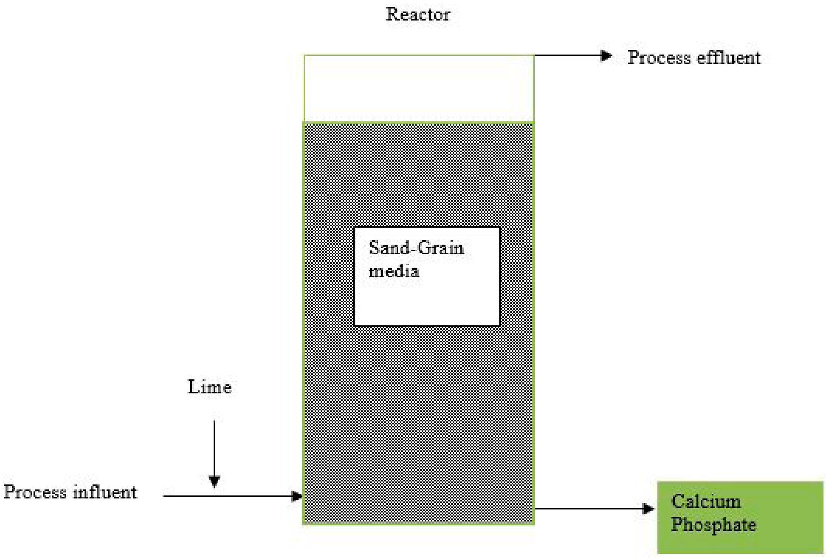


Figure 38. Crystalactor schematic diagram (adopted from Desmidt et al. 2015)

It is also reported that 101 kg of phosphorus is recovered per day, and 200–300 tonnes per year of phosphate pellets is produced at the Geestmerambacht treatment plant (Desmidt et al. 2015; Oleszkiewicz et al. 2015).

11.3.4 AirPrex

AirPrex technology is a controlled method of precipitating Struvite developed by Berliner Wasserbetriebe in Germany. This technology recovers phosphorus along with increased biosolid treatment. The sand and grain washing of the struvite ensures purity of the recovered Struvite (Desmidt et al. 2015). A schematic of AirPrex technology is shown in figure 39.

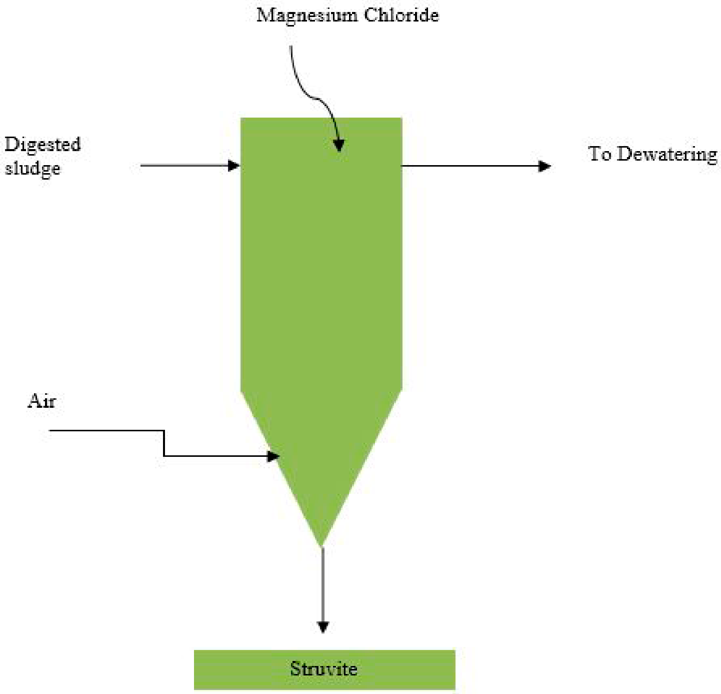


Figure 39. A basic schematic of AirPrex technology for Struvite recovery

11.3.6 Phospaq ™

Phospaq™ is a struvite recovery technology developed in the Netherlands. It has been successfully operated by Waterstromen in Olburgen, the Netherlands and has been reported to remove on average 82% of the reactor influent stream Phosphate (Oleszkiewicz et al. 2015).

The schematic diagram of the Phospaq process is shown in figure 40.

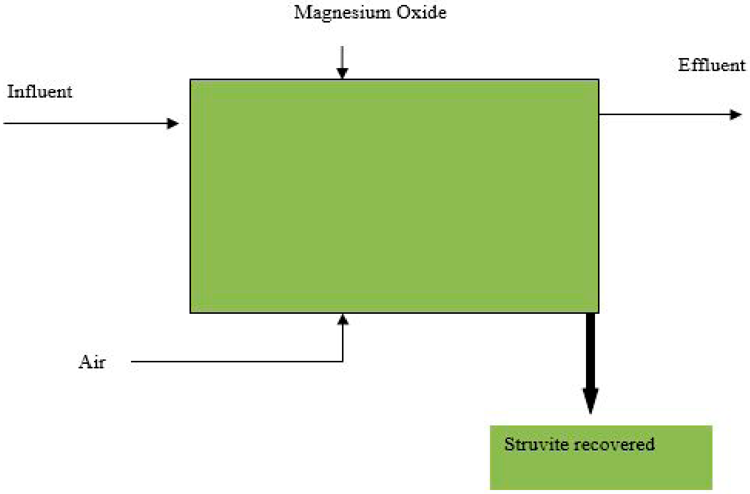


Figure 40. A basic schematic of Phospaq process

11.3.7 P-Roc

P-Roc is a technology which has been reported to remove 80% of the phosphorus in the stream entering through the crystallization reactor. The system utilizes the suitable seed crystals like Calcium silicate hydrate (Oleszkiewicz et al. 2015).

The process was developed at the Institute of Technical Chemistry, Water and Geotechnology (Forschungszentrum Karlsruhe GmbH, ITCWGT) in cooperation with the Universities of Karlsruhe and Darmstadt and the Leibniz University Hannover. (Nieminen 2010.)

11.4 Phosphorus Recovery from Chemical Sludge

Metal salts that are dosed in the main stream to remove phosphorus usually result in metal-phosphate precipitate. Iron present in the sludge from chemical phosphorus removal systems reduce the yield of recovery due to the formation of ferro-phosphorus. In addition, there are thermo-chemical extraction methods to recover phosphorus from chemically bound phosphate compounds. (Oleszkiewicz et al. 2015.) Chemical sludge has less plant-available phosphorus, but it can still be applied in the land after effective safety tests for plants and soil. Some studies suggest that the chemically precipitated form of phosphorus after iron salt addition may be available for plants to be used as a slow release fertilizer. (Smith et al. 2002; cited by Oleszkiewicz et al. 2015.)

11.5 Phosphorus recovery from Ash

The sludge that is incinerated leaves a residue in the form of ash. The untreated incineration ash contains heavy metal compounds above the legal limits and so cannot be applied in the agriculture (Desmidt et al. 2015). Ash from the incinerated sludge can contain up to 95% of the influent phosphorus load. Therefore, it has a great potential for phosphorus recovery. (Oleszkiewicz et al. 2015). The most efficient systems to recover phosphorus from the incineration ash are described below.

11.5.1 ASH DEC

At present, ASH DEC technology is provided by a Finnish company Outotec. The technology applies thermo-chemical treatment to the sewage sludge and consequently produces raw fertilizers with high phosphorus bioavailability and low pollutant content. The mono-incineration of the sludge destroys the organic pollutants.

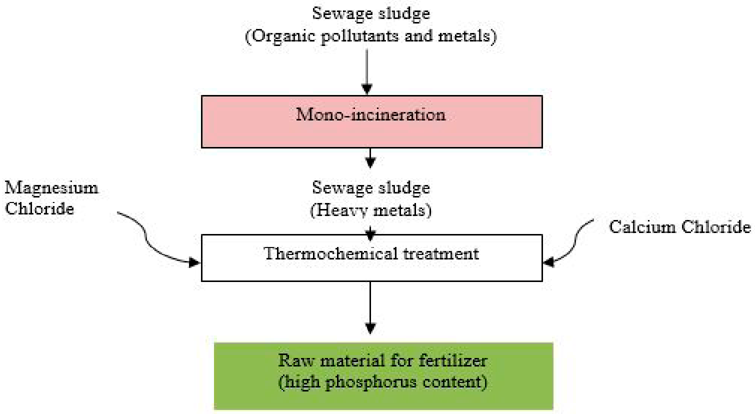


Figure 41. ASH DEC process for phosphorus recovery from ash (modified from Adam et al. 2009)

The residue of the incineration are ashes with high phosphorus content, but still contain heavy metal compounds above the legal limits for use in agriculture (Adam et al. 2009). In the second step, the sludge ash is mixed with chloride donors: magnesium chloride and sodium chloride to a temperature of 1000 degree Celsius as shown in figure 41. At this temperature, the heavy metals evaporate (Desmidt et al. 2015). Ultimately, ash, which has high phosphorus bio-availability and low pollutant content, remains.

11.5.2 Seaborne, PASH , BioCon, SEPHOS

Seaborne was developed by the Seaborne Environmental Research Laboratory in Germany. The process enables nutrient recovery through incineration of solids. The nutrients from the sewage sludge ash are recovered with no heavy metal contaminants and other organic pollutants.

Similarly, PASH technology was also developed in Germany by the Institute of Applied Polymer Science. The schematic of the PASH technology for phosphorus recovery from ash is shown in figure 42.

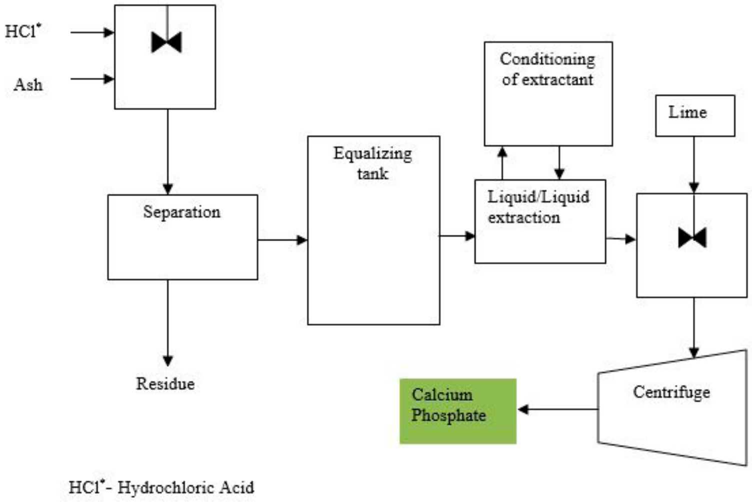


Figure 42. PASH process for calcium phosphate recovery from ash (Oleszkiewicz et al., 2015)

In addition to PASH, there are other phosphorus recovery processes. Such technologies based on phosphorus recovery from ash include BioCon and SEPHOS, both of which were developed in Germany.

11.6 Phosphorus recovery from the mainstream

In the mainstream phosphorus recovery, a portion of the return activated sludge or waste activated sludge is fermented in a separate anaerobic tank to release phosphorus (Metcalf & Eddy et al. 2014). The phosphorus which is then released can be recovered using chemical precipitation with lime or magnesium for struvite recovery. (Oleszkiewicz et al. 2015). PhoStrip is one way to recover phosphorus from the mainstream. Figure 43 shows the schematic process of PhoStrip.

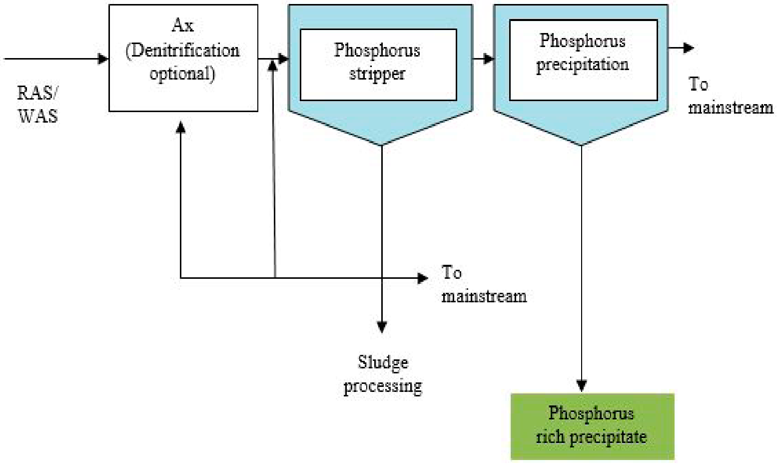


Figure 43. Schematic of the PhoStrip process (Oleszkiewicz et al. 2015)

11.7 Ammonia Recovery

There are technologies available for nitrogen recovery (Oleszkiewicz et al. 2015). The method to recover nitrogen in the form of ammonia is to strip off the concentrated solutions and absorb ammonia using acid. There are two methods of ammonia recovery, namely, steam stripping and air stripping.

11.7.1 Ammonia Steam Stripping

Figure 44 shows the schematic of the ammonia steam stripping process. In this process, the wastewater is fed to the stripper column and heated by steam. The ammonia rich steam is then discharged to the condenser, and then to the ammonium neutralization chamber. The end product of ammonium sulfate is produced after acid addition.

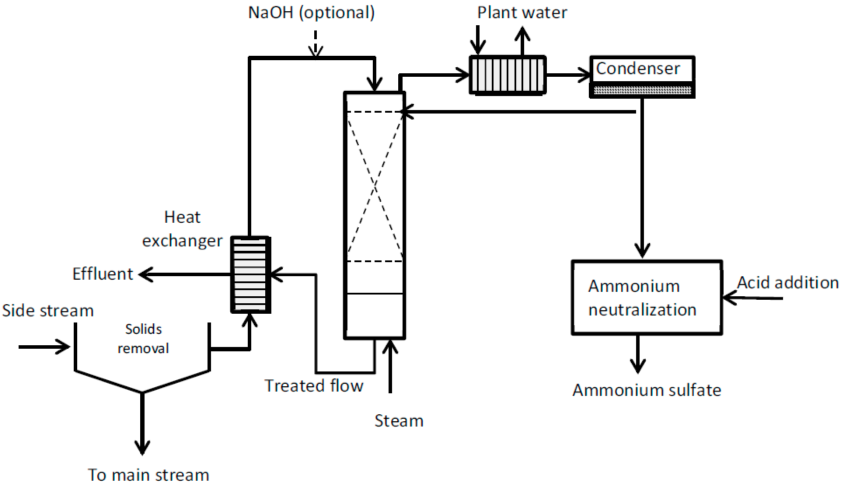


Figure 44. Ammonia steam stripping flow diagram (taken from Oleszkiewicz et al. 2015; developed after Metcalf & Eddy 2014; Gopalakrishnan et al. 2000)

11.7.2 Ammonia Air Stripping

Figure 45 shows the ammonia air stripping flow diagram. The process involves raising the pH to an optimum level and then increasing the contact between air and wastewater to strip ammonia.

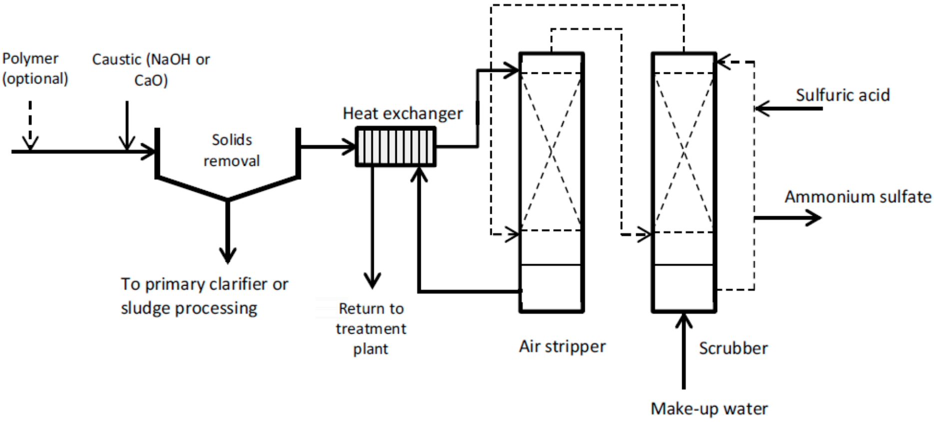


Figure 45. Ammonia air stripping flow diagram (Oleszkiewicz et al. 2015)

12. NUTRIENTS APPLICATION POST RECOVERY

12.1 Struvite or Magnesium Ammonium Phosphate

The recovery of nutrients such as phosphorus and nitrogen from wastewater needs to be followed by their application. Liu et al. (2012) described the application of struvite as a valuable resource. Struvite is considered a recyclable, environmentally friendly fertilizer with a 12.6% phosphorus, 5.7% nitrogen and 9.9% magnesium content respectively. Along with this, it has low or no heavy metal content and is a slow release fertilizer. This slow releasing property can be most advantageous in environments like grasslands, forests and coastal agricultural fields where highly soluble fertilizers are undesirable. The nitrogen release rate depends on the size of the crystals with small crystal size releasing more nitrogen. Furthermore, it was also reported that the phosphorus release rate was 100%.

However, agricultural application also depends on the safety factor. Heavy metals can pose a serious threat to agricultural production. During crystallization process, trace amount of heavy metals can find their place into the crystal lattice. Since these metals can accumulate in the soil and diffuse with the aquatic bodies, the presence of heavy metals is not desirable at all. Liu et al. (2012) investigated the presence of heavy metals in the struvite, and the result showed that the presence of heavy metals was below the legal limit for fertilizers.

Similarly, Baur et al. (2011) presented the benefits of the first struvite recovery installation of North America at the Durham Advanced WWTP in Tigard, Oregon. It was reported that after two years of operation, one million pound or 455,000 kg of Struvite was recovered. The benefits were the reduction of the biosolids generation as well as the chemical costs. The sales from Struvite generated revenue only added to the benefits. The struvite products were 1–3.5 mm in size, white, hard, odorless, dense, dustless and free of organic material. The legislations of 34 US states, Canada, UK and EU recognize it as fertilizer. The product had NPK ratio of 5-28-0 + 10% Mg, with no potassium and very low nitrogen so that it could be blended with the contemporary fertilizer to meet the specific need of the plants (Oleszkiewicz et al. 2015). The areas where this struvite fertilizer could best be applied were turf, nursery containers, and golf courses. It is reported that the British Columbia Ministry of Environment and fishery group purchased the struvite prills larger than 3.5 mm to bring fish back into the stream.

The other reported benefit of magnesium ammonium phosphate is the slow release rate of nitrogen, which reduces NO and N_2O emissions and increment in the uptake efficiency of crops.

12.2 Application of Sewage Sludge

The environmental risk assessment of the application of sewage sludge in Australia has been performed by Pritchard et al. (2010). Since Australia is a large exporter of agricultural products, it has to ensure the producer responsibility. This includes quality assurance that the crops and other agricultural products are free from contaminants that are detrimental to plant and human health. The products from sewage sludge that are produced in Australia are dewatered biosolids cake, lime-amended biosolids, alum sludge and compost. Since many rural WWTPs in Australia use alum dosing to remove phosphorus, a precipitate of alum is formed in the sludge, which is typically land filled. It was reported that the application of alum sludge reduced the shoot uptake of phosphorus when applied at the N-value of the sludge to meet requirements. However, satisfactory crop production can be achieved where the initial soil phosphorus level was adequate. Similarly, the land application from the lime-amended biosolids was comparable to the equivalent application of agricultural lime with a similar neutralizing value. Composting is another way to blend the product to make it suitable for the market needs. There are private companies that further process biosolids and produce suitable products in Australia; with typical processes consisting of initial blending of raw materials, windrowing temperature control, mixing and final blending. The concern for the long-term application of the sewage sludge, however, is the contamination due to heavy metals. (Oleszkiewicz et al. 2015.)

Batziaka et al. (2008) investigated the biosolids from the Thessaloniki WWTP in Greece for the pH test and contamination release. It was observed that the maximum phosphorus release occurred at $pH < 3$ and at $pH > 10$. The toxicological examinations showed that maximum toxicity occurred at very low and very high pH conditions.

Abba et al. (2015) mention that almost 40% of the reused sewage sludge in Italy is spread in the agricultural soil of Lombardy. The authors recommend that in order to improve the quality of sludge in the agricultural soil, the high-quality sludge should be separated from the sludge suitable for spreading as shown in the following table.

Table 9. High quality sludge and sludge suitable for spreading (Abba et al. 2015)

Heavy Metals (mg/kg)	**High Quality Sludge**	**Sludge suitable for spreading**
Cd	<5	<20
Cu	<400	<1000
Ni	<50	<300

Pb	<250	<750
Zn	<600	<2500
Hg	<5	<10

A detailed research was made by Viraraghavan and Lonescu (2002) in the Regina WWTP in Canada to examine the phosphorus-laden sludge and its land application. Their experimental studies showed that the mixing of phosphorus-laden sludge produced after the aerobic digestion with dewatered anaerobically digested primary sludge met the heavy metal criteria set by the guidelines for agricultural use. The authors mention that mixing these two sludge provided the advantages such as high fertilizer value and low heavy metal concentrations.

Valsami-Jones (2004) suggested the options for the application of phosphorus rich wastewater sludge. The sludge could be applied to agricultural land, forestry, parks, gardens etc. and could be used in the construction of pavement. The phosphates recovered from the wastewater streams could be utilized as a feedstock to the phosphate industry, a mineral fertilizer such as struvite and a mixing ingredient with compost (Oleszkiewicz et al. 2015).

Some existing technological solutions such as LYSTEK process biosolids in advanced medium. The resulting product is a liquid fertilizer that has high nutrients amount and is pathogen free (Singh et al. 2006). Such a process reduces the volume of sludge-required disposal by 75%. Another opportunity is to add biosolids to the anaerobic digester, which increases the methane production by 50% (Oleszkiewicz et al. 2015).

The following table shows the characteristics of untreated biosolids and biosolids treated with LYSTEK technology.

Table 10. Differences between untreated biosolids and biosolids treated with LYSTEK technology (Janssens 2014)

Parameter	**Untreated biosolids**	**Biosolids treated with LYSTEK**
Total Ammonium Nitrogen (NH_4-N, mg/kg)	6128	4222
Total NOX Nitrogen (mg/kg)	4	2
TP (mg/kg)	32000	52500
Potassium (K, mg/kg)	800	150000
Sodium (Na, mg/kg)	2000	45000
Zinc (Zn, mg/kg)	1100	1575
Copper (Cu, mg/kg)	740	1050

12.3 Irrigation

Murray and Ray (2010) presented a model that has been later described by Oleszkiewicz et al. (2015) where the nutrients from wastewater are recycled directly to the agriculture. The strategy is to increase agricultural yield and completely remove the nutrient removal process inside the treatment plant. The proposed model is shown in figure 46.

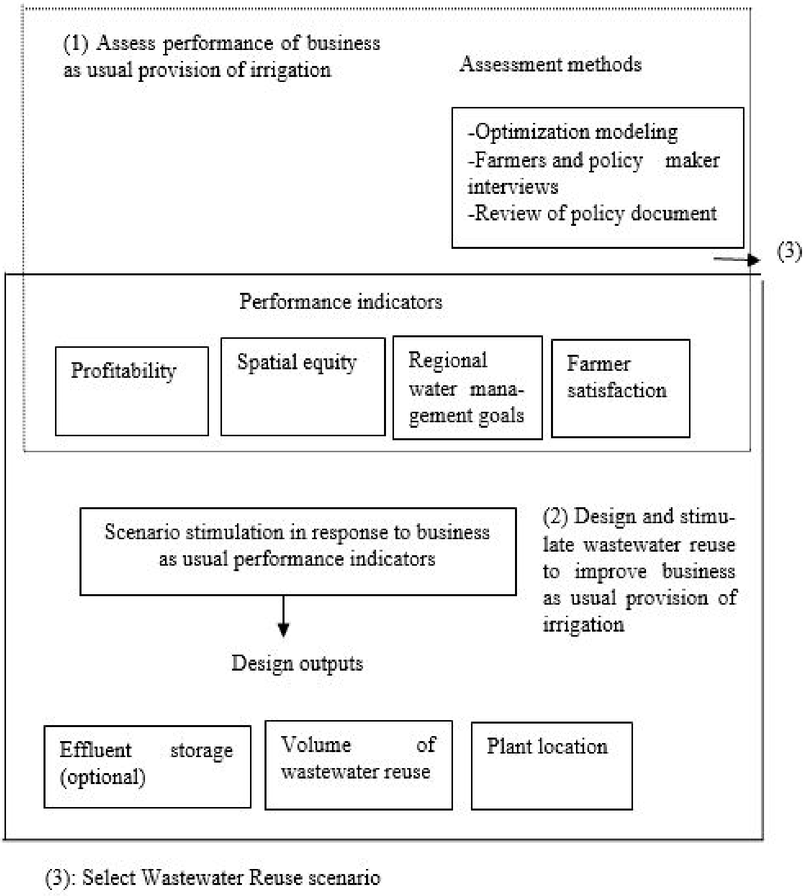


Figure 46. Model presented by Murray and Ray (2010)

The authors mention that this model of wastewater management can potentially increase agricultural yield, conserve surface water, offset chemical fertilizer demand and reduce the cost of wastewater treatment due to the elimination of the nutrient removal processes. The re-use centered management of wastewater, is however, thinly implemented. It was estimated by the authors that this model could increase profit by $ 20 million per year.

12.4 Ash

The incineration of both biological and chemical biosolids results in ash with high phosphorus and metal concentrations. The direct application of incinerated sludge is limited by the presence of heavy metals. Therefore, effective treatment to recover nutrients from ash are further required to eliminate heavy metals.

Ash can be used for non-agricultural land application. The cost of incineration can be EUR 517 per ton of dry solids. When the factors such as energy recovery from renewable fuel, aggressive air pollution control measures, and final disposal costs are taken into account, incineration technology for ash begins to look sustainable. (Oleszkiewicz et al. 2015.)

12.5 Stabilized Chemical Sludge

Some studies have suggested that the chemically precipitated form of phosphorus from iron salts addition can be available for re-use as a slow release fertilizer (Oleszkiewicz et al. 2015), and can be applied to the land at the rate of equal to greater than biological sludge.

Pritchard et al. (2010, cited by Oleszkiewicz et al. 2015) have examined the use of alum sludge as a fertilizer in Australia, and was reported that the application of alum sludge caused lack of bio-available phosphorus for plant roots when dosed on the existing nitrogen concentration of the biosolids. Due to the concern of heavy metals contamination, more research is required to effectively utilize the chemical sludge.

13. PHOSPHORUS RECOVERY POLICIES

The importance of phosphorus recovery is increasing all over the world due to the imminent threat of phosphate rock reserves depletion within this century. Municipal wastewater can be a significant supplier of phosphorus with efficient recovery technologies. According to Cornel and Schaum (2009), a modern version of a WWTP can transfer over 90% of the phosphorus from sewage to sludge after nutrient removal processes.

After the full-scale phosphate recovery techniques, it is possible to produce an end product that has the potential to be used as a fertilizer or as a secondary material for the fertilizer industry. The controlled precipitation technologies such as Phospaq produce struvite that is slurry and sandy. However, the controlled crystallization methods such as Pearl and Phosnix produce a clean product that can be used as fertilizers or mixed with other fertilizers. (Desmidt et al. 2015.)

The bitter truth still remains that at the European level, struvite is not yet recognized as a fertilizer and requires special admission from national governments to obtain the status of fertilizer (Desmidt et al. 2015). In Finland, phosphorus recovery gained very little attention. However, the common interests towards phosphorus recovery has risen along with other European counterparts (Nieminen 2010). Due to the influence of the national objectives and legislations, full scale phosphorus recovery installations are operational mostly in the European countries such as Austria, Belgium, Germany, the Netherlands, North America and Japan.

Table 11 shows the policies of nations that are the pioneers of nutrient recovery technologies.

Table 11. Phosphorus recovery technologies and national policies of some countries (Nieminen 2010; Desmidt et al. 2015)

Country	Recovery Technology	Description
Austria	Ash Dec	The fertilizer product of the Ash Dec technology has been licensed.
Belgium	NuReSys	Belgium recognizes the full-scale struvite production from NuReSys technology. The fer-tilizer is marketed as BIOSTRU
Germany	Ash Dec, Seaborne	The fertilizer product of the Ash Dec technology has been licensed. The products of the Seaborne process are used only locally.
Japan	PHOSNIX	Japan markets the product of the PHOSNIX process as min-eral fertilizers in rice cultiva-tion.
The Netherlands	PHOSPAQ, ANPHOS	The Netherlands has one of the toughest regulations regarding the maximum heavy metal content of sludge that is ap-plied to agriculture. This has led to the innovations of phos-phorus recovery technologies such as PHOSPAQ and ANPHOS. Along with this, the country has incineration facili-ties to meet such stringent leg-islation.
The United States, The United Kingdom	Ostara's PEARL	Only the full-scale struvite product of Ostara's Pearl tech-nology is certified as fertilizer. The fertilizer is available un-der the brand name of Crystal Green ™

Regarding the application of sludge to the agricultural land, Sweden has tough regulations. On the other hand, the Swedish Environmental Protection Agency (SEPA) proposed an intermediate target for phosphorus recycling whereby at least 60% of the phosphorus in wastewater should be restored to the productive soil, and of which half should be returned to arable land (Stark 2007; cited by Desmidt et al. 2015).

In Germany, the German Federal Environmental office (UBA) has encouraged the recovery of nutrients from effluent and sewage sludge. In addition, the German Fertilizer legislation (Düngemittelverordnung) from 2008 allows the recycling of sewage sludge ash as fertilizers if they meet the required pollutant limits of certain heavy metals. (Desmidt et al. 2015; Stark 2007.)

14. EXAMPLES FROM VARIOUS COUNTRIES

The field of nutrient recovery is developing rapidly across Europe, North America and other parts of the world. The motivation behind the rapid progress and commercialization of the nutrient recovery technologies are due to the stringent phosphorus limits in the WWTPs, national policies and the urgent threat of phosphate rock depletion within this century. National policies, such as in Germany which announced the objective to develop new technologies in the field of nutrient recovery in 2003 (Nieminen 2010), have undoubtedly led to the invention of new technologies. Germany and Switzerland have brought forward the sewage sludge ordinance into their national legislations, which will make phosphorus recovery mandatory from municipal sewage. This has recently been followed by Austria from the beginning of 2017.

Various countries were found to have differing technologies for nutrient removal and recovery during the research of this project. Most of the upcoming data were collected from the portal http://www.purebalticsea.eu which contains scientific information on the treatment practices of the Baltic countries.

The sludge produced during the treatment processes have high water content, and there is a need to lower the water content with efficient but low energy. Most of the countries with medium to large scale WWTPs were found to have a gravity thickening process in which the sludge settles down with the help of gravity in a circular tank with rotating scrapper. As for instance, this method of sludge thickening is utilized in the following treatment plants in the given countries, along with other countries.

- ✓ Denmark: Copenhagen
- ✓ Estonia: Tallinn, Tartu and Pärnu
- ✓ Finland: Turku and Oulu
- ✓ Germany: Berlin and Hamburg
- ✓ Sweden: Stockholm

Following sludge thickening, the stabilization of sludge is another target, whereby, biological and chemical reactions must be kept at a minimum level. This is achieved by anaerobic digestion devoid of oxygen in the digester, which also results in the production of biogas. A Combined Heat and Power (CHP) unit uses the biogas and produces electricity, which can be utilized by the treatment plants. This method seems to be very widely applied in the Baltic region, as for instance,

- ✓ Estonia: Tallinn, Kuresaare
- ✓ Finland: Helsinki, Tampere, Espoo, Kuopio, Jyväskylä
- ✓ Poland: Gdansk, Lublin, Szczecin.
- ✓ Sweden: Stockholm

With regard to the disposal of sewage sludge or ash from incineration, various countries were found to have different disposal methods. The available list is presented below.

Table 12. Sludge disposal practices of some countries (www.purebalticsea.eu)

Countries	**Practice**
Belgium, the Netherlands, Switzerland	Sludge disposal forbidden or re-stricted in agriculture. Thus, sludge is incinerated.
Estonia, Finland, Norway	Compost sludge for green areas
Greece, Iceland, Malta	Disposal to landfill
Belarus, Russia	Sludge to pits or ponds

In matters of recovery of nutrients, the installation of nutrient recovery technology for a particular type of wastewater differs from country to country. The processes such as AirPrex, Ostara's PEARL and WASSTRIP, and Phosnix show the best operative performances. However, some technologies such as Crystalactor have faced difficulties related to the feasibility of the processes (Nieminen 2010).

This chapter describes the technological development of the nutrient recovery processes of various countries. One country may have a wide range of technologies for the recovery of nutrients. Therefore, only selected technologies from each country have been described.

14.1 The Netherlands (Amersfoort WWTP)

In 2016, Europe´s first nutrient recovery facility to recover nutrients and to produce high-value fertilizer from wastewater was opened in Amersfoort, the Netherlands. Therefore, Amersfoort WWTP is a model of nutrient recovery and recycling inside the European Union. It is very beneficial to look into the nutrient recovery methods of this treatment plant.

The technology at Amersfoort WWT is the world´s first integration of three technologies: Ostara's PEARL and WASSTRIP technologies with Netherland´s LYSOTHERM, which makes it the latest of the second generation nutrient recovery method. This treatment plant is unique in that the fertilizer that it produces is ready-to-use. The plant is owned by Vallei & Valluwe and the design and construction of the facility was carried out by the Dutch company, Eliquo Water and Energy BV. The facility was constructed between November 2014 and September 2015, and was opened officially in 2016.

Figure 47. Aerial view of the Amersfoort WWTP (from www.dutchwatersector.com)

The wastewater treatment process at Amersfoort uses Canadian Ostara's technology and combines it with the Dutch technology of Thermal Pressure Hydrolysis (TPH) to enhance digestion. This new facility is 100% autonomous in Energy, and the energy surplus can provide 600 households with green electricity. The treatment plant has a capacity of 315,000 PE with 12,000 tons of dry sludge being treated annually (Eliquo 2015).

14.1.1 System Configuration

The following figure 48 shows the process flow diagram in the Amersfoort WWTP.

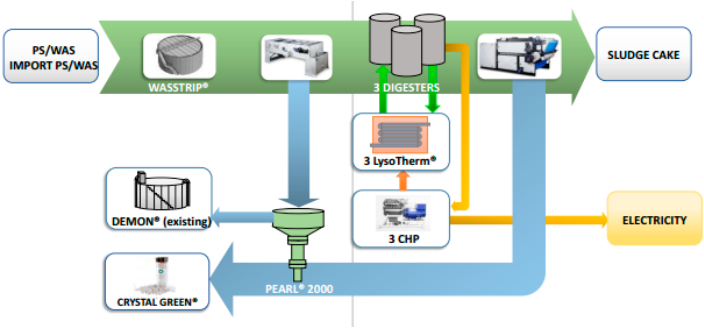


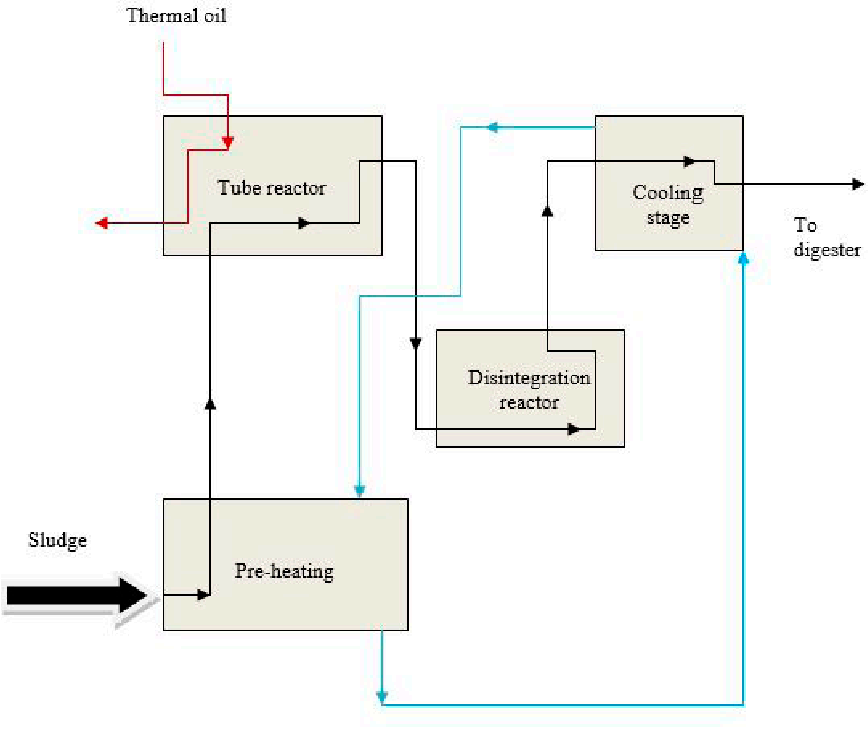
Figure 48. Process flow diagram of the Amersfoort WWTP, the Netherlands (Eliquo 2015)

The technology utilizes integrated approach, whereby, the WASSTRIP, PEARL and LYSOTHERM technologies work in unison to produce electricity, as well as a ready-to-use fertilizer called CRYSTAL GREEN.

As shown in figure 48, waste activated sludge is first sent to the WASSTRIP reactor where sludge is stripped to release internal phosphorus. This step ensures that the upcoming reactor PEARL receives the maximum amount of phosphorus. When the PEAL fluidized bed reactor receives the nutrient rich influent, magnesium is added in a controlled setting. Ultimately, nutrients are crystallized into fertilizer granules and bagged as CRYSTAL GREEN fertilizer.

14.1.2 Energy Efficiency

LYSOTHERM, on the other hand, is responsible for the thermal disintegration of the sewage sludge. The schematic of the LYSOTHERM is presented in figure 49.



- The black circuit represents sludge
- The blue circuit represents water used as heat transfer medium
- The red circuit represents the movement of thermal oil

Figure 49. A schematic diagram of LYSOTHERM technology (designed after Eliquo 2015)

As shown in figure 49, the sludge passes through the pre-heating system first, and then to the tube reactor where the sludge is heated within a fixed temperature range. The actual disintegration of the sludge takes place in the next reactor, known as the disintegration reactor. Then the sludge is cooled down in the cooling stage.

In order to maintain the necessary heat, the thermal oil circuit is installed. The process heat is typically recovered from the exhaust gases of the Combined Heat and Power (CHP) system. The heat produced by the combined heat and power engine is utilized to heat the digester and drive the sludge hydrolysis process. A water circuit for heat transfer is also used which makes the heat recovered from the disintegrated sludge in the cooling stage available for pre-heating. (Eliquo 2015.) The concept of the Lysotherm system at Amersfoort Treatment plant is shown in figure 50.

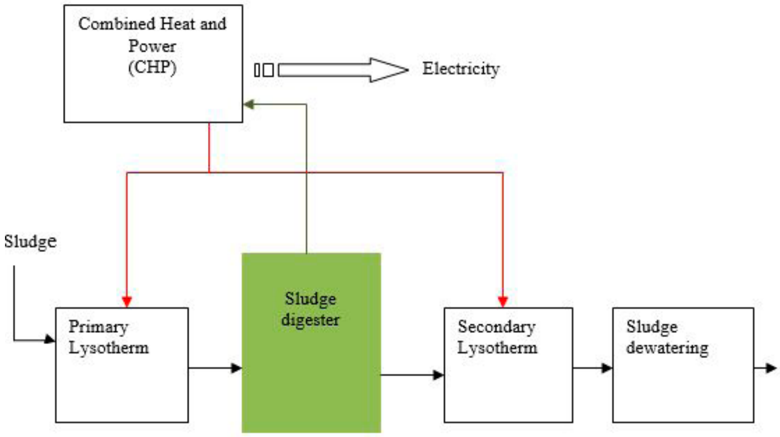


Figure 50. Production of electricity at Amersfoort WWTP (designed after Eliquo 2015)

The rate of conversion of the waste activated sludge from solids to biogas is very high as reported by the constructing company Eliquo Water and Energy BV. This is a favorable step as it increases the amount of the produced biogas. Surprisingly, the treatment plant generates surplus energy which can be sold back to the electricity grid.

14.1.3 Final Product After Recovery

Concerning the recovery of phosphorus, Amersfoort WWTP has utilized biological phosphorus removal accompanied by the Ostara's PEARL and WASSTRIP technologies to produce high-quality magnesium ammonium phosphate fertilizer which is marketed under the registered brand name of CRYSTAL GREEN.

14.2 Germany

14.2.1 Waßmannsdorf WWTP

The Waßmannsdorf WWTP utilizes AirPrex technology which was developed by Berliner Wasserbetriebe. The treatment plant has a capacity of 230,000 m³/day of the influent wastewater flow, and receives influent flow of 180,000 m³/day of the influent during dry weather conditions; and 1 million population equivalent (Nieminen 2010). In regard to the treatment process, Waßmannsdorf treatment plant utilizes biological phosphorus removal in the secondary treatment. The digestion of the sludge produces biogas which has been reported to meet over 60% of the plant´s energy requirements. The heat that is generated during energy production is utilized to heat the sludge and the buildings. (Berliner Wasserbetriebe; cited by Nieminen 2010).

The treatment plant was only updated with the AirPrex technology in 2010 replacing the old precipitation tanks. The problem of spontaneous precipitation of struvite in the old precipitation tanks was replaced by AirPrex technology which made it possible to remove struvite from the bottom of the tank continuously. The AirPrex process recovers phosphorus from the digested sludge and prevents the struvite problems in the processes following the digestion such as dewatering (Oleszkiewicz et al. 2015). The existing AirPrex technology at Waßmannsdorf WWTP is shown in figure 51.

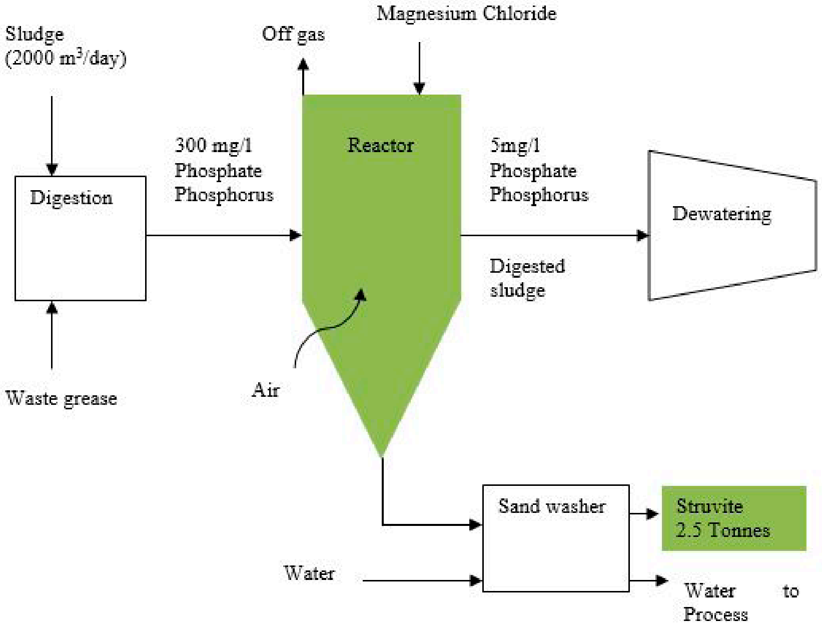


Figure 51. A basic schematic of AirPrex at Waßmannsdorf WWTP (designed from Oleszkiewicz et al. 2015)

As shown in figure 51, the digested sludge from the digester is sent to the precipitator reactor where crystallization takes place. For the induction of the struvite crystals, magnesium chloride salt is dosed into the reactor.

Figure 52. The bottom of the reactor where Struvite is discharged (Nieminen 2010)

The struvite crystals can be continuously removed from the bottom of the reactor, pictured in figure 52. The efficiency of the reactor can be analyzed from the schematic diagram; for 300 mg/l of phosphate phosphorus has been reduced to 5 mg/l of phosphate phosphorus accounting for almost 98% of decrement in the phosphate content.

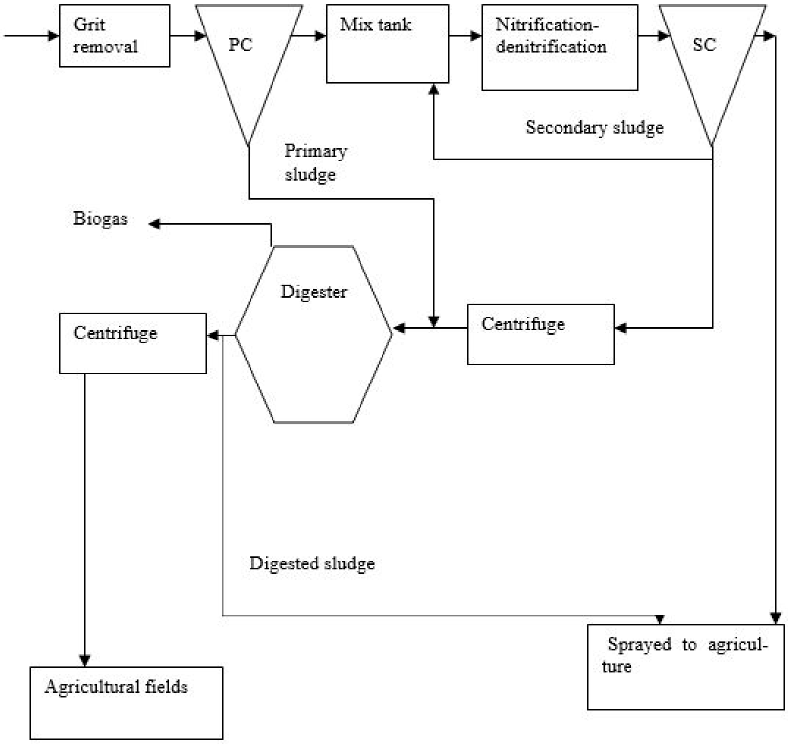
The struvite crystals that are collected from the bottom of the reactor are transferred to the sand washer and washed. The washed struvite is then stored in the container trolleys.

The detailed study of the Waßmannsdorf WWTP performed by Nieminen (2010) shows that the struvite production by AirPrex technology amounted to almost 2.5 tons per day. The struvite also meets the German Fertilizer ordinance and hence, is sold as a raw material in the production of fertilizers where it is mixed with another fertilizer. As available from the records, the investment cost for the installation of the AirPrex technology was 2.5 million Euros, and the ideal price of the produced Struvite was 50 €/ton (Nieminen 2010). Besides, as reported by Oleszkiewicz et al. (2015), there are claims that AirPrex reduces polymer use by 30%, sludge disposal cost by 20% and maintenance cost by 50%.

14.2.2 Steinhoff WWTP

The Steinhoff WWTP in Brunswick (Abwasserverband Braunschweig), Germany is going to be Europe´s first full scale carbon, nitrogen and phosphorus recovery facility. The plant will combine thermal hydrolysis for enhanced sludge disintegration, struvite recovery and Ammonia stripping (Kabbe 2016).

The Steinhoff treatment plant reuses the wastewater in agriculture. The plant is owned by the sewage board of Braunschweig (Abwasserverband) which was founded in 1954, operating on an area of 4,300 hectares – 3,000 hectares of which is used for agriculture. The irrigation area from wastewater in Braunschweig is the largest in Europe. The wastewater from the surrounding areas enters the plant, after which it is mechanically and biologically treated. The schematic of the process is shown in figure 53.



Full forms: PC- Primary Clarifier, SC- Secondary Clarifier

Figure 53. Schematic of the Steinhoff WWTP (Ternes et al. 2007)

As shown in figure 53, the primary sludge that settles in the primary clarifier is sent to the digester whereby biogas is produced. The wastewater moves to the mixing tank, where biological purification begins. In the next activation tank, nitrification and denitrification takes place where carbon compounds are decomposed, and phosphorus and nitrogen are biologically removed.

The following tank is the secondary clarifier, where secondary sludge settles with gravity, and the effluent treated water is pumped to the infiltration fields for irrigation. Parallel to this, the sludge collected from the primary and secondary clarifier are pumped to the digester where thermal reactions take place. After digestion, a methane rich gas is produced which is utilized to produce electricity and heat.

14.2.3 Gifhorn WWTP

In 2006, Gifhorn WWTP, pictured in figure 54, installed Seaborne Technology. The goal of this technology is to recover nutrients from the sewage sludge and to produce fertilizer without contamination of heavy metals or other organic pollutants. Among various steps of the methodology, at the beginning the biosolids are separated with the help of centrifuge and a filtering system as shown in the figure. This step is followed by a mono-sewage incineration plant. Subsequently, in the next step, the heavy metals are precipitated with the aid of digester gas which is rich in hydrogen sulfide (Müller et al. 2007). The final products of the technology are ash, struvite and ammonium sulfate.

Figure 54. Seaborne plant (Müller et al. 2007)

Figure 55 shows the schematic of the Seaborne process at Gifhorn WWTP.

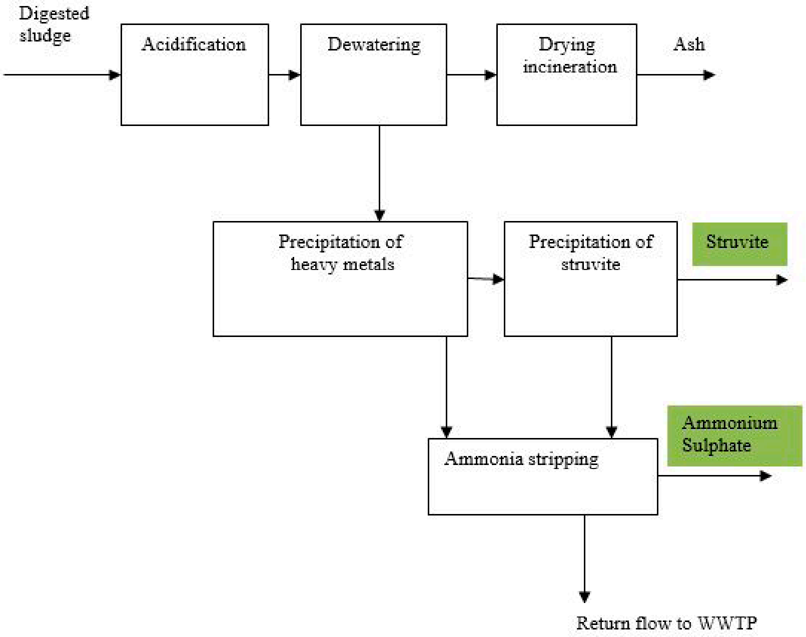


Figure 55. Schematic of Seaborne technology at Gifhorn (simplified from Cornel and Schaum 2009)

The Seaborne process, in principle, allows the recycling of nitrogen and phosphorus from sewage sludge and other organic wastes. Ultimately, the remains of the processes are synthetic fertilizer, digester gas, a heavy metal rich residual and wastewater (Müller et al. 2007)

The detailed study of the costs at Gifhorn WWTP has been performed by Nieminen 2010. The produced struvite was sold at 5 €/ton to be used as fertilizer, and the cost of recovered phosphorus was 46 €/kg. The significant share of the costs was due to chemical consumption. The struvite product from this technology was reported to contain very low heavy metal concentrations that met EU regulations.

14.3 Japan (Lake Shinji Clarification Center)

Japan is credited with the development of the Phosnix technology. The technology was designed by the Unitika Ltd Environmental and Engineering Division. The process enables the induction of granulated Struvite after effective phosphorus removal and recovery from the digester wastewater of the sludge treatment processes. It has been reported that the nutrient removal efficiency is 90% and the full-scale reactors are able to produce between 500 to 550 kg of struvite per day. (Ueno and Fuji 2001; Nawa 2009).

Figure 56. Phosnix reactor, Japan (Nawa 2009)

Figure 56 shows two Phosnix reactors at Lake Shinji Clarification center. The larger reactor treats the waste stream of 500 m^3 per day, and the smaller one treats the waste stream of 150 m^3 per day (Nieminen 2010). The process is reported to treat flows with 100–150 mg/l of Phosphate-phosphorus and recovering 90% of them as struvite.

Seventy percent of the phosphorus load in the treatment plant came from the supernatant, and the goal of the process was to reduce the chemical dosage to remove phosphorus and the amount of the sludge generated. (Oleszkiewicz et al. 2015.)

14.3.1 System Configuration

Figure 57 shows the configuration for the struvite recovery plant at Lake Shinji Clarification center in Japan.

As shown, the filtrate of the sewage treatment is fed into the reactor, which is in liquid phase. Magnesium chloride is added to provide magnesium: phosphorus ratio of 1:1, and sodium hydroxide (caustic) is added to adjust the pH to 8.2 to 8.8. Mixing is done with the aid of aeration, and after 10 days, struvite pellets are harvested. Oleszkiewicz et al. (2015), report that the process can recover up to 90% of the phosphorus as struvite.

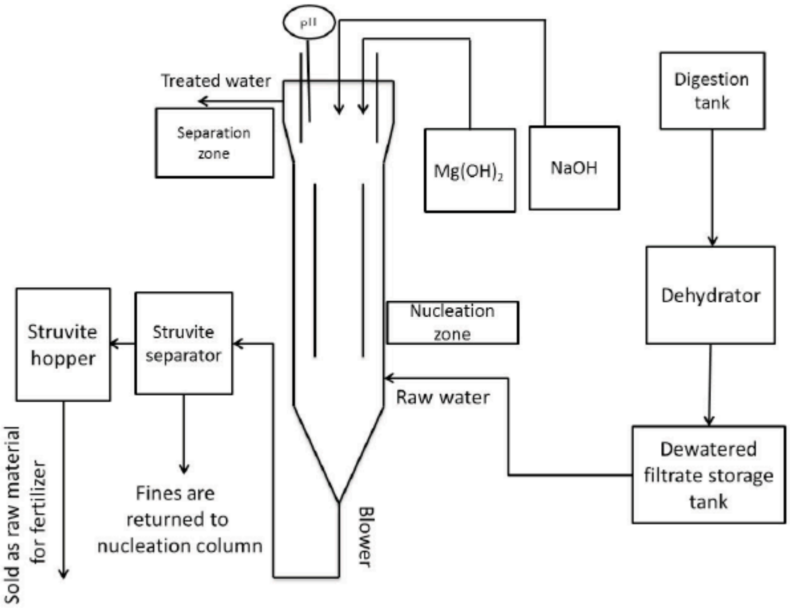


Figure 57. A schematic configuration of Phosnix process at Lake Shinji Clarification center (Oleszkiewicz et al. 2015)

14.3.2 Costs and Outcome

Nieminen 2010 reports that the produced Struvite of the Clarification Centre was sold to fertilizer companies at €250/ton. The fertilizer company mixes the struvite with other products and adds potassium. The fertilizer is sold in a 20 kg bag, with a price tag of €100-200.

The average savings are estimated to be €171 000 per annum (Nieminen 2010). The price is much lower compared to other traditional phosphorus removal processes (Oleszkiewicz et al. 2015).

14.4 Norway (VEAS Treatment Works, Oslo)

VEAS wastewater treatment works has a population equivalent of 650 000. The plant has installed a closed loop Ammonia Stripping unit, with a reported ammonia removal of 86.4% (Yasin 2012), and currently, it produces 3000 tonnes of ammonium nitrate per year by dry weight (Oleszkiewicz et al. 2015). The treatment of the sludge comprises of acid hydrolysis which is followed by anaerobic digestion at moderate temperature. The schematic diagram of the ammonia stripping at VEAS is shown in figure 58.

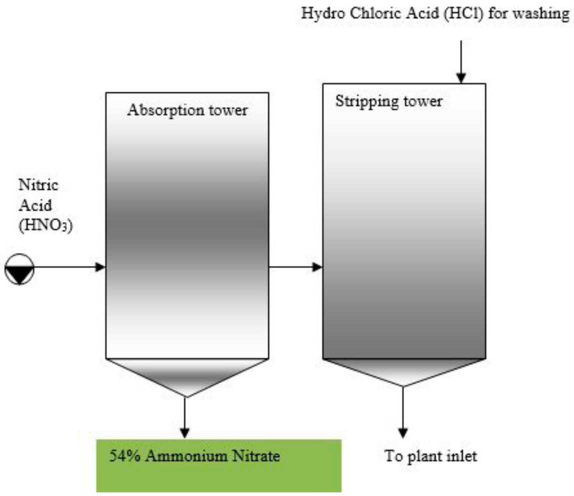


Figure 58. Ammonia Stripping at VEAS (Designed after Evans, 2007)

As shown in figure 58, nitric acid is added during the acid hydrolysis process. Originally, the plant was designed for sulfuric acid, however, after 1998, it was switched to nitric acid because the ammonium sulfate product from the sulfuric acid is acidic to the soil and farmers were against it (Evans 2007).

The plant has reported that it reduces 60% of the organic matter. The methane content of the biogas from the acid phase is 50% and from the mesophilic anaerobic digestion is 70%. And to sanitize the sludge, slaked lime is added. During hydrolysis, nitric acid is dosed which produces 54% ammonium nitrate. At least 90% of the ammonia is air-stripped and is recovered from the filtrate. Ultimately, 3000 tons of ammonium nitrate is produced per year. (Evans 2007). The cost of replicating the plant is estimated to be 580,000 Euros as of 2007.

Switzerland (Kloten/Opfikon WWTP)

Kloten WWTP utilizes a new stripping method for ammonia recovery where carbon dioxide is used as a pre-treatment to treat the liquid generated from the anaerobic digester and the source separated urine from water free urinals and no-mix toilets (Oleszkiewicz et al. 2015). This process, ultimately recovers ammonium sulfate as a marketable nitrogen fertilizer.

The urine is pre-treated using struvite precipitation after the addition of Magnesium; and consequently, the production of ammonium fertilizer was increased with the addition of pre-treated urine to the centrate from the digester. The liquid flux was increased by 10% by the addition of urine which resulted in a 40% increase in production of fertilizer (Morales et al. 2013; Oleszkiewicz et al. 2015).

Figure 59. Aerial view of the Kloten WWTP, Switzerland (from www.Poyry.ch)

The following figure 60 shows the schematic of the Kloten WWTP.

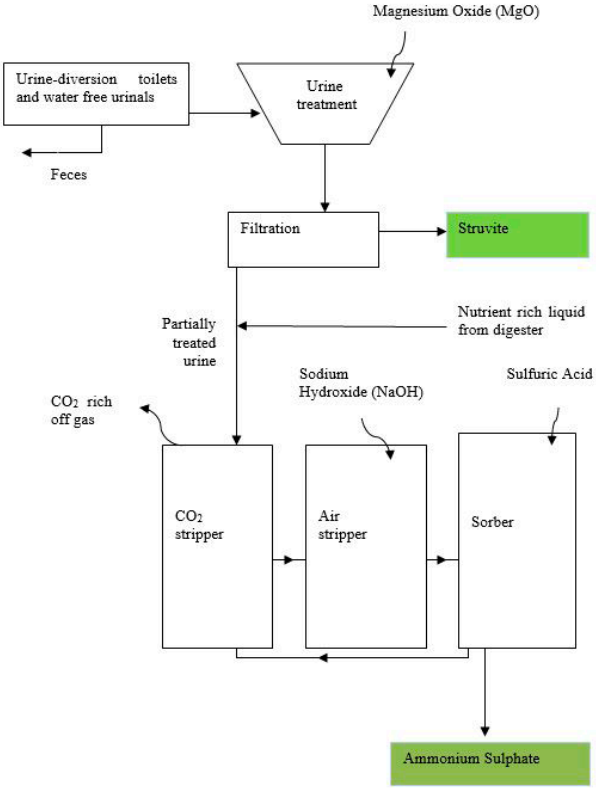


Figure 60. Co-treatment of sludge liquid and treated urine (Morales et al. 2013; Oleszkiewicz et al. 2015)

Morales et al. (2013) report that the ammonium removal rate with this process was 99%.

14.6 Sweden

Sweden has almost all urban households connected to the municipal treatment plants. The average degree of nutrient purification in the Swedish WWTPs as of 2010 has been reported to be 95% for phosphorus and 59% for nitrogen. Along with this, the Swedish Environmental Protection Agency has suggested an objective to recycle 40% of the phosphorus in the sewage sludge to the farmland by 2018. (Sellberg 2016).

14.6.1 Overview of Swedish Treatment Processes

Due to the high requirements and strict regulations of the phosphorus removal from the wastewater, most of the WWTPs have both biological and chemical treatment processes. To make sure that the farmlands do not accumulate heavy metals and other substances; a quality certification for the WWTPs has been developed, known as Revaq. The quality certification was developed by the Swedish water and wastewater Association, the Federation of Swedish Farmers, the Swedish Food Federation and the Swedish Food Retailers Association. As of 2015, 50% of the Swedish population was already connected to the Revaq certified treatment plants (IEA 2015).

The average degree of nutrient purification at Swedish WWTP in 2010 was 95% for phosphorus and 59% for nitrogen. Since the requirement of the phosphorus removal in Sweden is very high, most of the WWTPs have both biological and chemical treatment processes. The Enhanced Biological Phosphorus Removal Process (EBPR) is known as Bio-P in Sweden, which is supplemented by chemical treatment due to the strict requirements. Käppalaverket and Källby WWTP have biological processes combined with chemical processes that have resulted in an economical profit due to the reduction in cost of chemicals. (Sellberg 2016.)

14.6.2 Sludge Management and Phosphorus Recovery

Due to the nutrient content of the sludge, Sweden has traditionally applied sewage sludge to farmland for agricultural fertilization. However due to controversy surrounding the direct application of sewage sludge in Europe, various processes for nutrient recovery have been developed. The Swedish Environmental Protection Agency along with Sweco, investigated different processes to apply phosphorus recovery technologies in Sweden. Ostara process was deemed unlikely because it works only in combination with Enhanced Biological Phosphorus Removal processes. AshDec was found to have a higher potential of recycling over 95% of phosphorus from the wastewater after the roasting of sludge ash. A drawback, as mentioned by Sellberg (2016) is that this model requires ashes with a high amount of phosphorus and there are no WWTPs with such operation in Sweden. However, AshDec was concluded to have a greater potential in the country.

15. EMERGING IDEAS AND TECHNOLOGIES

New technologies and ideas are constantly emerging in the field of water services. A large part of the inventions seems to come from the Engineering consulting companies and the research projects carried out with educational institutes, universities and the universities of applied sciences. Even though the full-scale implementation of emerging technologies might not be feasible everywhere, mostly due to the economic costs and practical technological challenges, they largely determine the direction of future development in the water treatment methods.

This chapter outlines the emerging trends and technologies in the nutrient recovery methods; in pilot, small or large scale.

15.1 Nutrient Recovery from Animal Manure

Livestock manure is a mixture of urine, water and feces; and urine contains more than 55% of the excreted nitrogen of which more than 70% is in the form of urea. After successful nutrient recovery techniques, the final products such as K-struvite and calcium phosphate can be produced. The molecular composition of K-struvite is $KMgPO_4.6H_2O$, and that of the struvite is $MgNH_4PO_4.6H_2O$. The difference is that K-struvite has the replacement of NH_4 ion into K ion. (Desmidt et al. 2015.)

Extensive development and research into the treatment system has been performed by Vanotti & Szogi (2009). The treatment method has the following steps:

1. Biological nitrification of the liquid manure to oxidize Ammonium to nitrate.
2. Reduction of natural buffers.
3. Increasing the pH of the nitrified wastewater through the addition of calcium (Ca) or magnesium hydroxide to precipitate phosphorus.

The hydrolysis of the urea by the enzyme urease produces ammonium nitrate ion (NH_4^+) and carbonate.

$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4{+} + CO_3^{2-}$

After the addition of calcium or magnesium hydroxide into the liquid manure, carbonates, phosphates and ammonia are formed according to the following reactions.

$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2CaCO_3 + 2H_2O$

$5Ca^{++} + 4OH^{-} + 3HPO4^{--} \rightarrow Ca_5OH(PO_4)_3 + 3H_2O$

$Ca(OH)_2 + 2NH_4{+} \rightarrow 2NH_3 + Ca^{++} + 2H_2O$

Vanotti & Szogi (2009) patented a technology based on their previous backgrounds. The schematic of the technology is shown in figure 61.

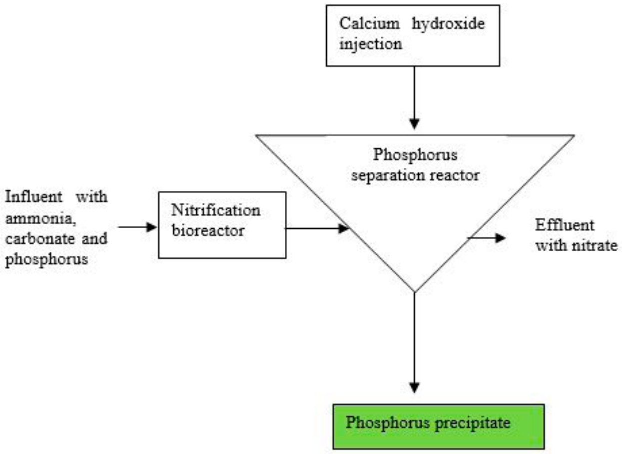


Figure 61. Technology for nutrient recovery from animal manure (Vanotti & Szogi, 2009)

As shown in figure 61, the final product is a calcium phosphate rich sludge which can be a source of phosphorus fertilizer. A full-scale demonstration of the process was performed by Vanotti & Szogi, and it was reported that the second generation version of this technology is now available (Vanotti & Szogi 2009).

Phosphates in manure are precipitated by adding magnesium in the presence of Ammonium. This results in the formation of struvite and other products, collectively called as MAP. Alfter et al. (n.d.) suggest some methods to precipitate MAP from the manure.

1. A Simple Method in which solid but reactive magnesia is added to the manure in the storage tank, and mixed for a short time. The result is that the entire phosphate is precipitated as MAP and is sedimented at the bottom of the tank. Therefore, a liquid phase and a

solid phase is formed in the tank. The authors report that the liquid phase is completely free of phosphates and hence, the filtered liquid can be irrigated by farmers into their field without any phosphate problems. The solid phase can be stored and later utilized as a phosphate and nitrogen fertilizer.

Figure 62. Magnesium Oxide powder mixed with the manure storage tank (Alfter et al. n.d)

The advantages of this method are reported to be low chemical costs and no requirement of any special equipment. The disadvantages, however, are bad odor and that the majority of the ammonium remains in the solution.

2. An improved method, in which, the phosphate content of the manure raised to the same level as that of the ammonium content. Consequently, additional phosphate is provided to the tank by adding magnesium phosphate solution. The result is a complete precipitation of the entire inorganic phosphate and ammonium, which settles as sediment at the bottom of the tank. The disadvantage, as reported by the authors, is that the method is expensive and the chemical costs rise to 15 or 20 €/m^3 depending on the concentration of the manure.

3. A complete method is proposed by the authors whereby efficient measures have to be followed. A digester has to be installed to use the organic substance for the production of the methane. After digestion, the organic substances are converted to soluble inorganic substances, and hence, ammonium and phosphate are precipitated. The solids need to be separated and rinsed with hot water to get MAP into the solution. During precipitation, phosphate together with ammonia is recovered.

15.1.1 Putten Calf Manure Treatment Plant, the Netherlands

The Calf Manure Treatment Plant in Putten, the Netherlands, treats almost 115,000 m^3 of calf manure per year. Before the recovery of Phosphate, the manure is separated into a liquid and solid fraction. The liquid fraction is processed in a biological activated sludge system where the organic carbon and nitrogen are broken down. After nitrification-denitrification and settling, the phosphate rich effluent is treated with a magnesium source such as magnesium oxide. Consequently, K struvite is formed. It is reported that 125 kg of phosphorus is recovered per day. (Desmidt et al. 2015.)

Since the European legislation at this moment does not recognize K-struvite as a fertilizer, it cannot be directly applied into agriculture. In the Putten treatment plant, K-struvite is transported to Thermophos, a company that produces phosphorus, where it is processed. (Desmidt et al. 2015.)

15.2 Phosphorus Recovery from Source Separated Urine

Hug and Udert (2013) have investigated the use of magnesium electrodes for the recovery of phosphorus from the source-separated urine with average concentrations of 197 mg/L of phosphate phosphorus (PO_4-P) and 2540 mg/L of ammonium nitrogen (NH_4-N). The process used a magnesium anode and a steel cathode, which resulted in an electrochemical precipitation of struvite. Magnesium was electrochemically dissolved from the sacrificial magnesium electrode.

Similarly, Udert et al. (2015) have comprehensively researched struvite precipitation, nitrification-distillation and electrolysis for the urine treatment in VUNA project. Struvite precipitation has been successfully tested in many pilot projects, where mineral struvite ($MgNH_4PO_4$-$6H_2O$) is precipitated from the stored urine. Stored urine has the conditions necessary for the struvite formation such as high pH, high ammonia and phosphate concentrations (Udert et al. 2015), and thus requires only an addition of magnesium.

The model of the struvite precipitation from source separated urine is shown in figure 63.

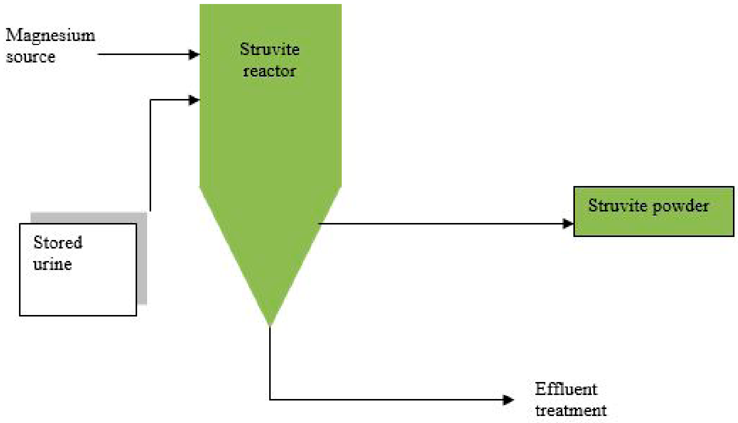


Figure 63. Phosphorus recovery from Urine (Designed after Udert et al. 2015)

As shown in figure 63, magnesium is dosed at the beginning of the process which requires the knowledge of the exact dosage for the phosphate production.

Udert et al. (2015), mention that besides using magnesium dosing in the form of a powder, magnesium can be dissolved electrochemically with anode-cathode setup. Combined with a reliable process, electro-precipitation can also be a promising approach for onsite reactors at remote locations.

Within the project, Udert et al. (2015), operated the reactors for nitrification and distillation. In the procedure, the stored urine is pumped to the nitrification reactor with slow-growing nitrifying bacteria at the stratum. The nitrified urine is heated to 80 degrees Celsius for several hours, which ensures disinfection, and stabilizes ammonium nitrate. It is reported that nearly all the nutrients are recovered in the final product except for some in the excess sludge. The method is reported to be suitable for those regions where fertilizers are scarce.

15.3 P-ROC

The P-ROC process is short for Phosphorus Recovery from Wastewater by Crystallization of Calcium Phosphate Compound. The process was developed by Forschungszentrum Karlsruhe in Germany which is unique because it recovers phosphorus without the dosage of chemicals and only needs calcium silicate hydrate crystals that are the by-product from the building material industry (Oleszkiewicz et al. 2015).

The phosphorus rich water is fed into the reactor and calcium silicate hydrate crystals are added. As a result, Calcium Phosphate is formed which can be separated. Oleszkiewicz et al. mention that the phosphorus removal rate with this process is approximately 80%. The flow chart of the process is shown in figure 64.

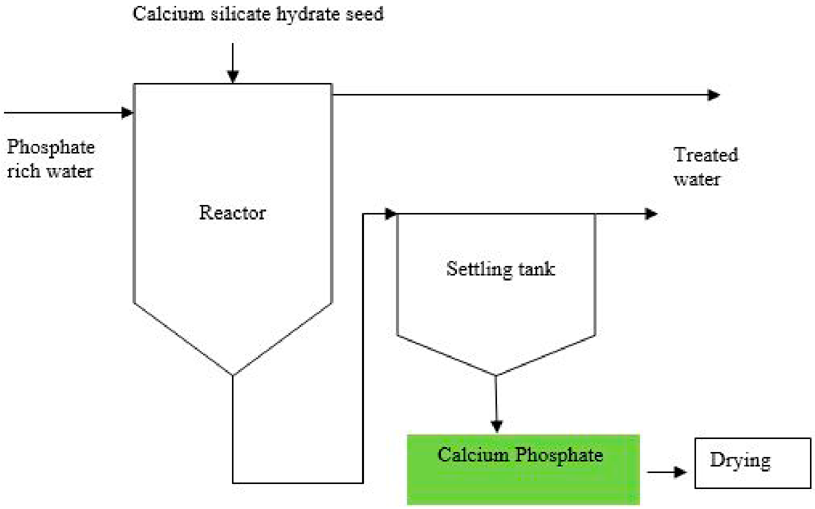


Figure 64. P-ROC process (Berg and Schaum 2005)

The phosphorus rich product, calcium phosphate, can be applied to agriculture and used in the phosphate industry as a raw material. The product is separated and dried.

The process was reported to not require pH adjustments. The products formed met the requirements of the phosphate-industry as a phosphate rock substitute. Berg and Schaum (2005) highlight that these products have less cadmium and uranium contamination than the natural phosphate rock itself. However, the fertilizing properties of the products need further research.

15.4 Phosphorus Recovery by Adsorption Methods

Adsorption is process of the adhesion of particles in a surface. There have been recent developments and investigation into the field of adsorption technologies.

15.4.1 Adsorption by Agricultural By-products

Nguyen et al., 2012, have outlined a sustainable methodology of adsorption for phosphorus recovery. This process utilizes the Agricultural By-products (ABP), such as cotton, wheat stalk and pine saw dust.

The authors mention that the advantages of this methodology with the agricultural by-products are abundant availability, low cost, high efficiency, and no detrimental environmental impacts. In addition to these, agricultural by-products loaded with phosphorus can be used as fertilizers in agricultural production (Nguyen et al. 2012). Various agricultural by-products have been investigated, such as, pine sawdust, orange waste, coir pith, egg shells, cotton stalk, giant reed etc. The natural phosphorus adhesion occurs in the cell walls of these by-products. However, the authors mention that efficient phosphorus removal requires some form of chemical modifications. This particular field can be sustainable for the future with further research.

15.4.2 Adsorption on Natural Zeolite

A zeolite is a mineral, which acts as an adsorbent due to its porous structure. Khanal (2013) proposed nutrient recovery from source separated urine by adsorption on mordenite and polonite, shown in figure 65. The two-month laboratory scale study showed that mordenite could provide ammonium nitrogen removal up to 79% and polonite could provide a phosphate phosphorus removal up to 97%.

Figure 65. Left: Polonite and Right: Mordenite (Khanal 2013)

15.4.3 Adsorption on Metal Oxide

The technology of phosphorus removal by adsorption of metal oxide was developed in Japan by Asahi Kasei Chemical Corporation. The resin of metal oxide and polymer is highly selective for phosphates and discards other ions that are present in the wastewater. The process was reported to have very little amount of phosphorus in the effluent water.

The schematic process diagram is shown in figure 66.

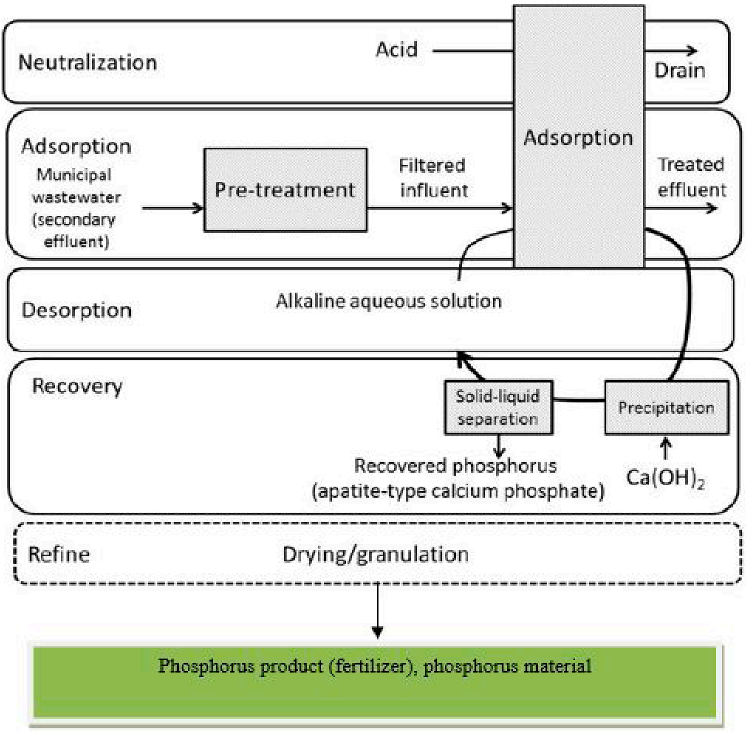


Figure 66. Adsorption technology developed by Asahi Kasei Corporation, Japan (Oleszkiewicz et al. 2015)

15.5 Self-Healing WWTP Tanks

Utility Waterschapsbedrijf Limburg has installed two WWTPs in Simpelveld and Roermond, the Netherlands with a completely new concept. The plants premiered in December, 2016, and it was reported that the investment cost was EUR 10.7 million. The concept of the process is brought to the market by Verdygo, a private parent company of Waterschapsbedrijf Limburg, together with international construction firm Strukton, engineering consultancy Royal HakoningDHV and wastewater construction firm Aan de Stegge (WWI, 2017).

The concept is to adjust the tanks to the changing scenarios, such as increase or decrease in the incoming water load, changing temperature along with the changes in policies such as strict discharge regulations. A special bacteria is mixed with concrete during construction which is reported to survive in the cement for about 200 years. The most important task of these bacteria is to produce limestone to fill any cracks that appear.

Figure 67. Self-healing WWTP, the Netherlands (from dutchwatersector.com)

The process allows the operators to avoid large concrete clarifier tanks of the conventional sewage treatment plants. This new method allows the expansion of the existing plants along with the maximum flexibility during the replacement of parts. As shown in figure 67, the plant is built aboveground to provide full flexibility. Along with this, all the technical equipment is designed in a size of containers that are transportable. All the parts of the process, such as, the grit removal chamber, jacks, aeration tanks and pumps are replaceable as well as expandable. The operating mode of the treatment plant is aerobic Nereda technology which is based on the granular activated sludge.

The plant is reported to deliver annual savings in maintenance costs of 20%, and the construction period is shortened by one-third. And with the prevention of large cracks in the concrete, minimum amount of steel reinforcement is required within the concrete structure. The other two materials which are used for the tanks are wood for the sludge storage, and coated steel for buffering of influent. (Dutchwatersector 2017.)

15.6 Phosphorus Retention from Agricultural Runoff

An investigation into the phosphorus absorbing material was carried out by Klimeski (2015). The study focused on the laboratory as well as large scale application of phosphorus retention materials for the treatment of agricultural runoffs in Finland. Tests were performed on the calcium rich materials such as Sachtofer PR®, steel slag, FiltraP®, Filtralite P® and iron rich materials with a phosphorus influent of 50mg/l. Sachtofer PR® was found to be the most promising material, and thus was further employed in meso (20 kg) and large (7 tons) filters to treat influent water. The large filter treated agricultural runoff from 17 ha of cropland.

It was found that calcium materials as well as iron rich materials have high phosphorus retention capabilities. Most of the phosphorus input into the large filter was delivered under high flow conditions due to the fast snowmelt in spring and heavy rainfall in autumn. Therefore, Klimenski (2015) suggested that design parameters of peak flows have to be considered in a phosphorus removal structure. Similarly, the research outlined that the industrial byproducts such as steel slags and mine drainage are competitive retainers due to their lower costs.

15.7 Membrane Based Technologies

Three membrane based technologies are emerging: forward osmosis, membrane distillation and electrodialysis. These processes have the capability of mass transfer. Forward osmosis recovers nutrients through struvite precipitation. In this process, a semi permeable membrane is placed between two solutions of differing concentration. Due to the osmotic pressure difference, water is driven through the membrane which recovers nutrients (Xie et al. 2016).

In membrane distillation, water is transported through vapor phase and the distillated is recovered.

In electrodialysis, the ion-exchange membranes are arranged which select for a particular type of ions. The process provides a selective mechanism for nutrient recovery.

15.8 Sewage Sludge Incineration with Recycled Woodchips

Large amount of phosphorus is present in the ash after the incineration of sewage sludge. A process model of sustainable phosphorus extraction from ash has been developed by Dr. Yariv Cohen at the Swedish University of Agricultural Sciences. This method enables extraction of phosphorus and different substances from the ash, sewage and mining waste.

The procedure of the model is shown in figure 68.

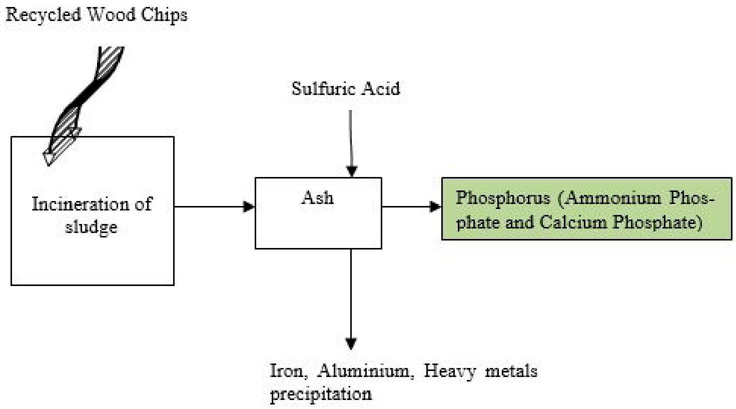


Figure 68. Phosphorus extraction model developed by Dr Yariv Cohen in Swedish University of Agricultural Sciences (designed after literature review)

Burning wood chips with sludge, as shown in figure 68, also makes the aerobic decomposition process almost odorless. This is beneficial because the process can be carried out in the neighborhood in a sustainable manner.

Ragn-Sells AB, a Swedish company focusing on the sludge distribution, has planned for a large-scale production of this model to exploit this untapped resource. The plant processes some 30,000 tons of ash per year. However, for the process to be economically profitable, the phosphorus content in the ash needs to be 5%.

(The presented information is edited from http://advantage-environment.com/workplace/phosphorus-revisited-new-recycling-technology/)

15.9 Phosphate Recovery by Steel By-products

Steel byproducts have a phosphate removal capacity. When the steel shavings rust, iron oxide is formed on their surface. This oxide binds with phosphate ions and thus removes phosphates from the drainage water. The research has been carried out at the South Dakota State University, USA, by Assistant Professor Guanghui Hua (2015) of Civil and Environmental Engineering.

Figure 69. Steel byproducts from machine shops

It is reported that the carbon steel performed better than the stainless steel because iron oxide formed on the carbon steel is more reactive to phosphates.

The procedure was optimized by pumping the stimulated drainage water first through a column filled with wood chips and then to a column filled with steel byproducts. During three months of research, it was found that the removal rates of nitrates and phosphates were 100% respectively.

(The presented information is edited from https://phys.org/news/2015-09-steel-byproducts-phosphorous-agricultural-drainage.html)

15.10 Phosphorus Purification by Iron-Oxidizing Bacteria

Takeda et al. (2010), in Japan, proposed a new model in which the phosphorus recovery from natural body is possible using iron-oxidizing bacteria and a woody biomass as a carrier. The woody biomass was immersed in water abundant in iron oxidizing bacteria and removed 1–10 weeks later. The results showed that the immersed carrier collected iron produced by the bacteria and contained 0.2 mg/g of phosphorus after 3 weeks.

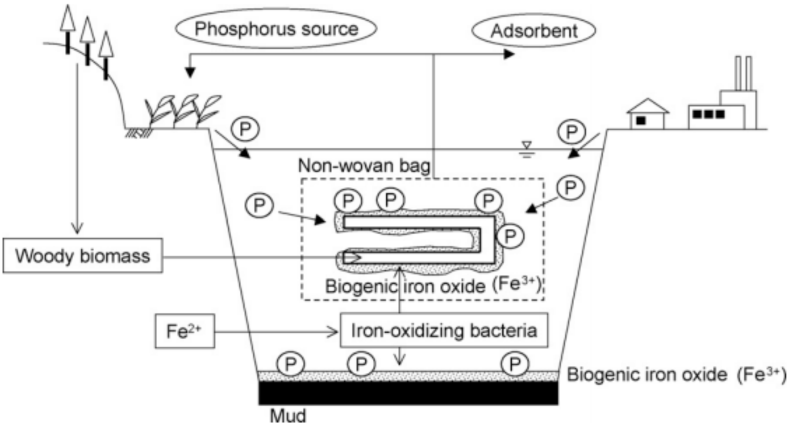


Figure 70. Model Proposed by Takeda et al. (2010)

The woody biomass was able to collect biogenic iron oxide with an adequate amount of phosphorus in the immersion period of 3–6 weeks. This oxide could absorb phosphorus from a rich solution, and it is reported that almost 70% was available for plant uptake.

The benefit of this model, as shown in figure 70, was that it did not require any chemical addition, and the woody biomass and the iron-oxidizing bacteria are abundantly available. The authors suggested that the proposed model could be potentially helpful in the effective phosphorus recycle from natural water bodies and in the improvement of the quality of the aquatic environment when carried out in large scale.

15.11 Gypsum as a Soil Amendment

Gypsum is a soil amendment that is known to improve the soil structure, and retain soluble phosphorus in soil. SITRA (2015) reports that the use of gypsum on soil is beneficial in mitigating soil erosion as well as decreasing phosphorus run-off into the water bodies. Its application reduces phosphorus runoff, and in the meantime, retains phosphorus that is usable for plants. However, it cannot be used near lakes or in their catchment area because of the run-off of sulfates that are present in the gypsum.

Gypsum waste are generated as by-products of the fertilizer industry. Furthermore, gypsum waste can be spread into the field with regular agricultural machinery. This means that no new investments are required for the machinery. In the TRAP project in Nummenpää in Nurmijärvi, Finland, 4 tonnes of gypsum were spread per field hectare. The result was astonishing; as the runoff of phosphorus bound to soil particles fell by 57%, the runoff of dissolved phosphorus fell by 43% and the overall phosphorus runoff fell by 54% (SITRA 2015).

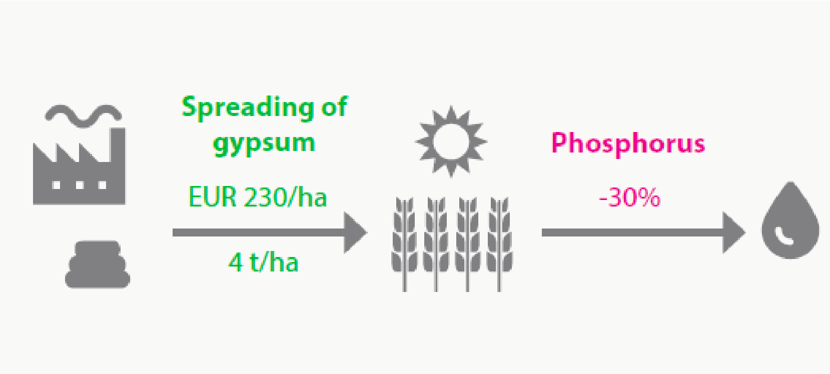


Figure 71. Spreading of gypsum and reduction of phosphorus (SITRA 2015)

Similarly, Salonen et al. (2001) tested gypsum to manage internal phosphorus in lake Laikkalammi, Finland. The authors found that the gypsum treatment was a versatile method compared to the other sediment inactivation method. It was noticed that gypsum acted through three different mechanisms: as a mechanical cover, a binding site for phosphorus, and it changed the microbiological composition of the sediments by creating more favorable conditions to sulfur bacteria instead of methane bacteria.

16. NUTRIENT REMOVAL AND RECOVERY IN FINLAND

Finland is rich in surface waters with abundant lakes, ponds and rivers. Therefore, it is very important to protect and safeguard these resources from agriculture. The reduction of impacts of agriculture on the water resources is a national objective, evident by decrees and directives concerning the protection of surface waters, removal of nutrients from the wastewater, and fertilizer regulations. Along with this, the government has included bio-economy and circular economy in the national policy. This has led to national discussions and research into the nutrient removal and recovery technologies. This chapter highlights the status of Finland in terms of the removal of nutrients, their recovery and reuse in the water services.

16.1 Nutrient Removal

The government of Finland has issued directives concerning the nitrate and phosphate pollution that lead to eutrophication. The national legislation for nutrient removal is issued through the Government Decree on Urban Wastewater Treatment, which demands the following level of reduction of nutrients from the incoming wastewater.

Table 13. Government of Finland Decree on Urban Wastewater Treatment 888/2006. Legal limits of nutrient discharge concentration from WWTPs in Finland.

Parameter	**Concentration**	**Minimum Percent-age of Reduction**
TP	3 mg/l (less than 2000 PE) 2 mg/l (2,000 – 100,000 PE) 1 mg/l (more than 100,000 PE)	80%
TN	15 mg/l (10,000 – 100,000 PE) 10 mg/l (more than 100,000 PE)	70%

In addition to the national directive, HELCOM suggests the following level of nutrient removal:

Table 14. Helsinki Commission (HELCOM 2010) discharge limits

Parameter	Concentration	Minimum Re-duction
TP	0.5 mg/l	90%
TN	15 mg/l (10,000–100,000 PE) 10 mg/l (more than 100,000 PE)	70–80%

Due to the above mentioned legal guidelines, simultaneous precipitation with ferrous sulfate is widely used in Finland, which results in the effluent phosphorus concentrations of 0.1 mg/l–0.2 mg/l with phosphorus and organic matter removal degrees of more than 90% (Ruotsalainen 2011). This model of nutrient removal seems advantageous as existing treatment plants can easily adopt with easy operation and low capital costs. The cumulative effect of the national and the HELCOM effluent directives have led to the efficient technological development in Finland, particularly, in the field of nutrient removal. As for instance, Viikinmäki WWTP in Helsinki, which is the largest treatment plant in the Nordic countries, has a phosphorus removal efficiency of 97% and nitrogen reduction rate of 91%. The following bar graph compares Finland´s average nutrient reduction rate with its peers.

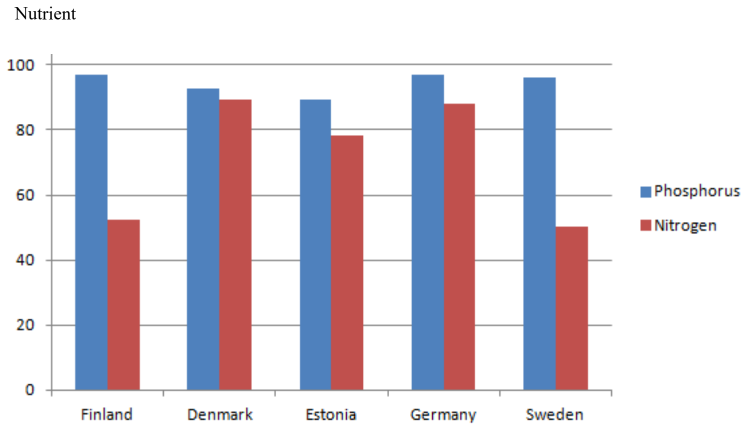


Figure 72. Comparison of percentage of average nutrient removal among 5 countries (designed after literature review of Ruotsalainen 2011)

As shown in the diagram, Finland has average phosphorus removal rate of 96.9%, and average nitrogen removal rate of 52.4%. In Finnish inland waters, phosphorus is the critical nutrient in eutrophication and therefore nitrogen removal requirements concern more with the coastal WWTPs. Finland´s level of phosphorus reduction is higher than the other four countries. The best performing country in the bar graph for average nitrogen removal is Denmark, with reduction rate of 89.4%.

The most widely applied model of nutrient removal in Finland is the combinations of mechanical, biological and chemical processes. Some treatment plants, for example, in Turku and Helsinki have advanced treatments after the combination of mechanical, biological and chemical processes.

Table 15 shows some of the existing model of nutrient removal in Finland.

Table 15. Nutrient removal processes in Finland (Ruotsalainen 2011)

Nutrient removal model	**WWTP(WWTP)**
Mechanical + Biological + chemical	- Imatra WWTP - Mikkeli WWTP - Joensuu WWTP
Mechanical + Biological + Chemical + Advanced	- Oulu WWTP - Turku WWTP - Helsinki WWTP

Similarly, table 16 shows the nutrient removal status in some of the Finnish WWTPs.

Table 16. Nutrient removal status of some WWTPs in Finland with phosphorus and nitrogen reduction percentages. (Ruotsalainen 2011)

WWTP	**Influent P (kg/day)**	**Effluent P (kg/day)**	**% P red.**	**Influent N (kg/day)**	**Effluent N (kg/day)**	**% N red.**
Loimaa	31.5	0.9	97.1	194.9	125.0	35.9
Kokkola	87.0	2.3	97.4	570.2	481.0	15.6
Pieksämäki	68.4	0.6	99.2	291.6	135.2	53.7
Riihimäki	116.1	2.8	97.6	757.8	186.1	75.4
Oulu	330,6	3.8	98.8	2247.6	1180.4	47.5
Turku	712.4	13.7	98.1	4001.1	788.6	80.3
Helsinki	1784.7	58.0	96.8	12009.1	1071.5	91.1

Table 16 shows that the percentage of phosphorus reduction in Finnish WWTPs exceed over 90%. Since phosphorus is the critical nutrient for eutrophication in Finnish inland waters, nitrogen removal requirements are concerned mostly in coastal areas.

16.2 Nutrient Recovery

For nutrient recovery, there seems to be boundless opportunity for Finland to export product expertise to the world as circular economy and nutrient recycling are high on the government agenda. The efficient nutrient removal Finnish technologies that have efficiencies of over 90% provide further opportunities to recover phosphorus and nitrogen, and convert them to valuable products.

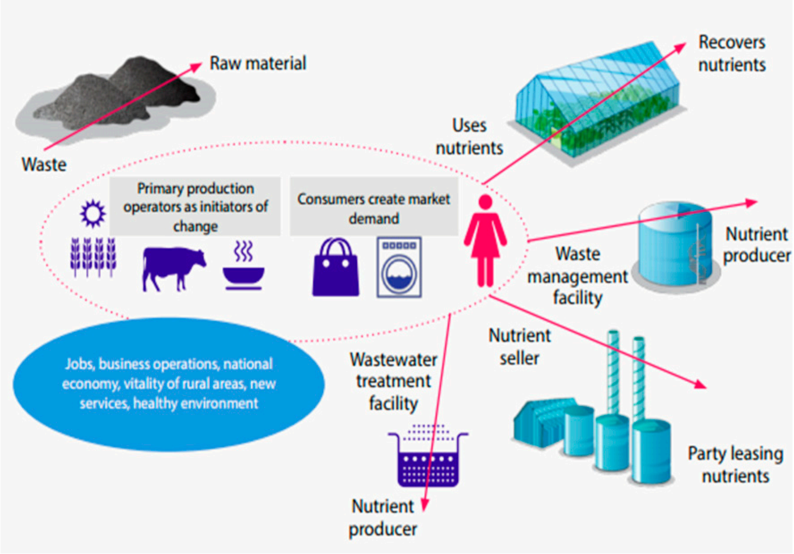


Figure 73. A model of nutrient recovery for Finland (SITRA 2015)

Finland produces approximately 140,000 tonnes of treatment plant sludge from municipal wastewater each year. The division of this sludge occurs as follows:

Table 17. Distribution of sewage sludge use in Finland (SITRA 2015)

Percentage of total Sludge	**Use**
62%	Landscaping and reforming of Landfill
33%	Biogas production plants
2%	Agricultural soil amendments
2%	Landfill or final disposal

As evident, the sludge from municipal WWTP has been traditionally used in Finland without recycling into nutrient products.

Despite the traditional means of sludge practice, Finland is home to many emerging technological companies. The rapid emergence of further technologies can be forecasted in Finland due to its eco-innovation. A recent 2017 European Union environmental implementation review has placed Finland 2nd in the rank of eco-innovative countries of the European Union. The following technological companies have provided the latest outlook into the Finnish nutrient recovery developments (information provided by SITRA 2015).

16.2.1 KemiCond

Kemira Oyj has developed a chemical sludge conditioning process, called KemiCond. As reported, one plant of the KemiCond process is capable of treating 12,000 metric tons of dry sludge solids per year.

The actual performance of the process has been observed in Oulu Waterworks. The sewage sludge is treated using KemiCond process, and the treated sludge is forwarded for composting. The Finnish Food Safety Authority, EVIRA, has approved the KemiCond sludge as a soil amendment according to the required legislation.

Another use of the process has been observed in Pori, where the hygenisation of unpurified dewatered sludge takes place by KemiCond. The treated final product is shipped for recycling.

16.2.2 Outotec : AshDec

Outotec is a Finnish exporter of technology and has several operations in the European Union. Concerning nutrient recovery, Outotec´s AshDec technology treats wastewater sludge with incineration. The ash from the incineration is pelleted, and thermally decontaminated. Ultimately, it is processed into a fertilizer.

16.2.3 Envor

Envor, another Finnish company, has developed a technology for nitrogen recovery from the reject water of the biogas production plants. The nitrogen in the reject water is separated by gasification and the collected nitrogen gas is converted into liquid ammonium sulfate.

17. DISCUSSION

Nutrient removal and recovery technologies are constantly emerging and updating. With the limit of technology for the nutrient removal based at 0.01 mg/l for TP and <3 mg/l for TN, many research institutes, consultancies, and technological engineers have devoted their time in the improvement of conventional processes. The challenge is to design an environmentally friendly and low-cost technology with the least amount of Greenhouse gas emissions. The financial analysis of some of the nutrient recovery processes is presented below (from the works of Ruotsalainen 2011)

Table 18. Financial analysis of some nutrient recovery technologies (Ruotsalainen 2011)

Technology	**Example WWTP**	**Financial Analysis**
Crystalactor	Geestmerambacht	4.2 M€ Investment cost
AirPrex	Waßmannsdorf	2.5 M€ Investment cost, price of phospho-rus product 400 €/ton.
Ostara	In Canada	2–4 M€ and paid back time 3–5 years
Phosnix	Lake Shinji, Japan	Produced struvite sold for 250 €/ton
Seaborne	Gifhorn	Produced struvite sold for 5 €/ton to be used as fertilizer

New technologies that have the capacities to enhance nutrient removal and recovery are rapidly developing. It has been found that a suitable model of nutrient recycling varies from country to country due to traditional trends and national policies. The selection of the best practice depends upon the characteristics of the incoming wastewater as well as the existing situation of tanks, technologies, etc. at the treatment site. Oleszkiewicz et al. (2015), mention that achieving effluent TP below 0.3 mg/l and TN below 5 mg/l triples the operation cost.

The next step after nutrient removal is nutrient recovery. With rapid population growth and increment in the per-capita sewage production, thousands of tons of phosphorus are discharged into the municipal wastewater. An emphasis has been made in the circular economy of the European Union, which intends to recover and recycle phosphorus from wastewater. As the phosphate rock reserves deplete, the importance of phosphorus recovery has increased inversely.

Recovered nutrients can be reused in the form of treated wastewater, stabilized biological sludge, stabilized chemical sludge, ash, high purity fertilizers such as struvite and ammonium sulfate/ nitrate (Oleszkiewicz et al. 2015).

Figure 74 shows the nutrient reuse options after recovery.

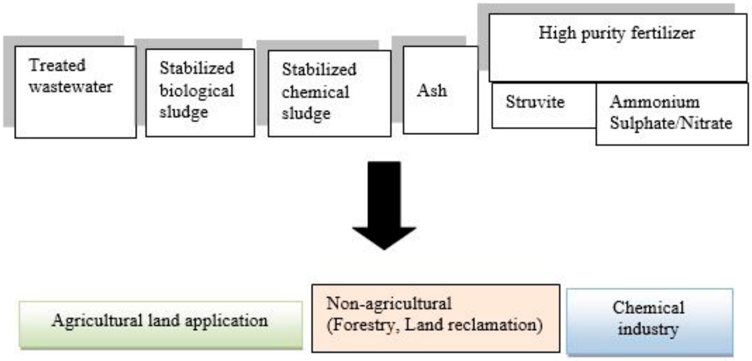


Figure 74. Nutrients reuse (Oleszkiewicz et al. 2015)

With the installation of the Europe´s first nutrient recovery facility to recover nutrients and to produce high-value fertilizer from wastewater in Amersfoort, the Netherlands, similar developments are already taking place in Germany. This trend shows that the most widely applied model of nutrient recycling can be the production of high value fertilizer that meets the nutritional and legal requirements. The proposal for the revision of the EU laws concerning the land application of such fertilizer has already begun. This points to a future where phosphorus is recovered and reused from the wastewater with a minimum dependence on phosphate rock fertilizers based on mining.

In this report, various nutrient removal technologies, nutrient recovery technologies, emerging and new ideas as well as examples from various countries were studied.

With so many available nutrient recycling models, it is definitely a great technological leap forward from the last decade. This has been fueled by national policies as well as innovative research projects. Even though the options seem many, the best choice of the technology depends upon the available financial funds and the energy calculations for sustainable maintenance. However, encouraging news of successful nutrient recovery and recycling technologies recently installed in the Netherlands and Germany are going to unleash similar achievements in other countries as well. As for instance, Finland has already included circular economy in its national policy from 2016, and many other countries are soon to follow. It could be rightfully said that the future of nutrient recycling seems brighter than ever inside the European Union.

18. CONCLUSION

An extensive research into the available technologies in the field of nutrient removal and recovery shows that there are numerous ways to enhance nutrient recycling. As Europe is moving towards a circular economy, new technologies are emerging that provide state-of-the-art efficiency.

The available technologies seem to provide many options for nutrient removal, recovery and reuse. During the selection process, however, a life cycle assessment for each technology needs to be performed country-wise to assess the best suitable technology. The characteristics of wastewater or agricultural run offs vary according to climate, population equivalent, type of dietary habits as well as national policies. This means that the amount of fatty acids as well as the carbon content required during the nutrient removal and recovery processes vary depending on the region of investigation. In terms of nutrient removal, the research shows that the combination of biological nutrient removal, post denitrification, chemical precipitation and filter membrane is the most expensive as well as the most effective technological model. This method can lower TP to 0.01 mg/l and TN to less than 3 mg/l in the discharged effluent. In addition to the nutrient removal capacity, some other parameters such as energy consumption and energy efficiency are equally important in the technological analysis. The real practical challenges to install the advanced models, however, are financial costs and energy consumption.

Nutrient recovery technologies differ from each other on the type of the recovered product. There are several ways to reuse the nutrients present in the sewage sludge. In a circular economy, the nutrients return back to the agriculture with an added value. The technologies such as Ostara's Pearl and Wasstrip have been reported to recover nutrients in the form of struvite fertilizer which meets the legal and nutritional demands. This acts as an incentive to recover more phosphorus and provide a reliable substitute for the depleting phosphate rock reserves. In addition, the nutrients could be reused in agriculture in the form of stabilized biological and chemical sludge, ash, and other ammonium sulphate or ammonium nitrate products. Agriculture is not the only destination for these products, as, chemical industries as well as other land reclamation works could very well utilize these recovered nutrients.

All in all, it could be said that a glorious period of nutrient recycling has already begun. As for now, an assumption can be made that with the current pace of technological development, the future of nutrient recycling is full of new ideas and techniques that will lower the operation costs as well as minimize the energy demand.

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