



## **BIOREFINE**

# **Recycling inorganic chemicals from agro- and bio-industrial waste streams**

Project/Contract number: 320J - Biorefine

Document number: BIOREFINE – WP2 – A7 – P1, 2, 5 – D

## **Techniques for nutrient recovery from household and industrial wastes**

Date: 17/07/2015

Start date of project: 1 May 2011      Duration: 56 months

Authors: M. Alonso Camargo-Valero, L. Bamelis, L. De Clercq, F. Delvigne, E. Meers, E. Michels, D. R. Ramirez-Sosa, A. Ross, H. Smeets, C. Tarayre, P. T. Williams

Authors' Institutions: DLV InnoVision, Gembloux Agro-Bio Tech, Ghent University, University of Leeds

Project funded by the European Regional Development Fund through INTERREG IV B		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

## Table of contents

Table of contents.....	2
1 Glossary.....	3
2 Introduction .....	6
3 State-of-the-art nutrient recovery techniques from household and industrial wastes .....	6
3.1 Composting of organic domestic waste .....	6
3.2 Composting combined with energy production .....	13
3.3 Anaerobic digestion – Rainbarrow farm plant.....	22
3.4 Anaerobic digestion – Nestlé’s Fawdon factory .....	25
3.5 Nutrient recovery from landfill leachate.....	27
3.6 Phosphorus recovery from sewage sludge: generalities.....	28
3.7 Wet chemical treatment of sewage sludge ash.....	32
3.8 Production of struvite from sewage sludge: PHOSPAQ® process.....	35
3.9 Production of struvite from sewage sludge: OSTARA® process .....	41
3.10 Phosphorus precipitation from industrial wastewater .....	44
3.11 Production of pellet fertilizer from sewage sludge.....	46
3.12 Incineration and metal recovery from household and industrial wastes (designed by SELCHP, UK).....	49
3.13 Incineration and metal recovery from household and industrial wastes (designed by LondonWaste) .....	54
3.14 Removal of heavy metals from sludge and sediments.....	57
3.15 Removal of metallic compounds from ashes (IPALLE, Belgium).....	63
4 List of useful contacts .....	68
5 Bibliography .....	71

## 1 Glossary

AD: Anaerobic Digestion

Al: Aluminium

APC: Air Pollution Control

BTF: Bio Trickleing Filter

CaO: Calcium oxide

CH<sub>4</sub>: Methane

CHP-unit: Combined Heat and Power unit

CO<sub>2</sub>: Carbon dioxide

CSDU: Centre de Stockage des Déchets Ultimes

C/N ratio: Carbon to nitrogen ratio

DM: Dry Matter

EBPR: Enhanced Biological Phosphorus Removal

Fe: Iron

FeCl<sub>3</sub>: Iron (III) chloride

GAC: Granule Activated Carbon

HC: Hydrocarbon

hrs: Hours

H<sub>2</sub>O: Water

H<sub>2</sub>S: Hydrogen sulfide

kg/d: Kilogram per day

kg/m<sup>3</sup>.d: Kilogram per cubic meter per day

kg/t: Kilogram per ton

kg CaO/t: Kilogram of calcium oxide per ton

kg K<sub>2</sub>O/t: Kilogram of potassium oxide per ton

## Techniques for nutrient recovery from household and industrial wastes

kg MgO/t: Kilogram of magnesium oxide per ton

kg N/t: Kilogram of nitrogen per ton

kt P/y: Kiloton of phosphorus per year

kV: Kilovolt

kW: Kilowatt

kWe: Kilowatt electric

kWh: Kilowatt hour

kWh/d: Kilowatt hour per day

m<sup>3</sup>: Cubic meter

m<sup>3</sup>/d: Cubic meter per day

m<sup>3</sup>/h: Cubic meter per hour

MAP: Magnesium Ammonium Phosphate

mbar: Millibar

mg/L: Milligram per liter

mm: Millimeter

MWe: Megawatt electric

MWh/d: Megawatt hour per day

MWth: Megawatt thermal

μm: Micrometer

μS/cm: Micro-siemens per centimeter

N: Nitrogen

NaOH: Sodium hydroxide

Nm<sup>3</sup>: Normal cubic meter

Nm<sup>3</sup>/h: Normal cubic meter per hour

N<sub>2</sub>: Molecular nitrogen

## Techniques for nutrient recovery from household and industrial wastes

P: Phosphorus

Sm<sup>3</sup>/h: Standard cubic meter per hour

t/y: Ton per year

UASB: Upstream Anaerobic Sludge Blanket

UK: United Kingdom

VFG waste: Vegetable, Fruit and Garden waste

WWTP: Wastewater treatment plant

<: Inferior to

## **2 Introduction**

Domestic and industrial waste streams such as wastewater and organic waste contain a lot of valuable macronutrients (e.g. nitrogen, phosphorus and potassium) and micronutrients (e.g. heavy metals and rare earth elements). In the past, most of these materials were just landfilled or discharged, causing damage to the environment and a loss of nutrients. Since many years an advanced system of domestic waste collection, sorting and recycling is applied in most European countries, causing a gradual shift to sustainable resource management. Furthermore, the industry is making efforts to obtain a green image and invest in recycling and recovery techniques.

The Interreg IVB project BioRefine tries to facilitate the shift to a circular, bio-based economy in North Western Europe by delivering an action oriented approach to provide applied technological solutions for improved recycling and valorization of valuable minerals from different wastestreams. This report gives an overview of the most popular techniques (full-scale or under development) for nutrient recovery applied on solid and liquid types from domestic or industrial origin.

## **3 State-of-the-art nutrient recovery techniques from household and industrial wastes**

Different techniques can be applied to household and industrial wastes. Here, we will consider different types of wastes, including sewage sludge, leachate from landfills and other organic materials. Liquid and solid states will be considered.

### **3.1 Composting of organic domestic waste**

#### **3.1.1 General context**

Vegetable, fruit and garden (VFG) waste, produced by all households, can be composted on a small scale at home (the so-called small cycle) or selectively collected and composted on a large scale. The collection can be organized by inter-municipal waste agencies, as is the case in Belgium, from door-to-door or at the communal waste recycling depot. Some regions collect both VFG and green waste (from parks, gardens, nature reserves, roadside verges, etc.) together, others collect them separately (Vlaco vzw, 2015). Vegetable, fruit and garden (VFG) wastes can also be selectively collected and used for the production of heat and electricity through anaerobic digestion. From an energetic point of view, this is most favourable route, since both energy as heat and electricity and a valuable residual product, digestate, are formed. Digestate can be composted and results in a sufficiently hygienized product. In Flanders, the quality of the obtained compost is certified by the Flemish Composting Organization (Vlaco vzw), which means that quality is assured and the compost can easily be marketed. Besides composting, the digestate can also be processed by mechanical separation, drying, filtration, etc. as described in the BioRefine report 'Recovery techniques from digestate and digestate derivatives'.

### 3.1.2 Description of the technique

The professional composting process consists of different processing steps. Pre-treatment is necessary for a good composting process. This step includes mixing, size reduction and piling, and is shown in **Figure 1**. The optimal shape of the pile depends on the composting system. In general, the volume has to be large enough to prevent cooling and drought at the edges. The composting process is conducted by bacteria and fungi already present in the organic material. As long as there is oxygen present in the pile, the microflora and –fauna compost very intensively causing a temperature rise up to 50-77 °C. During the process, oxygen is used which results in incomplete oxidation of carbon compounds, causing the formation of fatty acids and other organic acids. This pH decrease causes the process to slow down. By turning the pile and if necessary moisturizing, more oxygen is brought into the system and the water content is optimized causing the decomposition to proceed. An important advantage of the high temperature in combination with the high moisture content is that weed seed lose their germinating power. In this way, a ‘hygienized’ product is formed. In general, the composting of green waste takes place in open air, while the composting of vegetable, fruit and garden waste takes place in a closed hall (Vlaco vzw, 2015).

In a third phase, the ripening process, the microfauna causes a structural and biological transformation of the material in the compost and plays a role in the mixture of organic and mineral compounds. Depending on the process, the post-ripening lasts from 3 weeks to 3 months. The last phase, the post-treatment, includes the refinement of the compost, meaning the sifting of unusable parts and fractionating the compost in different granulometric fractions depending on the end-use. In practice, this is conducted through drum or star sieves. The benefit of sieving is that possible contaminants (rocks, metal, plastic, etc.) remain in the sieve. At least one part of the sieve remainders will be transferred to the beginning of the process. In this way, enough structural material remains in the process and the starting material is inoculated with already active organisms (Vlaco vzw, 2015).

The process parameters of the composting process are precisely monitored. The regulation of humidity, temperature (around 55 - 70 °C) and ventilation is completely computerised. It is important to keep these conditions as optimal and stable as possible to assure a decent bacteriologic composting-process. In the case of the process used by EcoWerf, which collects the VGF-biomass from about 27 communities and has about 45,000 tons of VGF wastes composted each year in Flanders, the biomass is subdivided in different flows after the composting step:

- The biggest parts are not recuperated and will be disposed of as such after removal of the plastics.
- The smaller parts that fall through the first sieve will then be separated again by another sieve, which leads to two flows of materials:
  - o The biggest particles compose the part that has not completely finished the composting process and will therefore be used as inoculation material at the beginning of the pre-treatment. This also provides some structure to the fresh VGF wastes.

## Techniques for nutrient recovery from household and industrial wastes

- The smallest particles (size of about and less than 1 mm) are the actual compost. At this phase, the compost is not ready for consumption, as it needs some further maturation.



**Figure 1: Compost post-treatment.**

*Source: Vlaco vzw*

### **3.1.3 Unit operations**

The case described below is the set-up that is actually implemented at EcoWerf in Vlaams-Brabant (Belgium).

#### *Reception / Storage volume (A)*

The collected VGF will be dumped in this volume straight from the collection vehicle. In Flanders, a lot of VGF-composting units have implied a separate collection strategy, so there is no direct interference with other (non-organic) household wastes at this stage.

The residence time of the VGF-biomass during this storage step is rather limited: in order to obtain an optimal composting process, and to prevent rotting and production of odorous gases, it is necessary to have the biomass treated within short notice (max. 48 hrs). The biomass is taken from these bunkers with grip arms, and placed on belt conveyors for transport in between the different treatment steps.



*(Rotating) sieve (B)*

The sieve in the pre-treatment will make a first screening of the particles based on their size. A mesh-size of around 16 mm is commonly applied. The particles that fall through the sieve (< 16 mm) can go straight to the composting unit. The bigger particles will have to pass the crusher (see Unit Operation D) to decrease their size.

*Ferro Detector (C)*

Throughout the process there are different places where the metals present in the biomass (e.g. knives, forks, etc.) are removed. This is done by using a magnet which moves above the biomass (without actually touching it).

*Crusher (D)*

In the composting process, it is important to have a good surface/volume-ratio. As it is a microbiological process, the bacteria need the surface to attach themselves to. An increase of the surface-volume ratio is obtained by crushing the bigger particles at the inlet.

*Wooden branches remover (E)*

This is claw-like equipment that will remove the branches that came passed the sieve from the biomass. The wood that is recovered here can be chopped and used as structure material in the composting unit, or for the filling of the bio-filters for the odour treatment.

*Composting (F)*

Dependent on the type of biomass that is composted, one can choose to have an open-air composting or an indoor composting. For the application of VGF composting only indoor composting is applied.

There are different ways for the actual implementation of indoor composting, but the 2 most commonly applied are composting in a big hall, or tunnel composting. At EcoWerf, an indoor composting is applied. The biomass will remain for about 5 weeks in the “composting zone” in which it is turned around on a weekly basis to allow “passive” aeration.

In order to obtain an optimal activity of the bacteria, it is important to use optimal process parameters: of main importance are the right moisture content, oxygen level and temperature. In order to keep the moisture content at a high level, fluid is sprayed over the composting material – this can be fresh water, but in case possible it is the percolate liquid from the storage of the biomass that is used. The oxygen level is controlled by the ventilation of air through the biomass. As this ventilation has a big impact on the temperature of the composting biomass, the type of ventilation

will depend on the temperature: in case the temperature in the biomass is too high, outside air will be ventilated through the composting hall. On the contrary, in case temperature is too low the inside air will be recirculated and used for the aeration.

The air inside the composting hall has about 45°C and a relative humidity of 100%. During the process there will/can be an accumulation of odour in the air – what makes that it has to be treated before being discharged to the open air. This is done by a bio-filter system which is filled with wooden material that is also collected by EcoWerf.

### *Plastics removal (G)*

After the composting step, the plastic materials are removed by using a wind-shifter that uses the differences in density to lift out the plastics.

### *Sieve 1 - composted material (H)*

In a first step, the separation of the bigger material from the composted material is achieved. This material contains too big particles for recirculation and will be disposed of “as such”.

### *Sieve 2 - composted material (I)*

The next step is a separation between the actual compost, and the inoculation material. All particles that are above 10 to 15 mm diameter are considered as inoculation material. Inoculation materials are “compostable” but not yet fully composted – this part of the biomass will be recirculated to the start of the process where it is mixed with the fresh incoming compost.

The smaller particles (< 10 to 15 mm) are considered as the actual compost, and will pass a maturation step for assuring the stability of the material.

### *Maturation (J)*

The final step of the composting process consists of the maturation step which takes about 5 weeks. In this step, the composting process slowly continues, degrading the most resistant parts of the biomass. This maturation step can be done out- or inside, though it is more common to make it in a covered area. The need for “turning” the material remains in order to have some aeration, some additional (forced) aeration and humidification might be required to assure the continuation of the process.

The process scheme is shown in **Figure 2**.

3.1.4 Process scheme

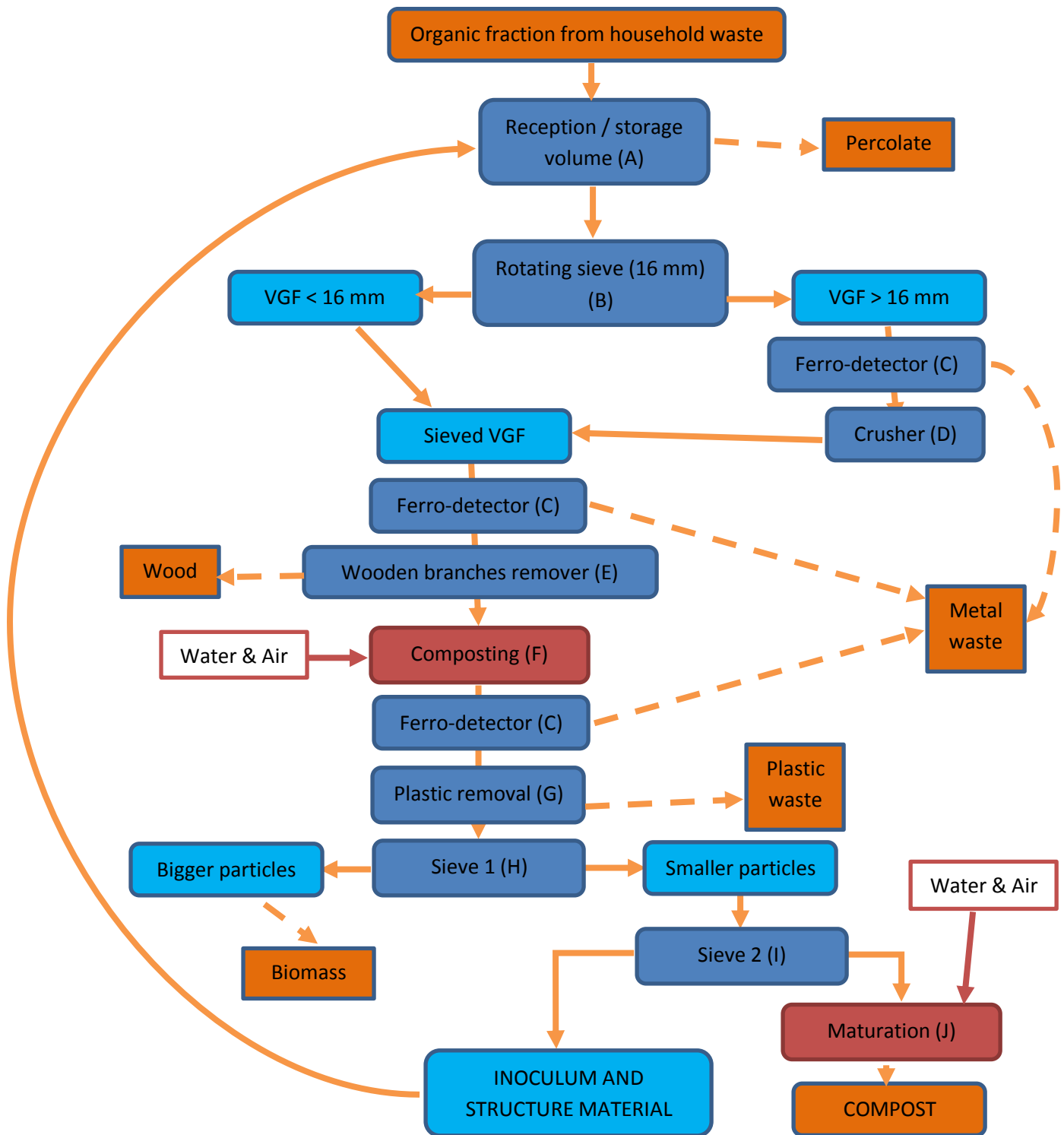


Figure 2: Process scheme of compost production.

Source: EcoWerf

### 3.1.5 Characterization of end product

Compost is a stable, hygienized and humus rich end product. It has a high content of stable organic matter and nutrients which become gradually available for plants. The composition of certified compost (according to Vlaco vzw) is shown in **Table 1**.

**Table 1: Average composition of Vlaco certified compost obtained from VFG and green wastes.**

	VFG compost	Green compost
<i>Dry matter (kg/ton)</i>	700	600
<i>Organic matter (kg/ton)</i>	250	200
<i>Electroconductivity (<math>\mu\text{S}/\text{cm}</math>)</i>	2500	1000
<i>pH-H<sub>2</sub>O</i>	8	8
<i>Total nitrogen (kg N/ton)</i>	12	7
<i>Total phosphorus (kg P<sub>2</sub>O<sub>5</sub>/ton)</i>	7	2.8
<i>Total potassium (kg K<sub>2</sub>O/ton)</i>	10	6
<i>Total calcium (kg CaO/ton)</i>	23	16
<i>Total magnesium (kg MgO/ton)</i>	5	3
<i>C/N ratio</i>	12	17
<i>Germinative seeds</i>	Absent	Absent
<i>Pathogens</i>	Absent	Absent

Source: Vlaco vzw

### 3.1.6 Useful contact(s) for more information

EcoWerf (Belgium)

Email address: see the website [www.ecowerf.be](http://www.ecowerf.be)

Vlaco vzw (Belgium)

Email addresses: [elke.vandaele@vlaco.be](mailto:elke.vandaele@vlaco.be), [wim.vanden.auweele@vlaco.be](mailto:wim.vanden.auweele@vlaco.be)

## **3.2 Composting combined with energy production**

### **3.2.1 General description**

This second process handles about a similar case to the previous one, but with an additional treatment step in between. In this case the production of composting material from VGF waste will be combined with the production of renewable energy.

The plant that is described below is the plant of Méthavalor (Sydème) in Morsbach (France). This site has been operational since 2011 and treats about 42,000 ton/year (385,000 inhabitants). Of this total amount, about 32,000 tons consist of VGF waste of the inhabitants of surrounding regions, 5,000 tons of organic waste from restaurants and similar stakeholders and 5,000 tons of green wastes. In the installation, 1 ton of VGF is converted to 100 m<sup>3</sup> of biogas (it corresponds to 70 litres of gasoil) and 200 kg compost.

#### *“Multiflux” sorting*

The collection of the waste is somewhat different from the regular collection process: inhabitants have to put their wastes in differently coloured plastic bags. Green bags are for the biological waste (VGF), orange bags are for plastics and metals and the blue bags are for the rest of the domestic wastes. All these bags are collected at the same moment – this allows reducing collection expenses, as they only have to pass once, instead of 3 times.

When all the bags arrive at the site, they are separated through “optical selection” and guided towards their specific processing scheme: the green bags will be sent to the biomethane valorisation, the orange bags will be sent to the stock of “recyclable waste” (recycling occurs at a different site), and the blue bags will be further treated (landfilled) at the “Centre de Stockage des Déchets Ultimes (CSDU)”.

#### *Preparation of the biodegradable waste*

After the separation of the green bags from the collected waste, the preparation of the bio-waste for use in the biogas production is done. As indicated above, there are several types of bio-wastes that will be processed in the biogas production: (1) VGF from households (green bags) (2) organic waste from restaurants, markets, etc. that arrive in bulk (3) green waste and (4) liquid waste (e.g. fats, food oil). Each type of waste is treated differently:

- *VGF from households (in bags)*

The first step is the opening of the plastic green bags. Once opened, the content is placed on a moving sieve, while the plastic bags are removed using a wind-shifter. This way all the bags are collected and can be recuperated. All the equipment that passes through the sieve will be directed straight to the intermediate storage. The material that is oversized will first pass a shredder system. Also the materials are removed using magnets that are located above the conveyor belts.

## Techniques for nutrient recovery from household and industrial wastes

- *Organic waste (in bulk)*

This type of waste is free of plastics as it comes straight from alimentary sources. The material is guided straight to the shredder system before being sent to the intermediate storage.

- *Green waste*

This type of waste is also crushed to smaller particles in the shredder.

- *Liquid waste*

There is no actual pre-treatment of the liquid waste. This type of bio-waste is stored and will be added into the process, where the different flows and the recycling flow from the digestate are mixed up.

### *Mixing step*

At this point, all the above mentioned flows are mixed together to the actual “feedstock” for the digester. But before this incoming organic biomass can be converted to biogas in the digesters, it is important to obtain a feeding mix that meets the process requirements of the digester. In order to have an optimal biogas production, several conditions must be respected:

- The incoming biomass (and so also the content of the digester) must show an optimal dry matter (DM) content. This is important to assure a good mixing and dynamics within the digester. As this is a “dry fermentor” type, it can take a higher DM content, which means that some problems might occur if the material is too dry.
- There must be some inoculation of the “fresh” biomass with a recycle-flow coming from the digester. This is important for “speeding” up the digestion process.

In order to meet these requirements, several precautions have been taken:

- There is a constant flow from the digestate treatment to this mixing point (= recycle flow) which assures the inoculation of the fresh material and a lowering of the DM concentration. Only the liquid part of the digestate (after the separation step) is recycled.
- Also the liquid waste is added at this point in order to lower the DM content. In case of lack or too little liquid waste to obtain a good DM-content, there is the possibility to add some fresh water.

From this point, the mixture (= fresh input material + water + recycle flow) is pumped towards the digesters.

### *Digesters*

The characteristics of the input material (i.e. a higher DM-content, about 30 to 35 % DM) require the implementation of a dry fermenter type of digester. This type of fermenter has the benefit that it can operate at a higher DM-content: digestate of 25 to 35 % DM, compared to up to 15 % DM in a

“wet digester”. The requirement of additional water to be added is therefore rather limited in this system.

In the set-up of Méthavalor, there are 3 parallel working horizontal digesters. Each digester treats about 15,000 ton/year. Working in multiple lanes provides optimal flexibility and capacity throughout the year.

Within the digester, the biomass is transformed to biogas through the anaerobic process. On average, a biogas production of 110 to 120 Nm<sup>3</sup> of biogas per ton of VGF material is measured. There is a seasonal variance in the biogas-production: in wintertime, the incoming material from the households does not contain garden wastes, which leads to a higher biogas production potential. In summertime, a bigger fraction of the incoming VGF is composed of garden wastes (grass, etc.) which have a lower biogas potential. This difference of composition leads to an overall lower biogas production per ton of VGF.

There are 2 outputs from a digester: biogas and digestate. On the site of Méthavalor, both these flows are further processed for valorisation.

### *Digestate treatment*

The raw digestate coming from the digester is separated into a liquid and a thick fraction. This is done by using a 2-step separation system. The first step consists of 3 parallel working screw presses, and the second step consists of 2 centrifuges which take out as much as DM as possible from the liquid fraction. This liquid fraction is collected by farmers and applied on land as a fertilizer. The thick fraction will go through a complete composting process in a tunnel composting unit. The final compost is sold in bulk or in smaller bags.

### *Biogas valorisation*

On the Méthavalor site, there are 2 different ways of valorisation of biogas: through a cogeneration unit and a unit of biogas production. These two plants are located on the site:

- *Cogeneration*

A part of the biogas is burned in a cogeneration unit to produce electricity and heat. The overall electricity production capacity is about 1.7 MWe. This electricity is primarily used to provide power to all the equipment on the site, and the non-consumed electricity is injected onto the grid. The heat produced by this cogeneration unit (about 2 MWth) is used for the heating of the digesters, and can be used for the heating of other applications on the site, or even at a different location. One Nm<sup>3</sup> of biogas corresponds to about 2.4 kWe and 2.8 kWth when it is burnt in a cogeneration unit.

- *Biomethanisation*

The part of the biogas that is not burnt in the cogeneration unit will be “upgraded” to a quality that corresponds to the quality of natural gas. In order to do this, CO<sub>2</sub> and other

impurities have to be removed from the biogas. This purification is achieved in different steps:

- Drying of the biogas (removal of water),
- Purification with active coal (removal of H<sub>2</sub>S),
- Compressing (increasing the pressure from 16 mbar to 10 bar),
- 2-step Pressure Swing Adsorption (removal of CO<sub>2</sub>),
- Filter (final H<sub>2</sub>S removal).

The bio-methane that is produced has to be odourised, so that people would be able to smell the gas in case of accidental release into the air. On the site of Méthavalor, this bio-methane is used as fuel. For each Nm<sup>3</sup> of biogas that goes into the system, about 0.5 Nm<sup>3</sup> of bio-methane is produced. The CO<sub>2</sub> that is separated from the methane will be recycled into the digesters.

### 3.2.2 Unit operations

#### *“Multiflux” sorting (A)*

The “Multiflux” system will assure the separation of the different types of coloured bags towards the right treatment system. It is a combination of cameras and optical sensors, combined with conveyor belts. There is always an additional “control step”, and in case 2 bags are accidentally (and wrongly) joined in a wrong direction, they will be automatically returned to the bulk storage.

#### *Bag Opener (B)*

All the organic waste coming from the households is delivered in plastic bags. In this step, the bags are brought to the ripper head on conveyor belts. The ripper head consists of ripper tines. The ripper head (rotor) holding the tines is rotating in the opposite direction to the flow of material.

#### *Plastic Removal (C)*

Plastic (from the bags and other) is removed using a wind-shifter.

#### *Sieve (D)*

As with the standard composting process the particles that go into the system have to be small enough to assure good interactions with the bacteria (both in the anaerobic treatment and in the composting unit.). Therefore, it is important to crush the parts that are too big. Normally, the size of the particles that go into the system should be below 16 mm. All the particles that fall through the sieve go straight to the intermediate storage. The bigger parts pass through the crusher. In this case, the sieving is included in the conveyor belt.



*Crusher (E)*

Particles the size of which is superior to 16 mm will be crushed to a smaller size.

*Ferro Detector (F)*

Metals are removed by using big scale magnets that are located around the conveyor belts.

*Sieve (G)*

With a mesh size of 12 to 16 mm, this will make a subdivision in particles that can be stored in the intermediate storage for further processing, and the bigger particles that will be returned to the crusher again.

*Intermediate storage (H)*

The intermediate storage is a storage place in which all the incoming organic flows (except the liquid flows) can be stored. Given the fast decomposition of the material, it is of most importance (e.g. for the biogas production) that the retention time in this intermediate storage is as low as possible.

*Mixer (I)*

At this point, the feed mix for the digesters is prepared, with a certain level of DM content and required inoculum. In this step, the mixing of incoming solid organic waste, incoming liquid organic waste and a part of the thin fraction of the digestate is achieved. Water can be added to the mix if necessary to regulate the water content.

*Digester (J)*

Three parallel operating horizontal dry digesters (type Kompogas) are installed. These reactors are all plug-flow digesters that work in a continuous regime, what makes it more convenient to handle the involved manpower and manage the downstream located biogas-valorisation equipment. The retention time of the organic material is about 14 – 20 days. A low-speed agitator prevents the sedimentation of dense media materials and will “push” the material to the exit of the digester. The temperature inside the digesters is 50 – 55 °C, which corresponds to thermophilic conditions. Benefits of this higher temperature (compared to the 37 °C of mesophilic reactors) is that the conversion and digestion process occurs faster, and that the material is free of spores, germs and micro-organisms after passing through the digester. On the other hand, the system is more sensitive to calamities and instabilities, which means that a closer monitoring of the system and the biology is required.

#### *First separation (K)*

A first separation of the digestate is done using 3 parallel working screw presses. In this separation, about 25 – 40 % of the DM will be removed from the digestate. The thick fraction is sent to composting, the thin fraction will be further treated. It is important to note that, at this point of the process, there is a lot of odour production due to the loss of pressure (difference between inside and outside the reactor) and therefore a release of ammonia. This is an important item to take into account for the set-up of a similar plant, as this will require an adequate odour treatment system.

#### *Second separation (L)*

In the second separation step, the DM that remained in the liquid fraction coming from the screw presses will be further removed. As in this step the DM-removal efficiency needs to be higher, 2 parallel working centrifuges have been installed. The removal efficiency of a centrifuge is normally about 75 % of the DM.

#### *Composting (M)*

The thick fraction coming from the screw presses and the centrifuges will be further composted. This is done in a similar way as the steps described before. The completely matured compost is sold in bulks or in bags.

#### *Cogeneration unit (N)*

A part of the biogas produced in the digester is transformed into heat and electricity in a cogeneration unit, or combined heat and power plant (CHP unit). The total capacity installed in Méthavalor is 1.7 MWe. The heat produced is used for heating the digesters and other equipment or even district heating. The heat produced by a CHP unit is available at different levels: the higher temperature level corresponds to the heat coming from the exhaust gases of the engine. The temperature at the outlet of these exhaust gases of the engine is comprised between 400 to 450 °C. About 20 – 25 % of the incoming energy is converted into this higher level heat. The lower temperature corresponds to the heat coming from the cooling water from the engine. This heat is available at 55 or 90 °C. As this second type of heat forms a part of the cooling system, the cooling away of this heat is crucial for the good functioning of the CHP-engine. In case the heat is not consumed by a useful application, it will be cooled away in air-coolers. About 20 – 25 % of the incoming energy is converted into this lower level heat. The power is used for empowering the overall plant – the remaining part is injected to the electricity grid. About 40-45 % of the incoming energy in the biogas is converted into electricity in the CHP-unit. Working with 2 separated CHP-engines (respective electric powers of 700 kWe and 1000 kWe) gives the benefit that in case of maintenance of one of the devices, the remaining can assure (partial) energy production to keep the plant running.

### *Drying (O)*

The biogas that is not burned in the CHP unit will be dried in order to remove the water from the biogas. This is done by a cooling step, leading to water condensation. After that, the condensed water is removed, and the biogas is heated up again.

### *Active Coal (P)*

Active coal is used to remove different kinds of impurities from the biogas, among which H<sub>2</sub>S, siloxanes and other volatile organic compounds.

### *Compressor (Q)*

The pressure in the digesters is only 16 mbar, which is not sufficient to pass the complete processing unit and to obtain actual bio-methane. For this process, a pressure of about 10 bar is required. The increasing of the pressure from 16 mbar to 10 bar is obtained with a biogas compressor.

### *Pressure Swing Adsorption (PSA) (R)*

Pressure Swing Adsorption (PSA) is a dry method used to separate gases via physical properties. The raw biogas is compressed to a high pressure, and then fed into an adsorption column. In this column, CO<sub>2</sub> (carbon dioxide) is retained, but not methane (CH<sub>4</sub>). If the column is saturated with CO<sub>2</sub>, the pressure is released and the CO<sub>2</sub> will desorb and be led off into an off-gas stream. In order to be able to work in a continuous mode, it is important to work with multiple columns in parallel, which will be closed and opened consecutively. The PSA-installation at Méthavalor has a capacity of about 100 Nm<sup>3</sup>/h (input biogas flow).

### *Filtration (S)*

Right before the release as vehicle fuel, a final filtration on all possible impurities has to be done.

### *Odourisation (T)*

Methane (CH<sub>4</sub>) as such is an odourless gas and cannot be smelled by humans. Therefore, in order to prevent unnoticed accidental releases, some odourisation has to be added to the bio-methane produced.

The treatment is presented in **Figures 3** and **4**.

### 3.2.3 Process scheme

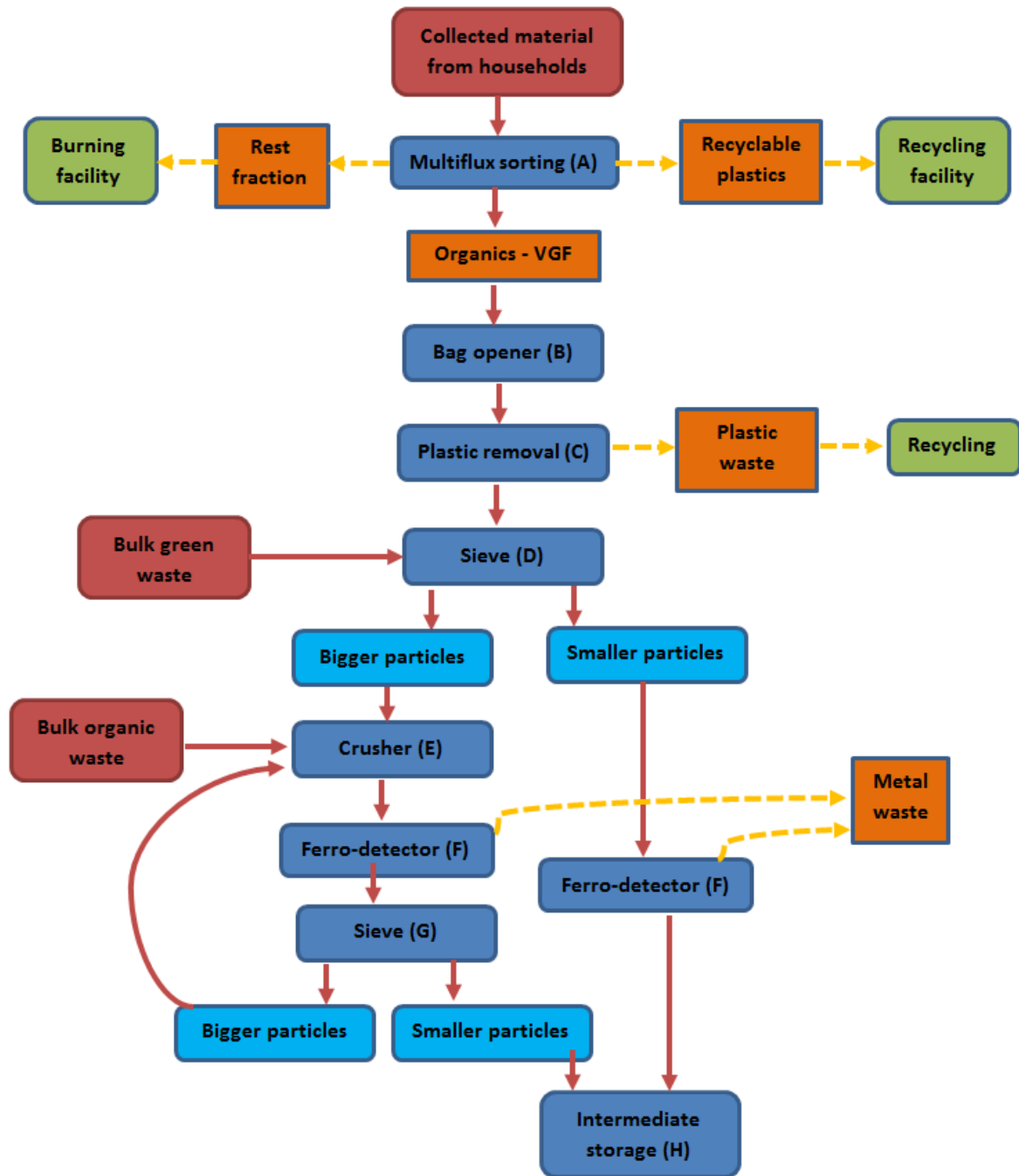


Figure 3: Process scheme of Méthavalor (part 1).

Source: Sydeme-Méthavalor

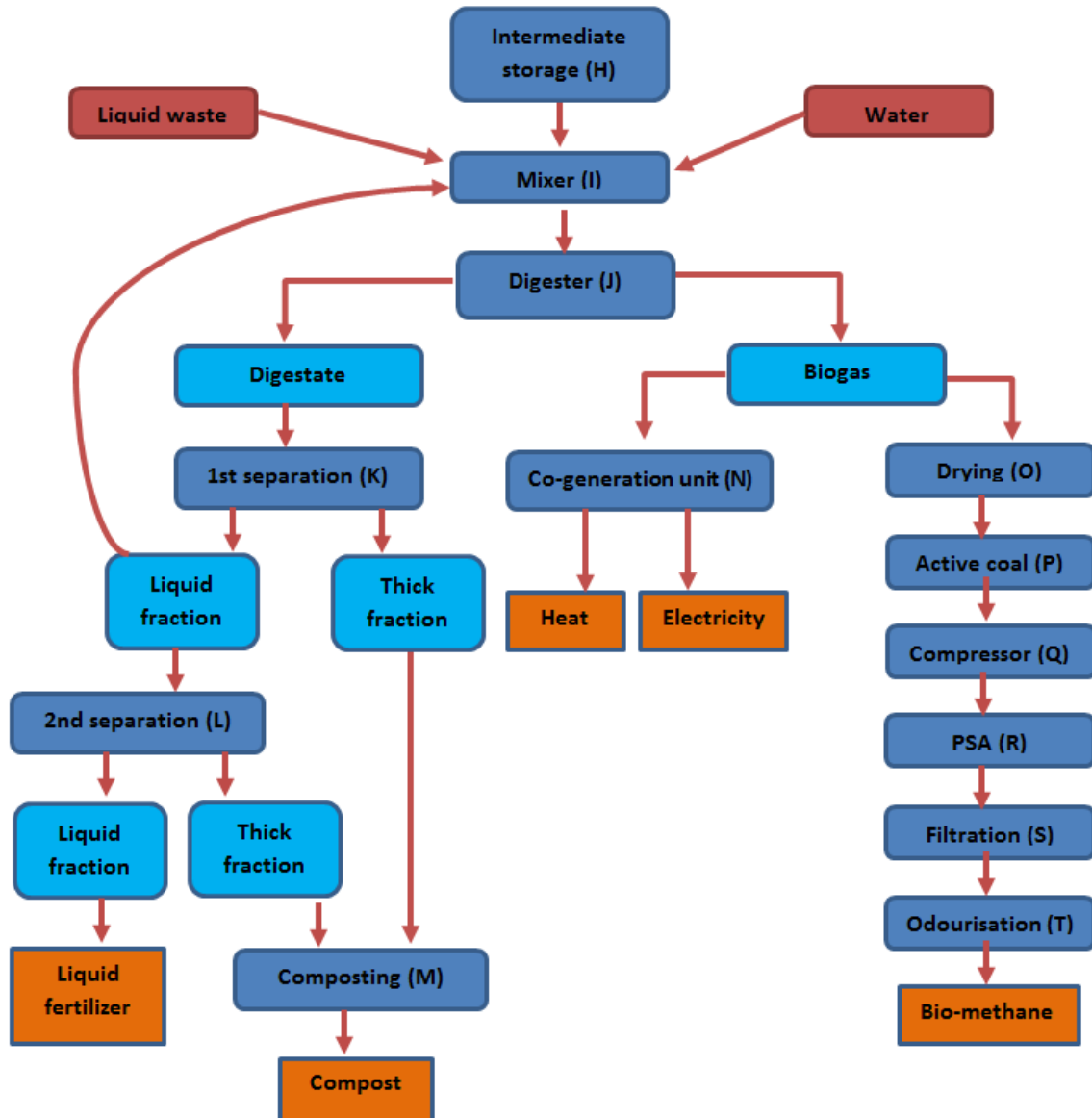


Figure 4: Process scheme of Méthavalor (part 2).

Source: Sydeme-Méthavalor

### 3.2.4 Additional comments

The overall investment cost of the Méthavalor site is significant (about 40,000,000 €). Nevertheless, the operating company would like to extend the amount of digesters and to increase the capacity of the plant.

### **3.2.5 Useful contact(s) for more information**

DLV Innovision (Belgium)

Email address: lies.bamelis@dlv-innovision.be

Sydeme-Méthavalor (France)

Email address: see the website [www.sydeme.fr/site/equip\\_methanisation1.php](http://www.sydeme.fr/site/equip_methanisation1.php)

## **3.3 Anaerobic digestion – Rainbarrow farm plant**

### **3.3.1 General description**

In 2012, the first commercial anaerobic digestion process with production of biomethane connected to Grid Plant in England was opened at Rainbarrow farm, in Cornwall. The anaerobic digester at Rainbarrow farm is fed with a feedstock consisting of maize, grass, potato waste, whey, and small amounts of food waste (chocolate and muesli) from local factories. The plant employs around 41,000 tons of maize grass and potato waste from local farmers and also organic waste from nearby factories and farms like chicken manure, Dorset Cereals and the House of Dorchester Chocolate Factory (Lermen, 2013).

Approximately 850 standard cubic meters/hour ( $\text{Sm}^3/\text{h}$ ) of biogas production can be achieved in Rainbarrow plant. The gas produced (with approximately 53 %  $\text{CH}_4$ ) is divided between the energy generator and biogas upgrading system (gas grid injection). About 200  $\text{Sm}^3/\text{h}$  of biogas is used to fuel a 400 kW generator. Around 50 % of the generated energy is used on site for driving installation and the rest is exported.

Up to 650  $\text{Sm}^3/\text{h}$  of biogas is led to the DMT Carborex<sup>®</sup> MS biogas upgrading plant, which clean out the  $\text{CO}_2$  from the gas stream with a multistage system of membranes to reach a gas with a content of 98.4 %  $\text{CH}_4$ . Before entering the gas networks, biomethane gets into the Net Entry Facility (NEF unit) where about 4 % propane is added to increase the energy content of the biogas. At the point, the distinct gas odour is also added to the biomethane to match the gas quality of natural gas. The biomethane flow produced in Rainbarrow is around 400  $\text{Sm}^3/\text{h}$  which is enough to provide gas for 4,000 houses in winter. Additionally, the plant produces 8,000 tons/year of digestate which can be used as a fertiliser (Langerak, 2013).

### **3.3.2 Unit operations**

The design of Rainbarrow multi-stage membrane system is based on the usage of highly selective membranes to obtain low methane losses (98%  $\text{CH}_4$ , which greatly reduces the consumption and cost for propane addition) and a pure  $\text{CO}_2$  gas (>99.5 % pure). It is the only upgrading technology that also removes significant amounts of oxygen (up to 70 %) (Langerak, 2013).

## Techniques for nutrient recovery from household and industrial wastes

After anaerobic digestion, the gas produced pass to the upgrading plant where desulphurisation, removal of carbon dioxide and dehumidification are done (Dirkse, 2015).

### *Biogas compression*

The incoming biogas is compressed to 8-10 bar with a returning compressor; biogas usually contains small concentrations in hydrogen sulphide. Therefore an oil free compressor is needed. The compressed biogas is cooled with water coming out of a cooling system.

### *Removal of carbon dioxide and hydrogen sulphide*

After the cooling step, carbon dioxide and hydrogen sulphide are removed in a scrubber. The scrubber is packed with packing material for mass and heat transfer. Absorption of gases is done with water at low and constant temperature. The recirculation water is fed into the absorber at the top, while the biogas flows through the absorber counter current to the water. Contact takes place in the absorber and the carbon dioxide and hydrogen sulphide in the biogas are reduced. Carbon dioxide and hydrogen sulphide are better soluble in water than methane. Some methane will also be absorbed, but this can be recycled in the gas-freeing steps.

### *Gasses' removal from circulation water*

Used circulation water with dissolved gasses is passed to 2 bar in a flash vessel in order to minimize the methane losses. The water is partly degassed and gas from the flash tank is recirculated into the inlet of the upgrading plant. Gas inside the multi-stage membrane system separates CO<sub>2</sub> from CH<sub>4</sub> due to different permeation rates at a membrane. The methane losses are controlled by adjustments of the pressure in the flash tank.

The recirculation water out of the absorber is recycled by gas freeing in three steps.

- The recovered gas stream, with CO<sub>2</sub>, H<sub>2</sub>S and CH<sub>4</sub> is injected into the pressure stages for methane separation. In the meantime, the recirculation water out of the absorber is recycled by gas freeing where pressure of the water is reduced from 10 to 2-4 bar to release more gases. The recovered gas is injected to the pressure stages.
- The gas out in the lowest gas-freeing tour with high concentration in CO<sub>2</sub> is sent back into the pressure stages or can be applied as industrial raw gas.
- The recirculation water coming from the methane recovery tower is sent into an air stripping unit for releasing of CO<sub>2</sub> and H<sub>2</sub>S. In the air stripping tower, air coming from outside is put into a desorption tower where the recirculation water is counter currently flowing down. Most of the CO<sub>2</sub> and H<sub>2</sub>S are removed by stripping. The treated recirculation water is pumped back to the absorber. The air coming from the air-stripping unit is sent to a Bio Trickling Filter (BTF) for biological reduction of H<sub>2</sub>S contamination. The BTF is a biological filter for the treatment of wastewater and air and consists in a cylindrical tank filled with

## Techniques for nutrient recovery from household and industrial wastes

plastic media. The media acts as a carrier material for biofilm. The wastewater is fed into the filler at the top, whilst the air flows through the filter parallel or counter current to the water. Intensive mixing takes place in the filter and the contaminations in the air and water are reduced by the biofilm.

### *Biogas drying*

An adsorption dryer is installed after the water absorption column to take out water from the upgraded biogas. The dryer is self-regenerating and consists out of two columns with drying agent. The upgraded biogas after the absorption is dried and polished prior being delivered to the gas grid by vessels filled with drying agent and activated carbon. The drying vessels are self-regenerating by guiding approx. 5-10 % of the dried gas through the column that is regenerating.

### *Biogas purification*

Before the dried gas is led into the column, it is heated in a heat exchanger, which is heated by biogas after the compressor. The regeneration pressure is approximately 200 mbar, which means that the gas has great ability to absorb the water in the drying agent. Granular Activated Carbon (GAC) vessels are polishing the upgraded biogas from H<sub>2</sub>S, siloxanes and traces of HC. In order to run the process optimally, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>O and H<sub>2</sub>S are measured continuously; a programmable logic controller system controls the process according to the gas analysis' results.

The scheme of the process is shown in **Figure 5**.



### 3.3.3 Process scheme

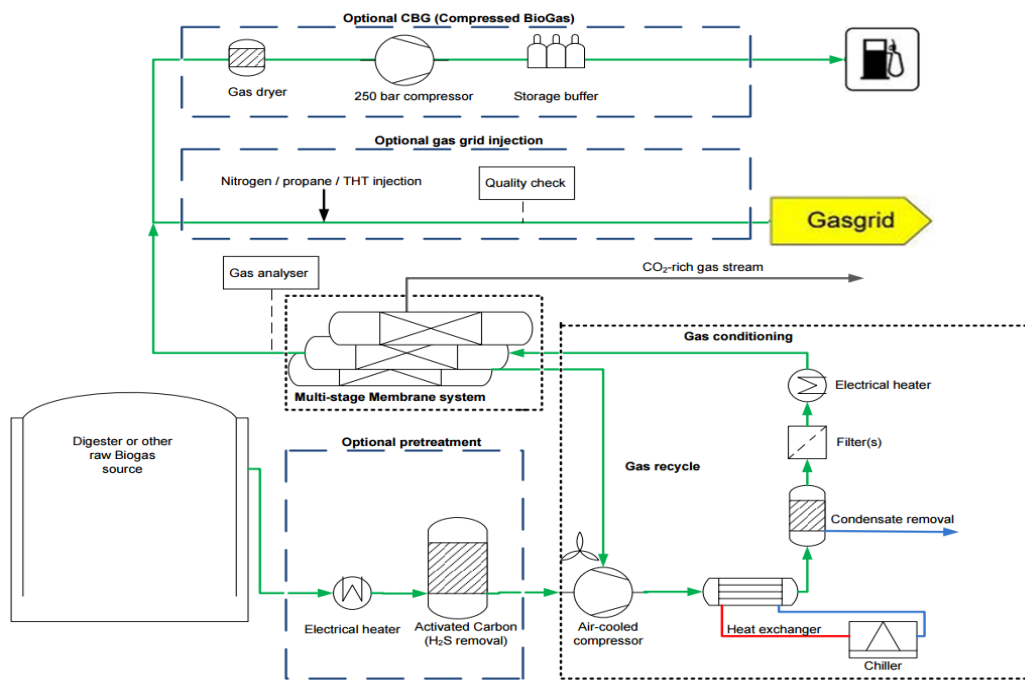


Figure 5: Process scheme of the DMT Carborex MS system.

Source: Lems R. and Dirkse E.H.M., (2010)

### 3.3.4 Useful contact(s) for more information

University of Leeds (United Kingdom)

Email addresses: M.A.Camargo-Valero@leeds.ac.uk, A.B.Ross@leeds.ac.uk

## 3.4 Anaerobic digestion – Nestlé’s Fawdon factory

### 3.4.1 General description

Nestlé’s Fawdon factory is one of the UK’s main confectionery production sites. The former Rowntree factory (Nestlé’s second largest UK site) produces a range of confectionery brands. Fawdon factory set off an anaerobic digestion plant for the treatment of its wastewater. This plant is part of an initiative to reduce carbon footprint from the factory, and started operation in August 2013 with a production of 300 kWe.

The anaerobic digestion plant is treating liquid effluent, reject confectionery and residual ingredients (mainly fed to pigs). By digesting these materials the plant is able to supply renewable energy to the factory, reducing disposal and power costs.

### 3.4.2 Unit operations

Nestlé's liquid AD facility is deploying a range of technology developed by Clearfleau (see **Fout! Verwijzingsbron niet gevonden.**), including several steps.

#### *Feedstock supply*

Two tanks balance variable flows. Solid residues are dissolved into the trade effluent, before being fed to the reactor.

#### *Anaerobic Reactor*

A 1,500 m<sup>3</sup> tank is fed by 275 m<sup>3</sup>/d of mixed feedstock. A separator returns degradable solids to the outside mixed digester tank.

#### *Biogas Handling*

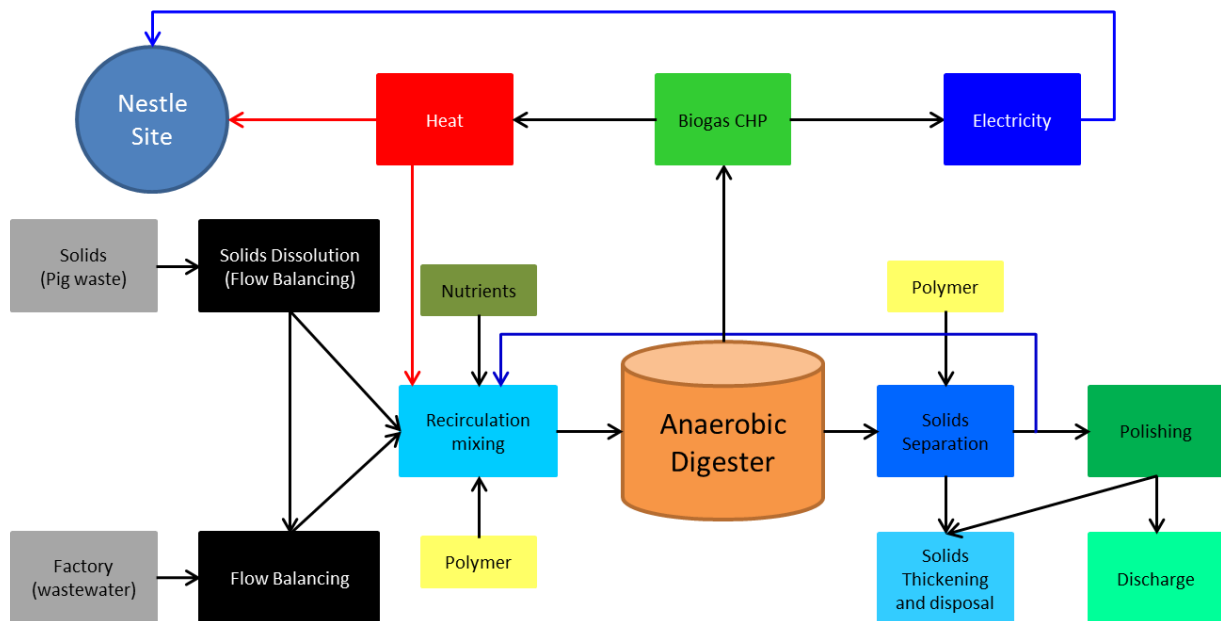
Biogas, generated in the digester and stored in the gas dome, is cleaned prior to burning in the CHP located alongside the AD plant. At present, most of AD plants have production of renewable electricity from Combined Heat and Power (CHP) engines, along with surplus heat. Electricity generated can be used on site (to replace bought-in power), or sold to the national power grid.

#### *Process Control*

Positioned centrally in the plant, the process control system includes mimics for all key elements of the process, linked to the site's supervisory control and data acquisition system.

The project is starting to decrease the site's CO<sub>2</sub> emissions and helping to control energy costs. It is part of an investment programme that is being undertaken by Nestlé at the site that will noticeably reduce its environmental footprint and act as a blueprint for sustainable production (Clearfleau, 2015; Gueterbock, 2014a; Gueterbock, 2014b; Clearfleau, 2013). The process scheme is shown in **Figure 6**.

### 3.4.3 Process scheme



**Figure 6: Nestlé's Fawdon Anaerobic Digestion Process.**

Source: Gueterbock R., (2014 a)

### 3.4.4 Useful contact(s) for more information

University of Leeds (United Kingdom)

Email addresses: M.A.Camargo-Valero@leeds.ac.uk, A.B.Ross@leeds.ac.uk

## 3.5 Nutrient recovery from landfill leachate

Municipal landfill leachate results from the percolation of rainwater through solid waste and is considered as a wastewater type with one of the greatest environmental impacts, due to high concentrations of ammonium, salts and organic matter. The conventional nitrification–denitrification is not very suitable for treating leachate. Since the level of ammonia is high, high hydraulic residence times (and thus large reaction volumes) are required to reduce the toxicity coming from ammonia.

Recent investigations have shown that ammonium can be recovered from landfill leachate by struvite, magnesium ammonium phosphate (MAP), precipitation (Oloibiri, 2013). The limitation of this type of recovery is that an external source of magnesium and phosphate is needed given the fact that landfill leachate is deficient in magnesium and phosphorus. Li and Zhao (2001) obtained a

reduction of the ammonium concentration in ammonium rich landfill leachate from 5,600 mg/L to 110 mg/L through struvite precipitation at a pH of 8.5 to 9.0. Results from Di Iaconi et al. (2010) showed that 95 % ammonium removal was achieved with a Mg:NH<sub>4</sub>:PO<sub>4</sub> ratio of 2:1:1, at pH 9. Similar studies confirmed that ammonium removal efficiencies of up to 90% can be achieved by struvite precipitation, involving addition of a magnesium and phosphorus source, followed by pH adjustment (Kim et al., 2007). Struvite precipitation from landfill leachate is a technique under investigation and is not yet implemented on full-scale.

### **3.6 Phosphorus recovery from sewage sludge: generalities**

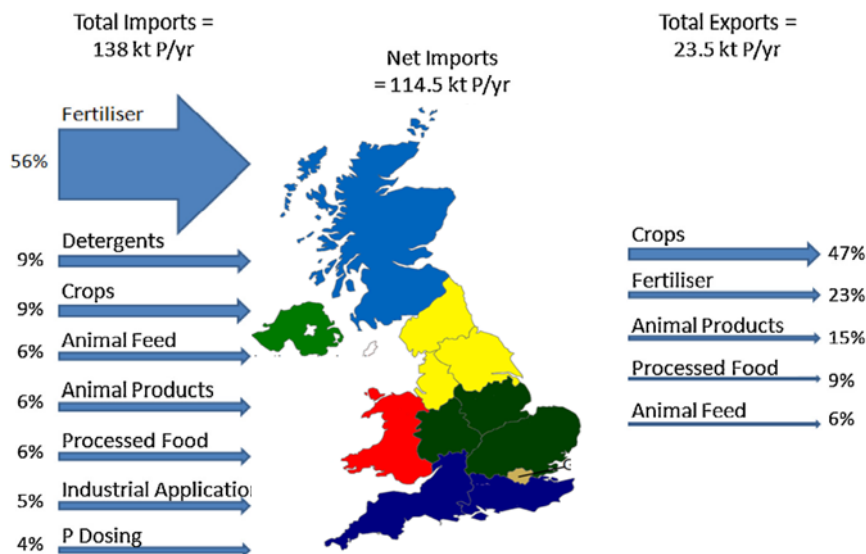
#### **3.6.1 Potentialities of sewage sludge in the United Kingdom: a case study**

Phosphorus (P) is an indispensable nutrient for plant growth and production of food. Modern agriculture employs mineral fertilizers, which are derived from phosphate rocks, to be applied regularly for a high production of goods. Due to phosphate rocks is a non-renewable source there are increasing concerns on lack of phosphorus and subsequent sustainability of agriculture and food security (Cooper and Carliell-Marquet, 2013).

Cordell et al. (2009) reported that phosphate rock reserves are decreasing along the time and also are located in few countries around the world (Morocco, China, USA and Western Sahara). Also, the discharge of treated or untreated wastewater to water bodies with high concentration of nitrogen and phosphorus has caused eutrophication. Owing to this, there is a need of P recovery from waste streams and the reuse for different purposes.

The UK relies on imported phosphorus, therefore it is crucial to identify areas of inefficient use and calculate loses for the potential recovery of N and/or P. **Figure 7** shows the imports and exports of phosphorus in the UK in 2009 (Cooper and Carliell-Marquet, 2013).

## Techniques for nutrient recovery from household and industrial wastes



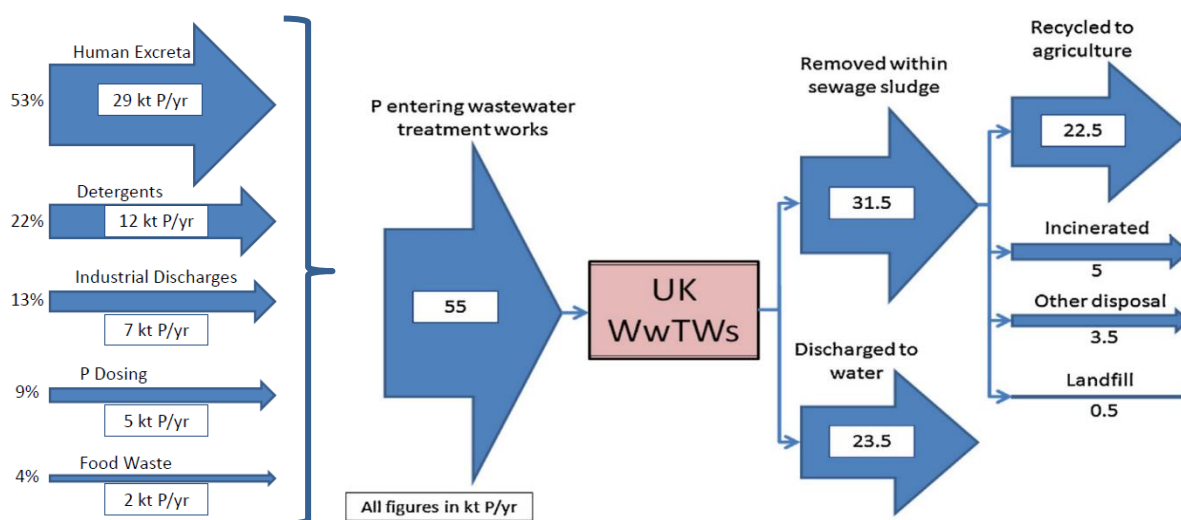
**Figure 7: Global overview of UK imports and exports.**

*Source: Cooper J. & Carliell-Marquet C., (2013)*

Around 60% concentration of the P in wastewaters comes from anthropogenic sources due to humans excrete most of the phosphorus they consume. Cooper and Carliell-Marquet (2013) determined that 48 % (55 kt P/y) of P net imports finishes in the UK wastewater treatment plants (see **Figure 8**) whereas just 40.9 % of this wasted P is recovered for using in agriculture and 23.5 kt P/y are discharged to water bodies.

Dried solids from treated sewage sludge is the main way that P and N are recycled from wastewater and is used for the application on land in the agriculture process in the UK with advantage of slow-releasing P which can be more efficient and release less P to runoff than fertilizers and manures. Around 1 million of tons of dry solids are applied to land each year with the advantage of it is inexpensive and has more environmental benefits than incineration or landfill (Environment Agency, 2012).

Other method for the removal of P and N is by chemical addition of  $\text{FeCl}_3$ , a conventional and well-known technology very widely used in the UK (95 % of the wastewater treatment works around the UK use this method). The main disadvantages are that it needs other processes, like tertiary filtration. The use of  $\text{FeCl}_3$  also involves a mix with the sludge, which could be expensive due to the addition of the flocculating agent (figure is estimated as £3.3 million/year for Wales). A last problem is that P is considered as a pollutant and not as a resource (Environment Agency, 2012; Vale, 2013).



**Figure 8: Phosphorus flows through UK wastewater treatment plants.**

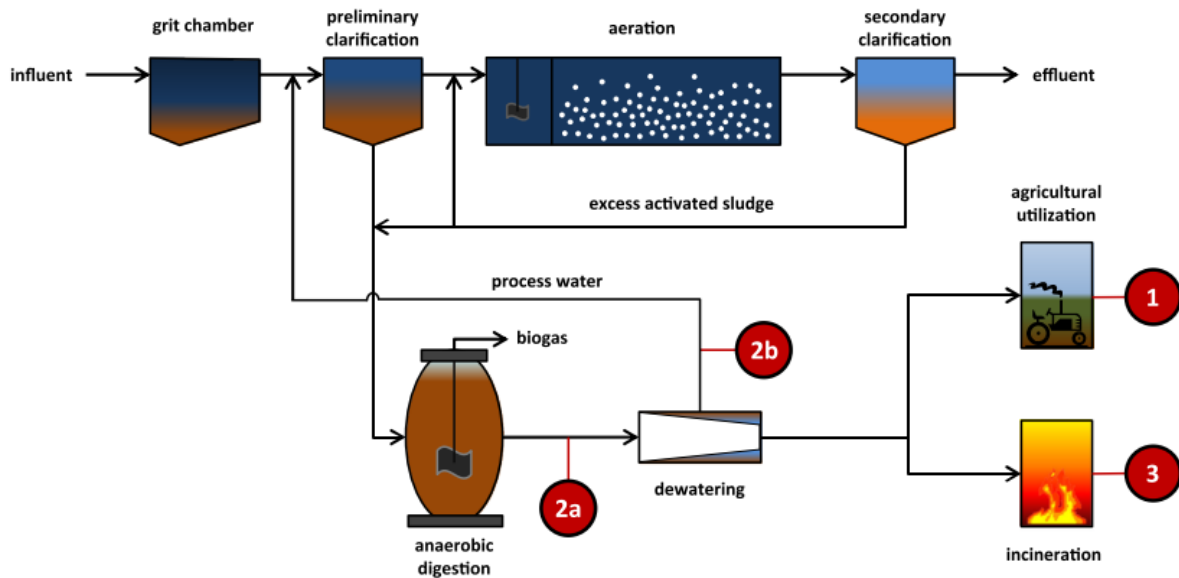
Source: Cooper J. & Carliell-Marquet C., (2013)

Phosphorus and Nitrogen recovery as struvite (magnesium ammonium phosphate) is a new trend on resource recovery from wastewater and involves the addition of  $MgCl_2$  at high pH for the production of struvite salts. Struvite recovery is only practical at high P concentrations and low water volumes. Economical recovery is only reachable at plants greater than 75,000 population equivalent (means the organic biodegradable load having a five-day biochemical oxygen demand ( $BOD_5$ ) of 60 g of oxygen per day; this means the oxygen used, largely by bacterial organisms, in breaking down the organic matter in wastewater) and P concentrations higher than 75 mg/L. To achieve such P levels, Biological Nutrient Removal is recommendable to be applied. The payback for some P recovery technologies can be as little as five years (Environment Agency, 2012). Phosphate removal and recovery will not just decrease the P concentration increasing in UK rivers and pollution; it also can result in production of struvite-type material which is rich in nutrients and can be sold for the use in crops production. It also helps to alleviate struvite-related damage to equipment further along the treatment train. Additionally, struvite has been classed as a product rather than waste by the UK regulations and then, has a high commercial value (Ofwat, 2005).

### 3.6.2 Wastewater treatment plants as phosphorus sources

The variety of existing phosphate recovery techniques from domestic wastewater can be applied at different points throughout the wastewater flow at the treatment plant (Schoumans et al., 2015; Desmidt et al., 2015). As shown in **Figure 9**, phosphate can be recovered from the liquid phase, the sludge phase or from sewage sludge ashes. Since in wastewater treatment plants without phosphorus recovery, about 90-95% of the total phosphorus load is retained in the sewage sludge, the theoretical P recovery potential from sludge is higher in comparison to the liquor phase (<50-60%) (Cornel and Schaum, 2009). However, currently most techniques aim at recovering phosphate

from dewatering streams, since the low concentration of suspended solids makes it relatively easy to separate the phosphate precipitates from the wastewater (Desmidt et al., 2015).



**Figure 9: Overview of the possible locations for phosphorus recovery from municipal wastewater (Ewert et al., 2014). 1 Direct agricultural utilization of dewatered sludge; 2a P recovery from anaerobically digested sludge before dewatering; 2b P recovery from anaerobically digested sludge liquor after dewatering; 3 P recovery from sludge ash after incineration.**

Source: Ewert W. et al., (2014)

### 3.6.3 Global overview of the techniques applicable to the recovery of nutrients from sewage sludge

#### *P-recovery from the liquid phase*

The phosphorus recovery methods from the liquid phase are implemented at a wastewater treatment plant with a biological phosphorus removal process, since the method requires the presence of free phosphates. The polyphosphate stored in the microorganisms after EBPR are partly released under anaerobic conditions which causes an increase of the free phosphate content in the sludge systems, while if the phosphorus would have been chemically removed with iron or aluminium salts, the phosphates would remain bounded to these metals after anaerobic treatment. The phosphorus rich water goes into a precipitation/crystallization tank where magnesium or calcium salts and if necessary seed crystals are added to remove phosphorus as calcium phosphate or magnesium ammonium phosphate (Cornel and Schaum, 2009), similar to struvite recovery from industrial wastewater.

### *P-recovery from the sludge phase*

Phosphorus can be recovered from the sludge phase by a wet chemical or thermal technology. By wet chemical treatment, phosphorus and all metals are extracted from the sludge. After being dissolved, the phosphate and metal ions are precipitated separately to obtain an uncontaminated phosphate fertilizer which can be directly used in agriculture (Sartorius et al., 2012). This process, however, requires large amounts of chemicals and special acid resistant equipment. Furthermore, many different residuals are produced and have to be disposed of at high costs (Sartorius et al., 2012). Struvite recovery from biologically treated sludge after anaerobic digestion has also been tested by Aquafin nv (Belgium). The technique is described in the Biorefine report 'Recovery techniques from digestate and digestate derivatives'.

### *P-recovery from sewage sludge ashes*

Phosphorus bound in sewage sludge ash can also be chemically or thermally treated. The wet chemical treatment involves re-dissolution by adding acid or base. In most cases, (heavy) metals are re-dissolved as well. After removal of the insoluble compounds, phosphates can be removed from the liquid stream through precipitation, ion exchange, nanofiltration, liquid-liquid extraction, etc. (Cornel and Schaum, 2009). Thermochemical treatment of sewage sludge ash removes heavy metals and improves the plant availability of phosphorus. Ashes are exposed to chlorine salts, such as potassium chloride or magnesium chloride, and thermally treated. A large fraction of the heavy metals is turned into heavy metals chlorides which vaporize and are captured by flue gas treatment (Cornel and Schaum, 2009). A typical wet chemical process (Leachphos process) is described below.

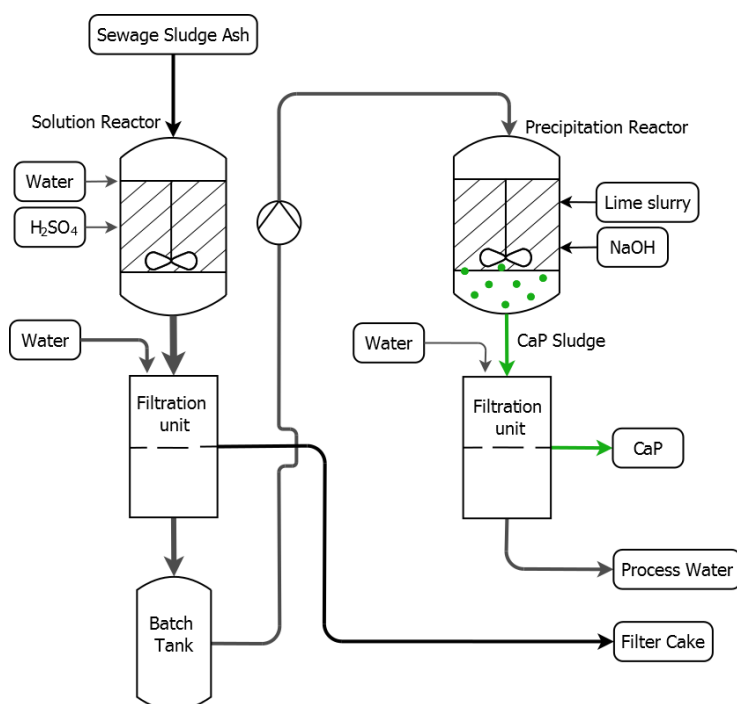
## **3.7 Wet chemical treatment of sewage sludge ash**

### **3.7.1 General description - Leachphos process**

The Leachphos process as described by the P-REX project partners Adam et al. (2015) consists of two sequential steps: a leaching and precipitation step (see **Figure 10**). The sewage sludge ash is leached with dilute sulphuric acid in a stirred batch reactor. About 70-90 % of the total phosphorus content in the ash ends up in the leachate. The leaching process is followed by a solid/liquid separation (filtration) step using a vacuum belt filter or a filter press. The leached sewage sludge ash filter cake is withdrawn and must be disposed. The phosphorus rich liquid stream is then pumped into a second stirred reactor in which the dissolved P is precipitated by dosing lime (CaO) or caustic soda (NaOH). If precipitation is conducted mainly with lime, phosphorus is present as calcium phosphate next to aluminium phosphate. First results indicated that the P compounds are present in an amorphous form. After separation of the product, the liquid stream requires additional treatment which includes a pH increase by dosing additional lime and a sulphidic metal precipitation by dosing an organosulphide precipitation agent in a third reactor followed by an additional solid/liquid separation step using a filter press. In this way, the metals in the wastewater are almost completely removed. Afterwards, the pH is adjusted to 7 and the wastewater is discharged to a WWTP or a receiving water body.



### 3.7.2 Process scheme - Leachphos process



**Figure 10: Flow chart of the Leachphos P recovery process.**

Source: Adam C. et al., (2015)

### 3.7.3 General description - Mephrec process

The Mephrec process is described by the P-REX project partners Adam et al. (2015). The input for the process is dried sewage sludge, sewage sludge ash, coke and other additives for slag formation (such as limestone, cement, etc.). The process can treat dried sludge or ash or a mixture of sludge and ash. As shown in **Figure 11**, if dried sludge is used, the dewatered sewage sludge (25 % DM) is first dried to 80 % DM with a low-temperature dryer or screw dryer. The dried sewage sludge is then compacted to briquettes by means of a high pressure press. When sewage sludge ash is used as raw material, it is mixed with 10 % water in a mixer before briquetting. The briquettes, coke and other additives are weighted, mixed and added at the top of the Mephrec reactor through a bucket system. This implies that a quasi-continuously supply of the reactor is guaranteed. In the reactor, the material is heated up to more than 1450 °C and moves from the top of the furnace down to the bottom where the liquid metal melt and slag melt are separated in a gravitary way. The liquid metal melt is tapped discontinuously. The slag melt continuously flows out of the siphon, directly into a water basin. Due to a scraper in the water basin, a uniform grain size is produced. The process step to transform the P-rich slag into a marketable fertilizer includes granulation and preferably addition of other nutrients to produce complex fertilizers. The produced iron alloy is enriched in phosphorus and could be used in the metal industry.

### 3.7.4 Process scheme - Mephrec process

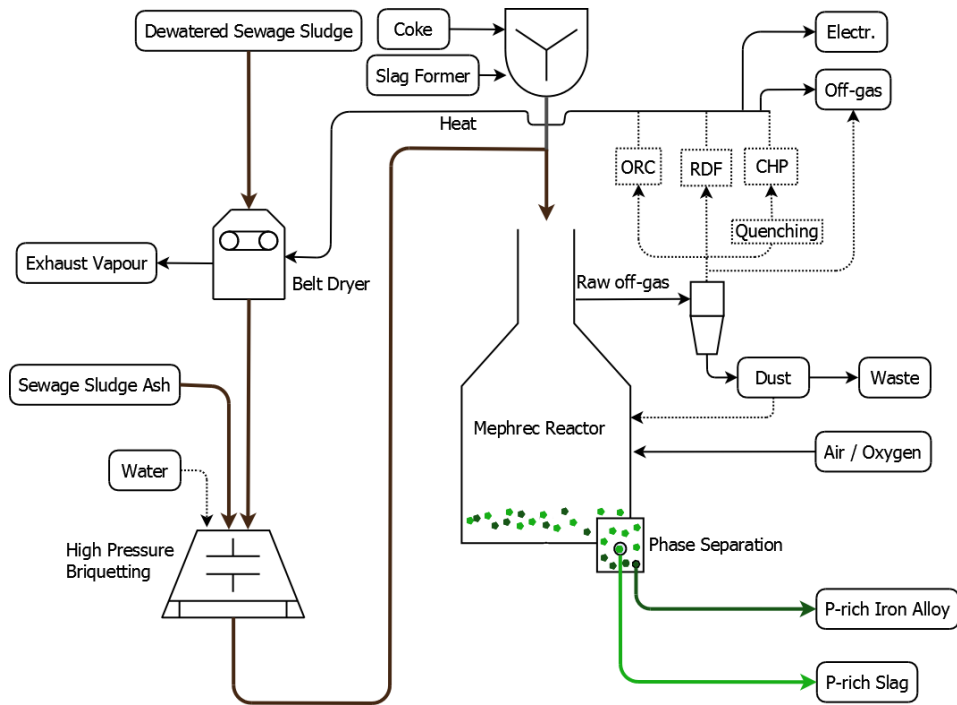


Figure 11: Flow chart of the Mephrec P recovery process.

Source: Adam C. et al., (2015)

### 3.7.5 Useful contact(s) for more information

European Sustainable Phosphorus Platform (ESPP)

Email addresses: [info@phosphorusplatform.eu](mailto:info@phosphorusplatform.eu)

P-REX project

Email address: [christian.kabbe@kompetenz-wasser.de](mailto:christian.kabbe@kompetenz-wasser.de)

### **3.8 Production of struvite from sewage sludge: PHOSPAQ® process**

#### **3.8.1 General description**

Severn Trent Water started the construction of a full scale P and N recovery in Stoke Bardolph, Nottingham (UK); using the process PHOSPAQ®™ where they are planning to extract around 500 tons/year of phosphate contained in struvite from 2014 (Hadden, 2009; Vale, 2013). PHOSPAQ®™ is a cost-effective technology compared to e.g. dosing of iron salts. Moreover, the produced struvite is an excellent slow release fertilizer for N, P and Mg.

The PHOSPAQ®™ process removes biological degradable COD, phosphate ( $\text{PO}_4^{3-}$ ) and ammonium ( $\text{NH}_4^+$ ) from wastewater. With oxygen, the COD is biologically converted into new biomass and  $\text{CO}_2$ . By adding magnesium oxide (MgO), phosphate and ammonium precipitate as struvite ( $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$  or MAP). The struvite granules are being removed from the water phase, and are ready for agricultural use (fertilizer) (Driessen, 2014). Severn Trent Water has come to an agreement with a fertilizer company who will blend the struvite with nitrogen to produce fertilizer with the required nutrient balance (Hadden, 2009).

The treatment used in wastewater treatment plants usually involves:

- A preliminary treatment – to remove grit and gravel and screening of large solids,
- A primary treatment – to settle larger suspended matter (mainly organic),
- A secondary treatment – to biologically break down and reduce residual organic matter,
- A tertiary treatment – to address different pollutants using different treatment processes,
- A sludge treatment – to treat the sludge by anaerobic digestion for the production of methane and bioenergy.

#### *PHOSPAQ® Process*

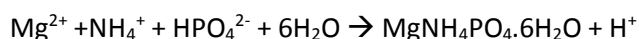
Severn Trent Water's Stoke Bardolph STW, Nottingham, UK is operating PHOSPAQ®, UASB<sup>+</sup> and ANAMMOX® technologies in a single process solution. The sludge dewatering liquors are first treated in a phosphate removal reactor (PHOSPAQ®™), while the sludge stream is treated in a UASB<sup>+</sup> reactor for biogas production. The two streams are then combined and then treated in nitrogen removal reactor (ANAMMOX®) (Durose and Jeffcoat, 2014).

The PHOSPAQ® process is operated to recover phosphate from effluents as struvite. Phosphate is becoming limited and PHOSPAQ® is envisaged as a cost-effective technology in comparison with dosing of iron salts. Furthermore, the produced struvite is an excellent fertilizer which contains N, P and Mg (Durose and Jeffcoat, 2014).

In the BIOPAQ® UASB bioreactor, organic compounds are transformed to biogas by bacteria in anaerobic conditions. The main advantages of this process are the production of biogas which is used for power generation, a high efficiency on COD removal, a small reactor height and a closed system with no odour emissions. It is anticipated that BIOPAQ® UASB reactor will produce approximately 3 MW hour/day, which is enough to power 200 houses (Durose and Jeffcoat, 2014).

After treatment of the sludge dewatering liquor by the PHOSPAQ® reactor, the effluent is combined with a nutrient rich trade liquor and subsequently treated by an ANAMMOX® reactor for the removal of nitrogen (Driessen, 2014). The process presents some advantages as low energy use, pipes not clogged by struvite because of P removal and an operational cost benefit of £165K per year when compared with a conventional aerobic wastewater treatment (Wild, 2014).

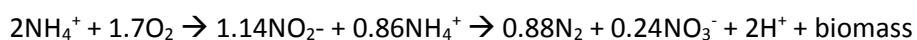
The PHOSPAQ®™ reactor works in a continuous aeration and stirring with magnesium addition for the formation of struvite. The chemical reaction can be described as follows (**Equation 1**):



**Eq.1: Formation of Magnesium ammonium phosphate (MAP): NH<sub>4</sub>-struvite**

For the stimulation of struvite crystallization, pH must be increased around 8 to 8.5 by stripping of carbon dioxide (CO<sub>2</sub>) (≈ 90 Nm<sup>3</sup>/h; 60 kWh/d) and addition of magnesium oxide (MgO, 125 kg MgO/d) when using a reactor of 50 m<sup>3</sup>, 7 m height, 3 m diameter. The addition of MgO is preferred instead of MgCl<sub>2</sub> because it is more economical and helps increasing the pH, which also eliminates the need for additional NaOH (Wild, 2014). PHOSPAQ® reactor has shown recovery percentages of 95 % of phosphate and around 22 % of ammonia in some wastewater treatment plants (Remy, 2014).

Additionally, Severn Trent Water uses the ANAMMOX® process for the removal of ammonia and nitrites as N<sub>2</sub> gas to meet the N discharge limitations (Driessen, 2009). After the removal of nitrogen and phosphates by struvite, one-step ANAMMOX® reactor converts ammonium and nitrites by combination of nitrification and ANAMMOX® process bacteria without requiring external carbon supply and low oxygen usage as shown in the equation below (**Equation 2**):



**Eq.2: Removal of ammonia and nitrite according to the ANAMMOX® process**

As a result, red granular biomass is generated due to specific enzymes. The reactor is continuously aerated, and can be controlled by measurement of nitrite and ammonium.

ANAMMOX® process is appropriate for different types of liquors, such as sewage sludge digestion liquors, dewatering liquors from Thermal Hydrolysis Plants and anaerobic effluents from industry (Driessen and Reitsma, 2014). An ANAMMOX® reactor is around 55 m<sup>3</sup>, 6 m height, 3.5 m diameter with a load of 2.2 kg N/m<sup>3</sup>·d and a fine bubble aeration (≈180 Nm<sup>3</sup>/h, 100 kWh/d) and 96 % N removal (Remy, 2014).

According to Remy (2014), the combination of PHOSPAQ® and ANAMMOX® treatments can achieve a struvite production of 212 tons (expressed in DM) per year with a recovery of 95 % of phosphate (73 kg/d) and ammonium removal of 75 %.

### **3.8.2 Unit operations**

#### *1) Conventional wastewater treatment process*

##### *Wastewater collection (1)*

Wastewater goes down into a pipe which takes it to a larger sewer pipe under the road. The sewer joins the sewage network which takes the wastewater to a sewage treatment works.

##### *Screening (2)*

The first stage for wastewater treatment is the removal of large objects that may block or damage equipment, or be unsightly if allowed back into the catchment surface water, such as face wipes, sanitary items, rocks, plastics, etc. The liquid flows through a number of sieves which remove these materials.

##### *Primary treatment (3)*

After removal of big debris, the wastewater is sent into large settlement tanks, which causes the solids (sludge) to settle to the bottom of the tank. These tanks have a circular shape and large arms (scrapers) which move slowly around the tank to push the sludge to the bottom. The sludge is pumped away for further treatment. The effluent overflows from the tank and is taken to the next stage of the treatment process.

##### *Secondary treatment (4)*

The effluent from the primary sedimentation is sent to rectangular tanks called 'aeration lanes'. The secondary treatment is an aerobic treatment (air is pumped to maintain a concentration of oxygen in the reactor) where a consortium of bacteria break down the organic materials of the water. The products from the aerobic sewage treatment are carbon dioxide, water and nitrogen gas. The effluent leaves the tanks into further settling tanks.

##### *Secondary sedimentation (5)*

The treated wastewater is passed to a final settlement tank, where the bacteria descend to the bottom. The sludge at the bottom of the tank is recycled back to the aerobic treatment stage to keep an optimal concentration in bacteria, and the rest is sent to sludge treatment. The clean water overflows from the settlement tank for disposal, although sometimes additional treatment is needed before disposal.

##### *Polishing (6)*

To meet some standards on specific pollutants and removal of small particles, cleaned water is often filtered through shallow gravel or sand beds as a final step.

### *Treated water discharge (7)*

After the whole treatment, wastewater is clean and sent back to local rivers and streams. The quality of the cleaned wastewater depends on the legal constraints of the state concerned.

### *Sludge thermal treatment (8)*

Collected sludge from the primary and secondary sedimentation tanks is then treated by a hydrothermal process to obtain a high degree of hydrolysis of carbohydrates, proteins, lipids and bacterial cell wall biomass. Hydrothermal process is energy efficient, reaches high digestion yields and increases biogas production. Sewage sludge treated by hydrothermal process (165 °C, 10 bar, 30 min) has been used amply as feedstock for methane production with good yields and productivity in many countries, including the UK, USA, Norway, Germany, etc. (Abu-Orf et al., 2011; Kepp et al., 2000; Panter, 2001; Ross et al., 2010). Thermal hydrolysis increases biogas yield, destroys *salmonella* and 99.9999 % of the pathogens. These bio-solids are approved by Water UK and the British Retail Consortium for use as soil conditioner for all types of crops. The biogas produced by the anaerobic digestion process can be used as fuel in a combined heat and power (CHP) plant or cleaned and injected directly into the national gas grid (Tillier, 2013).

### *Anaerobic Digestion (AD) (9)*

After the hydrothermal process, waste activated sludge is sent to bioreactors for anaerobic digestion. AD is a natural process in which a consortium of microorganisms breaks down organic matter in anaerobic conditions for the production of biogas (CO<sub>2</sub> and CH<sub>4</sub>) and digestate (a nitrogen-rich fertilizer). Biogas is normally used for the production of power in engines for CHP, burned to produce heat, or can be cleaned and used as natural gas or as a vehicle fuel. On the other hand, digestate can be used as a fertilizer or soil conditioner. AD is not a new technology, and has been widely applied in the UK for the treatment of sewage sludge for over 100 years (DEFRA, 2011). Around 660,000 dry tons of separated, treated solids go back into the environment as sludge every year. Thames Water uses the sludge for anaerobic digestion where bacteria grow at 35 °C for at least 12 days, turning organic matter into gas which is burnt in engines.

## 2) PHOSPAQ® Process

### *Stirring and Aeration (1)*

The water rejected from the anaerobic digester is sent to the PHOSPAQ® reactor for stirring and aeration with CO<sub>2</sub>. CO<sub>2</sub> bubbling increases the pH to around 8.0-8.5.

### *Magnesium addition (2)*

When pH is around 8, magnesium salts are added to stimulate the controlled formation of struvite, as shown in the previous reaction. Due to high pH, struvite crystallization is facilitated.

### *Struvite Separation (3)*

The PHOSPAQ<sup>®</sup>™ reactor is equipped with a specially designed internal separator for retention of struvite crystals. The average size of the struvite crystals harvested from the PHOSPAQ<sup>®</sup> reactors is 0.7 mm (Driessen, 2014). Big struvite crystals can settle and are harvested from the bottom of the reactor, whereas small crystals are kept in suspension in the reactor by the aeration. These small crystals in suspension are used as nuclei for further crystallization of struvite.

### *Extraction (4)*

Struvite is extracted from the bottom of the reactor and then dewatered. Product is dewatered by belt-filter or screw press down to 55 - 65 % dry struvite. During storage, the DM content increases over 70 %. Long term full scale experience has shown the PHOSPAQ<sup>®</sup> process to be a reliable way to remove and recover phosphorus from industrial wastewater (Driessen, 2014).

### *BIOPAQ<sup>®</sup> UASB bioreactor (5)*

This reactor converts organic compounds into biogas which is then used for the CHP engines onsite and produces approximately 3 MWh/day, contributing 7 % to the energy-neutral site's total gas output (Durose and Jeffcoat, 2014). BIOPAQ<sup>®</sup> bioreactor is based on a three-phase separator; it separates gas, water and sludge mixtures under high turbulence conditions and can work with high loading rates of 10 – 15 kg/m<sup>3</sup>·d.

### *ANAMMOX<sup>®</sup> digestion (6)*

The effluent of the PHOSPAQ<sup>®</sup> reactor is sent to the ANAMMOX<sup>®</sup> reactor. This reactor is aerated (bubble aeration  $\approx$  180 Nm<sup>3</sup>/h, 100 kWh/d) and contains granular biomass and a biomass retention system. The aeration provides high contact with the biomass and oxygen supply to promote the conversion to N<sub>2</sub> gas (**Equation 2**).

### *Granular biomass separation (7)*

The treated wastewater leaves the reactor by passing the biomass retention system at the top of the reactor. The granular biomass is separated from the cleaned wastewater and returned to the reactor to assure high biomass content. A high biomass content provides high conversion rates, which means that a small reactor volume is required.

## **3.8.3 Process scheme**

The system used by Severn Trent Water is presented in **Figure 12**. **Figure 13** represents the system used in the PHOSPAQ<sup>®</sup> Reactor.

## Techniques for nutrient recovery from household and industrial wastes

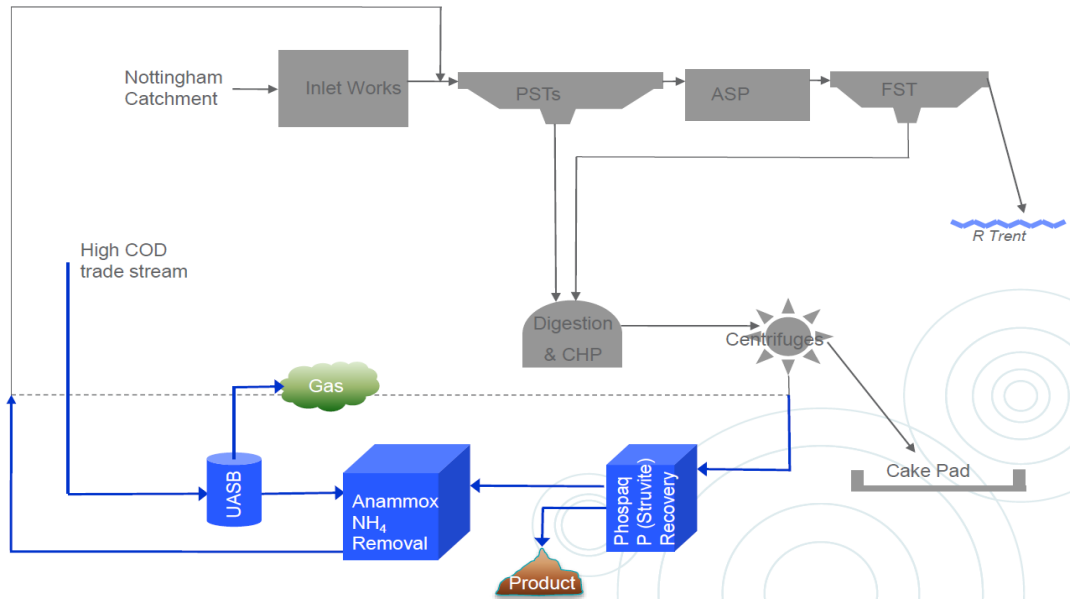


Figure 12: Full scale Phosphorus Recovery system used by Severn Trent Water.

Source: Wild R., (2014)

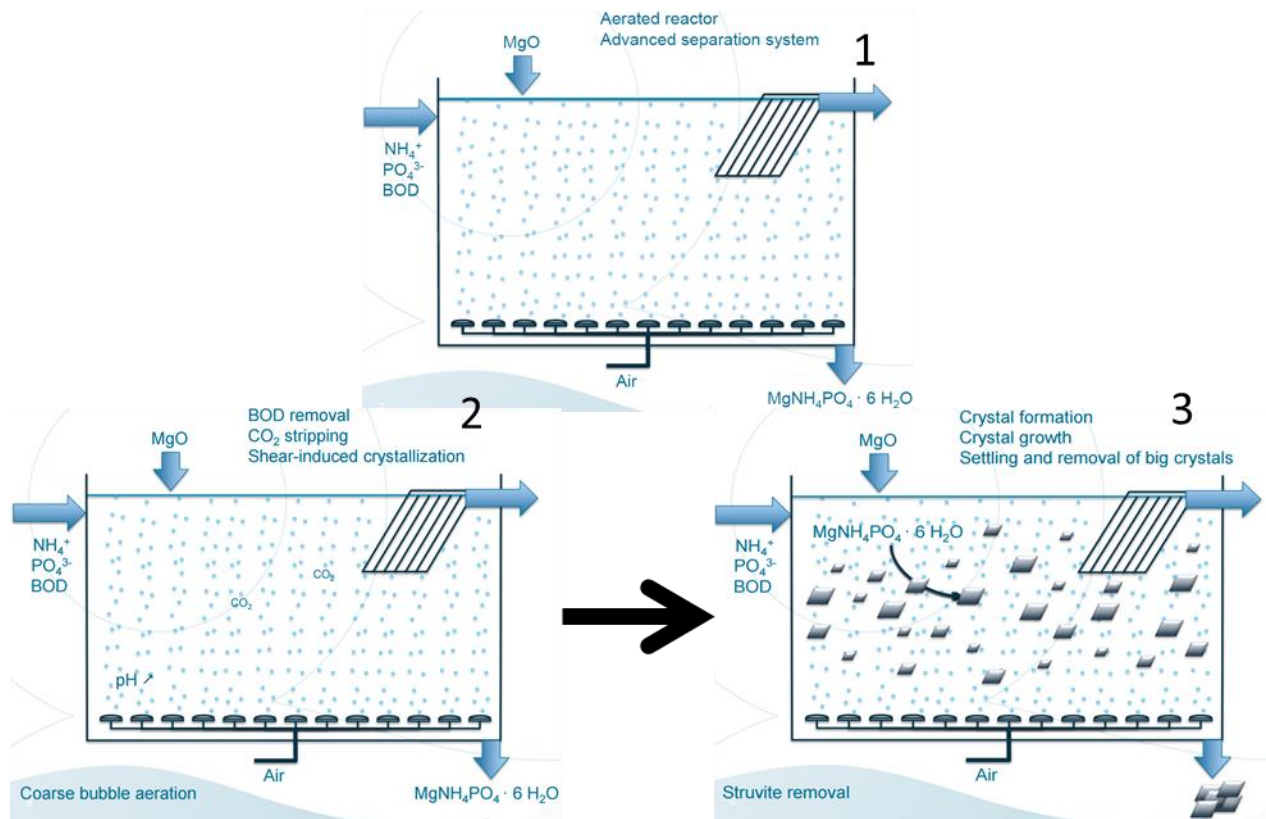


Figure 13: Principle of a PHOSPAQ® reactor.

Source: Remy M., (2014)



### **3.8.4 Useful contact(s) for more information**

P-REX Project

Email address: christian.kabbe@kompetenz-wasser.de

Severn Trent Water (United Kingdom)

Email address: see the website [www.stwater.co.uk](http://www.stwater.co.uk)

University of Leeds (United Kingdom)

Email addresses: A.B.Ross@leeds.ac.uk, cndrr@leeds.ac.uk, M.A.Camargo-Valero@leeds.ac.uk

## **3.9 Production of struvite from sewage sludge: OSTARA® process**

### **3.9.1 General description**

Currently Severn Trent Water and Thames Water (White Slough treatment plant, Berkshire, United Kingdom) use the fluidized bed reactor Pearl® process from OSTARA®. The final product from Pearl process is known as Crystal Green® and it is pelletized and ready for usage (Akinola, 2013; OSTARA®, 2013; Wentworth, 2014). Struvite usage is desirable in comparison with the use of bio-solids from treated sludge due to it allows for up to 40 % more P to be recovered (Vale, 2013). Struvite removal recovers phosphorus and other nutrients from wastewater and recycles them into an environmentally-friendly, premium-quality commercial fertilizer, without the use of harmful chemicals. For example, in the UK, the Pearl® struvite product contains very low heavy metal concentrations but it is currently somewhat expensive (at ≈ £1000/ton) for use in crop production (Akinola, 2013). It is estimated that by the end of 2015, Severn Trent Water will have over 600 plants removing P and 20 plants using Biological Nutrient Removal (Environmental Agency, 2012).

Besides the conventional wastewater treatment process, recovery of P and N can be achieved by OSTARA® process by a premium slow-release fertilizer called Crystal Green® (MAP). Severn Trent Water's Derby Sewage Treatment Works began operating an OSTARA® pilot plant in 2009 for the biological phosphorus removal and recover valuable materials from wastewater (Hadden, 2009, Vale, 2012). OSTARA® Pearl reactor employs the same chemical principle for the formation of struvite; in a continuous aeration, high pH and with magnesium addition.

OSTARA®'s struvite recovery process claims to be able to decrease the operating cost in the wastewater treatment plants and at the same time, to meet environmental regulations. Moreover, the recovery of pollutants (P and N) that are recycled into environmentally-safe and slow-release fertilizer is another advantage (Hadden, 2009). Among the Crystal Green® fertilizer advantages are: is certified product that can be used in horticulture and specialty agriculture, 100 % sustainable production process and renewable, contains only a small fraction of heavy metals, nutrients uptake

by plants is more effective compared to other fertilizer products, low overflow to surface waters due to the P and N slow release and, free of dust, right particle size range, and no chemical coatings (Morgenschweis, 2011). Crystal Green® pellets are periodically harvested from the plant, subsequently dried and packed as Crystal Green®, and delivered as a ready-to-use product to distributors and blenders. Crystal Green® production figures for a plant typically are between 200 to 1,000 tons per year; enough to fertilize 1,000 to 5,000 soccer play grounds.

At the same time, the advantages of the OSTARA® process are: P removal higher than 85 %, Process stability, N up to 40 %, reduced aeration, alkalinity for nitrification, reduced carbon demand for denitrification, reduced chemical consumption (Fe/Al), lower energy consumption and smaller quantity of sludge for disposal (Britton, 2009).

### 3.9.2 Unit operations

#### *Magnesium addition*

Liquor from dewatering of sludge is sent to the Pearl process (fluidized bed reactor) for struvite crystallization. Magnesium is added into the reactor as magnesium chloride solution to maintain a molar ratio of  $Mg:PO_4:P$  equal to 1.3:1 within the reactor (Britton et al., 2005).

#### *pH control*

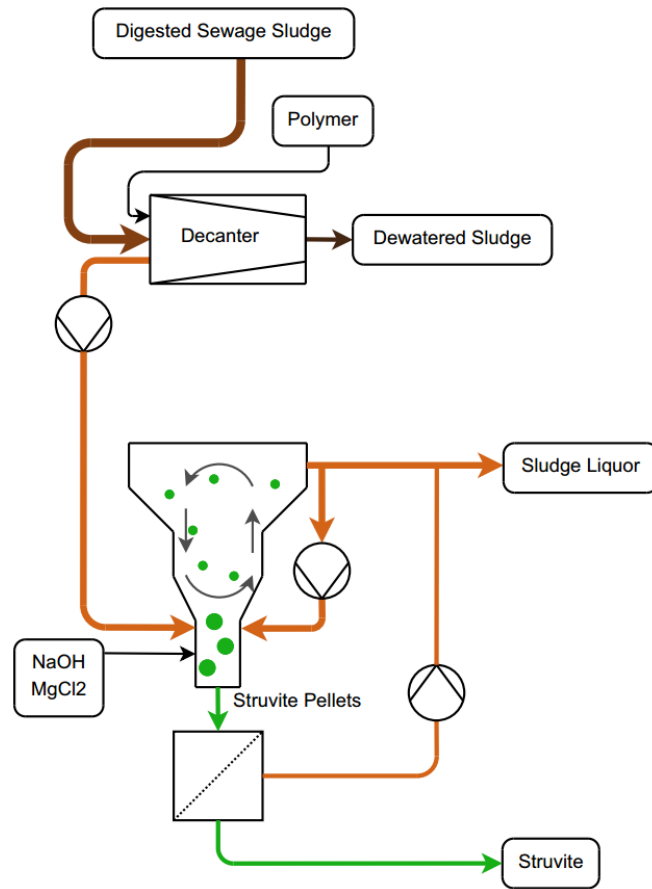
Struvite formation is influenced by pH, so NaOH can be added to improve nutrient removal performance. A reactor recycle pump controls hydraulic conditions and fluidization energy within the bed. The saturation point of a solution is strongly influenced by pH, which should be typically kept between 7 and 8. In some cases, additional NaOH is required.

#### *Pellets formation*

Fertilizer pellets begin as microscopic struvite crystals (created in the reactor), then grow as layers of struvite deposit on the particle surface. The result is extremely pure. These crystalline struvite pellets are harvested from the reactor when they have grown to sufficient size for sale as fertilizer. The harvested crystals are then air dried as a final step (OSTARA®, 2014). The pellets contain more than 99.9% pure struvite and have the right size and hardness to be applied as fertilizer.

The process scheme is presented in **Figure 14**.

### 3.9.3 Process scheme



**Figure 14: OSTARA®'s Pearl Process.**

Source: Britton A. et al., (2005), P-REX project, (2015)

### 3.9.4 Useful contact(s) for more information

P-REX Project

Email address: christian.kabbe@kompetenz-wasser.de

Severn Trent Water (United Kingdom)

Email address: see the website [www.stwater.co.uk](http://www.stwater.co.uk)

Thames Water (United Kingdom)

Email address: see the website [www.thameswater.co.uk](http://www.thameswater.co.uk)

University of Leeds (United Kingdom)

Email addresses: A.B.Ross@leeds.ac.uk, cndrr@leeds.ac.uk, M.A.Camargo-Valero@leeds.ac.uk

### **3.10 Phosphorus precipitation from industrial wastewater**

#### **3.10.1 General description**

Phosphorus can be recovered as struvite from industrial wastewater by the NuReSys<sup>®</sup> (Nutrient Recovery System) technology. The technology is applied on full-scale at a dairy processing company in Germany and at two potato processing companies in Belgium. The reactors are shown in **Figure 15**.



**Figure 15: Struvite recovery reactors (right: stripping reactor, left: crystallization reactor).**

*Source: NuReSys<sup>®</sup>, (2015)*

#### **3.10.2 Description of the technique**

After the wastewater is treated in a UASB (upstream anaerobic sludge blanket) reactor, the anaerobic effluent is aerated to strip CO<sub>2</sub> out of the liquid stream in a first reactor (stripping tank), which results in a pH increase (see **Figure 16**). In the second reactor (crystallization tank), a 29 % NaOH solution is added to obtain an optimal pH (pH 8-8.5) and MgCl<sub>2</sub> is added to recover phosphate as struvite (Desmidt et al., 2015). In the crystallization tank, a simple blade impeller and a specific

automated control algorithm, ensures the optimal pH value, reagent dosing and mixing intensity. The struvite crystals are removed from the crystallization reactor through intermittent purging (Moerman et al., 2009).

### 3.10.3 Process scheme

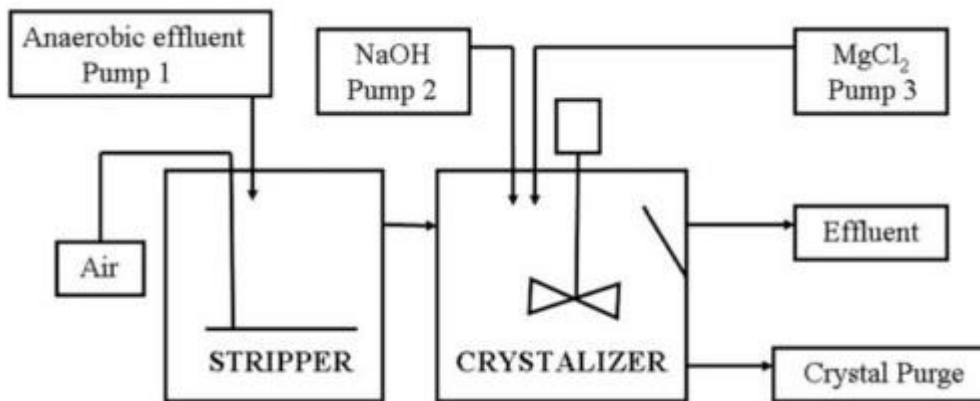


Figure 16: Schematic overview of the NuReSys® phosphorus recovery process.

Source: Moerman W. et al., (2009)

### 3.10.4 End-product

The end-product of the NuReSys technology is BIOSTRU®<sup>®</sup>, a commercially available struvite (magnesium ammonium phosphate) product (5 % N – 28 % P<sub>2</sub>O<sub>5</sub> – 10 % Mg, see **Figure 17**) that is a clean product that can safely be used as a slow release phosphorus fertilizer or soil amendment in agriculture and horticulture (NuReSys, 2015). A part of the produced struvite is exported to France for wine cultivation, while another part is mixed with compost (Desmidt et al., 2015).



Figure 17: Struvite obtained by the process developed by NuReSys.

Source: NuReSys, (2015)

### **3.10.5 Useful contact(s) for more information**

NuReSys (Belgium)

Email address: cd@nuresys.be

## **3.11 Production of pellet fertilizer from sewage sludge**

### **3.11.1 General description**

The Wastewater Treatment Plant of Wavre (Station d'épuration de la vallée de la Dyle, Belgium) possesses an original treatment unit applied to sewage sludge. The treatment applied to waste water in the common process consists of a preliminary treatment (screening and grit removal, de-oiling), a biological treatment and a tertiary treatment (phosphorus removal by the addition of  $\text{FeCl}_3$ ). The capacity of the WWTP has now reached a population equivalent of more than 200,000. The treatment of sewage sludge is composed of three parts:

- Anaerobic digestion with a cogeneration unit,
- Thermal drying of sewage sludge,
- Pelleting and storage on site (capacity of 6 months production).

Next, the pellets containing nitrogen, phosphorus and potassium can be used as fertilizers.

### **3.11.2 Unit operations**

Here, the process of water treatment will not be described as it is a common process used in many WWTPs. We will focus on the sludge treatment only.

#### *Sludge thickening step (A)*

Sewage sludge coming from the different treatment steps (primary, secondary and tertiary sludge) are collected in two thickening ponds. The concentration in DM is approximately doubled (from 2 to 4.5 % of DM). The aim of this step is to concentrate the material before the anaerobic digestion.

#### *Anaerobic digestion (B)*

Anaerobic digestion is based on the degradation of organic matter without oxygen, by the action of specific microorganisms. The degradation process is composed of three main steps: hydrolysis-fermentation, acetogenesis and methanogenesis. The products of this anaerobic digestion are digestate, water and biogas, composed of bio-methane and carbon dioxide. The digestion tank can accept an input flow of about 14,000 kg of DM and produces about 5,000  $\text{Nm}^3$  of biogas by day. About 35 % of DM is degraded through the anaerobic digestion process.

*Biogas storage and cogeneration (C)*

The biogas produced is used to mix the input flow coming into the anaerobic digestion tank, and a second part is used to provide the plant with electricity through a cogeneration device. The cogeneration motor possesses an important power (366 kWh) and decreases the emissions of greenhouse gasses from the plant. This device made the WWTP eligible for green certificates.

*Liming step (D)*

The liming step consists in adding lime to the digestate to avoid undesired microbiological activities. It also prevents the appearance of bad smells. The input flow of digestate has a concentration in DM of about 15 %.

*Thermal drying (E)*

The thin layer thermal dryer is 10.5 meters long and 1.2 meter wide and can accept about 100 kg of matter. The dryer possesses a double envelope in which a heat transfer fluid (250-260 °C) brings energy to evaporate the water contained in the limed digestate. The sludge is distributed over the thin layer by the action of a turbine, which leads to the evaporation of water. The circulation speed can be adjusted by the action of an axis equipped with mobile vanes. Another flow of hot gas is sent on the digestate to improve the drying process. About 3,300 kg of wet sludge come into the dryer by hour, and about 2,600 kg of water are evaporated, which leads to 800 kg of powder (dried digestate) with about 90 % of DM.

*Pelleting (F)*

The pelleting step leads to pellets of dried digestate. The pellets are next transported to the storage room, with a maximal capacity of about 2,500 m<sup>3</sup>, which corresponds to the quantity of pellets produced after 6 months of activity. The DM content is multiplied by 30 (from 3 % to 90 % of DM) throughout the whole process. The pellets can be easily transported and used as fertilizers in the fields.

The process scheme is presented in **Figure 18**.

### 3.11.3 Process scheme

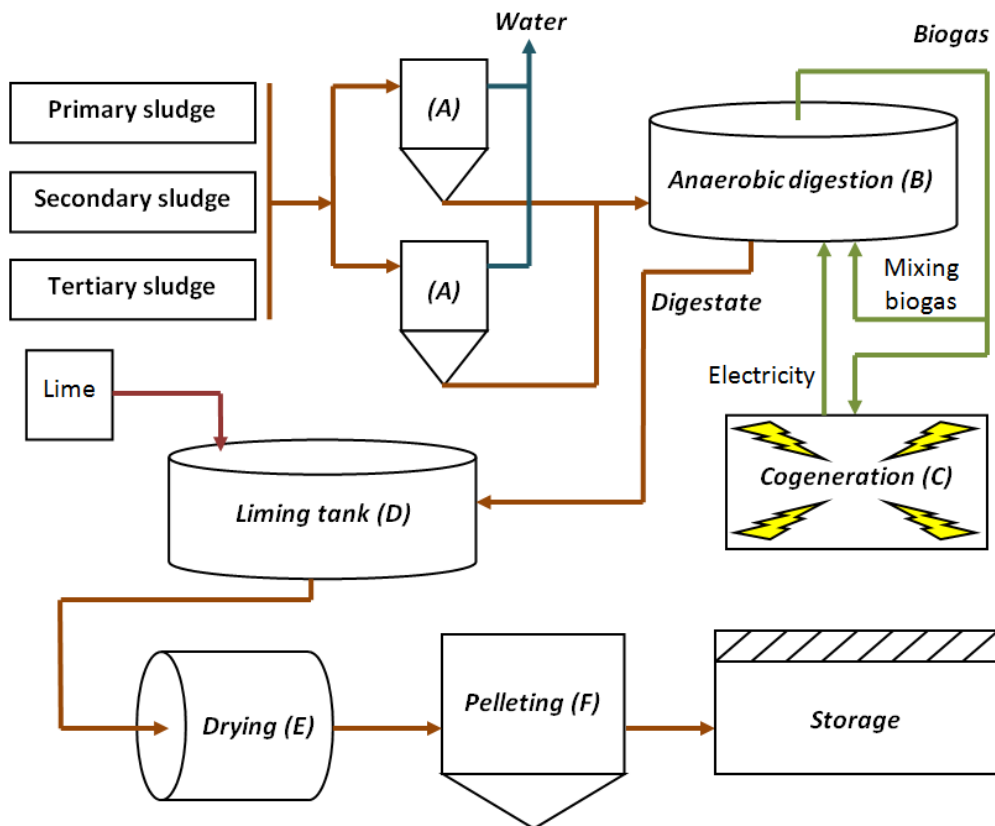


Figure 18: Process of pellet production from sewage sludge.

Source: Station d'épuration de la Vallée de la Dyle, Société Publique de la Gestion de l'Eau

### 3.11.4 Useful contact(s) for more information

Intercommunale du Brabant Wallon (IBW) (Belgium)

Email addresses: [vgooris@ibw.be](mailto:vgooris@ibw.be), [fdedoyard@ibw.be](mailto:fdedoyard@ibw.be)

Société Publique de la Gestion de l'Eau (Belgium)

Email address: [Christian.DIDY@spge.be](mailto:Christian.DIDY@spge.be)



### **3.12 Incineration and metal recovery from household and industrial wastes (designed by SELCHP, UK)**

South East London Combined Heat and Power (SELCHP) is an advanced Energy Recovery Facility built through a partnership between the public and private sectors. Opened in 1994 in South London, SELCHP is now regarded as an example of industry best practice, with similar facilities modelled on its design being constructed around the world.

#### **3.12.1 General description**

SELCHP receives waste from households and some businesses. Waste is tipped into a bunker, where a crane grabs it and places it into the feed hopper. It then drops down a feed chute onto a sloped grate, where it is constantly turned to allow all combustion phases (such as drying, ignition and combustion itself) to happen simultaneously and a constant high temperature to be maintained.

Ash from the burning process is transferred by an ash discharger and residue handling system to the ash pit. During the transfer, ferrous metals are removed for recycling and the remaining ash is sent for reprocessing into recycled material for road building or construction use.

Hot gases produced in the combustion process pass through a water tube boiler where they are cooled; the heated water is transformed into steam. A turbo-generator uses the steam to produce electricity for export to the National Grid.

The gases from the boiler go through a complex flue gas cleaning process, involving the injection of dilute ammonia solution to reduce nitrogen oxides to nitrogen and water; lime milk to neutralise acid gases and activated carbon to absorb heavy metals and any remaining dioxins.

Finally the particulate matter dust is removed from the gas stream by a bag filter before the cleaned gas is released to air. The resultant material known as Air Pollution Control Residue (APC Residue) is sent for disposal at a licensed hazardous waste site.

The power is generated when the steam leaves the boilers at a temperature of 395 °C and pressure of 46 bar, and is fed directly into a single 35 MW steam turbine generator. The turbine rotates the generator to produce electricity. Steam from the turbine is also used to pre-heat the combustion air for the waste burning process.

A bank of air cooled condensers condense the exhaust steam from the turbine and recycle the water back into the process. Electricity is generated at 11kV and transformed up to 132 kV for export to the London Electricity system which passes very close to the SELCHP facility. No supplementary fuel is required to maintain combustion, just refuse and controlled addition of air.

#### *Accepted Waste*

SELCHP facility is designed to handle and treat normal domestic refuse and similar waste. This is defined under 'acceptable' and 'unacceptable' waste below. 'Acceptable' waste means household waste and commercial waste which is considered suitable for incineration.

## Techniques for nutrient recovery from household and industrial wastes

The type of waste that is accepted at SELCHP for incineration is: 'rubbish and refuse normally collected and disposed of by residential households and commercial or institutional establishments'. This does not include wastes in quantities and concentrations which need special handling in their processing and disposal, for example bulky items, waste oil and other items of 'unacceptable' waste.

Acceptable wastes include leaves, twigs, grass and plant cuttings, paper, plastics, ferrous and non-ferrous metals, glass and other materials that normally appear in household refuse. To avoid doubt, Hazardous Waste as defined by the Hazardous Waste Directive (Council Directive 91/689/ECJ) is not acceptable waste.

### *Unaccepted Waste*

Processing any of the following materials may cause severe injury and damage:

- builders waste, liquid waste, non-burnable construction material, demolition debris; especially plasterboard or gyproc board,
- gas cylinders, beer kegs or any other pressure cylinders,
- petrol, oils, greases, solvents or paints,
- animal or human remains or waste,
- acid or caustic substances,
- clinical, pathological and biological wastes,
- asbestos substances,
- tree trunks,
- large quantities of sulphur containing materials,
- machinery other than small household items,
- drugs or poisons,
- motor vehicle batteries, motor cycles, motor engines, transmissions, rear ends, springs, fenders or major parts of motor vehicles, trailers, agricultural equipment, marine vessels or similar items, farm and other large machinery,
- items weighing more than 25 kg each,
- items larger than 1.2 m,
- items larger than 1.2 m x 0.15 m x 0.15 m,
- domestic 'white goods' e.g. fridges, freezers and washing machines, etc.

### **3.12.2 Unit operations**

#### *Air Cooled Condenser (1)*

The eight electrically powered fans push air through the finned tubes of the condenser. The air is cooling the low pressure steam from the turbine exhaust. Cooling condenses the steam back to water. Water is recycled back into the boilers, therefore minimising water usage in normal operating conditions.

#### *Steam Turbine and Generator (2)*

Steam arrives from the boilers, driving the turbine, which rotates the generator to produce electricity. The electricity leaves via 11,000 volt cables that pass through the floor.

#### *Tipping Hall (3)*

Vehicles drive up a ramp into the tipping hall. They then reverse to the edge of the pit and empty their contents into it.

#### *Refuse Bunker (4)*

Two semi-automatic cranes transfer refuse to boilers which burn up to 29 tons per hour. Each grab lifts up to 5 tons of refuse. Normally there is 4,500 tons of refuse in the bunker. The bunker can hold up to 6,000 tons.

#### *Feed Hopper (5)*

The refuse from the crane grabs is dropped here and fed onto the incineration grate in a controlled manner.

#### *Incineration Grate (6)*

Pull down handle on right hand side of viewing port, look up at 45 °C to see combustion of refuse. Note ash falling into quench bath below.

#### *Steam Boiler (7)*

Refuse is dropped into the chutes above. Hydraulic rams feed refuse onto the grate, where it burns at temperatures greater than 850 °C. Heat energy is released into a multi pass boiler where 76 tons per hour of steam are produced at 395 °C and 46 bar.

*Gas Treatment Scrubber (8)*

As the hot combustion gases pass through here they are mixed and cooled with a measured amount of lime milk sprayed in at the top. The lime falls through the gases, reacting with and removing any acid gases present and reaching the bottom as a dry powder where it is removed. The incoming acid gas content is continuously measured to ensure the right amount of lime is added.

*Bag House Filter (9)*

The bag house contains around 3,000 individual bag filters. All the gases from the waste combustion pass through the filter bags and any dusts are captured on the filter material. The cleaned gases are then emitted from the chimney stack. The dust is periodically dislodged from the bags by a pulse of compressed air. This removed dust becomes part of the Air Pollution Control residue.

*Induced Draught Fan (10)*

A powerful adjustable fan draws all the gases through the plant, keeping the whole process under a slight vacuum and ensuring there are no leaks.

*Residue Handling Crane (11)*

This device transfers the bottom ash and recovered ferrous metal to loading chutes prior to discharge into lorries for removal from site.

*Bottom Ash Handling (12)*

After combustion, the volume of the original refuse is reduced by 90 % and the mass by 70 %. From this remaining bottom ash an off-site, joint venture business recycles a further 1.5 % ferrous metal and up to 1.5 % non-ferrous metal such as aluminium, copper and brass. The off-site business also processes the bottom ash to produce a high performance aggregate, sold for use in road construction and other purposes.

*Under Fire Fan (13)*

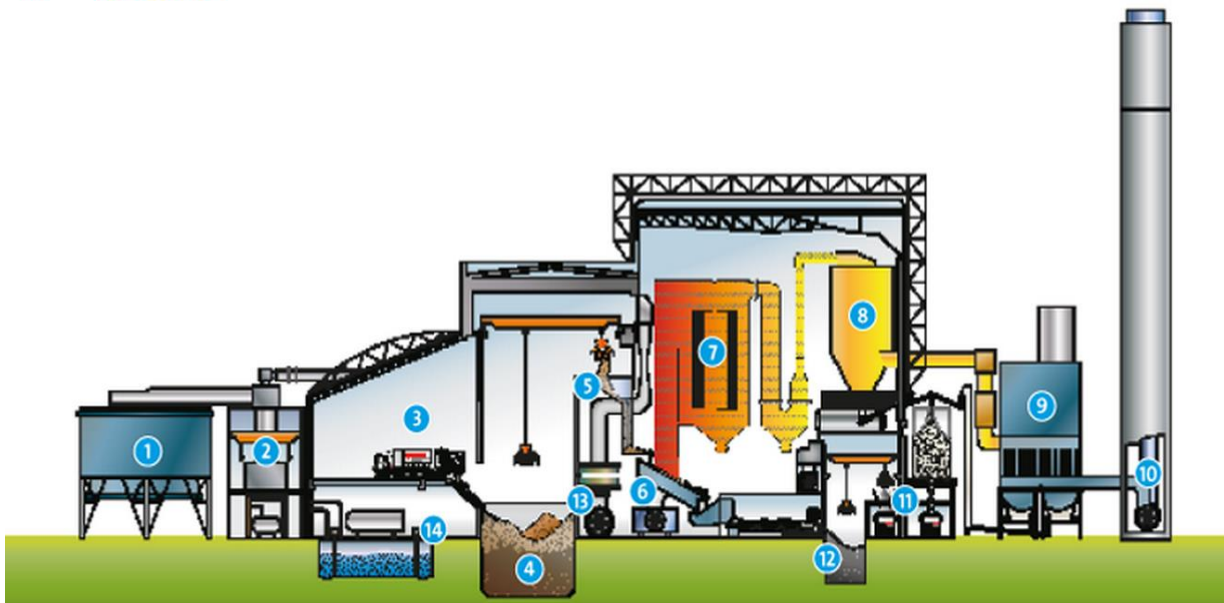
These large ducts are drawing air from above the waste pit which is through the concrete wall to the west. The air is fed into the furnace via fans from both below and above the flames. This air is vital to maintain the correct combustion of the waste. Drawing the air from around the waste pit also stops smells from escaping into the local area.

### Water Treatment Plant (14)

Two exchange units treat incoming mains water at the rate of 10 tons per hour per unit. The treated water is then used in the boilers for the production of steam to drive the turbine.

The process scheme is shown in **Figure 19**.

### 3.12.3 Process scheme



**Figure 19: Process scheme of the South East London Combined Heat and Power Plant.**

*Source: Website of South East London Combined Heat and Power Plant*

### 3.12.4 Useful contact(s) for more information

South East London Combined Heat and Power Plant (United Kingdom)

Email address: see the website <http://www.selchp.com/>

University of Leeds (United Kingdom)

Email addresses: A.B.Ross@leeds.ac.uk, cndrr@leeds.ac.uk, M.A.Camargo-Valero@leeds.ac.uk

### **3.13 Incineration and metal recovery from household and industrial wastes (designed by LondonWaste)**

#### **3.13.1 General description**

LondonWaste provides waste management services across London. The facilities recycle materials, compost organic waste and recover energy from waste. Waste considered unsuitable for other methods of recycling is sent to the Energy Centre. Here waste is incinerated to produce energy. The heat generated from the process turns water into steam which drives turbines to create electricity. This is fed into the National Grid. The export is around 85 % of the electricity generated in LondonWaste, which represents enough to power 72,000 homes throughout the year; the remaining 15 per cent powers all the centres on the EcoPark. From 1994, when LondonWaste Ltd was awarded the NLWA contract, up to the end of 2013, more than 9 million tons of waste have been diverted from landfill.

#### **3.13.2 Unit operations**

##### *Waste Input (1)*

Residual Waste is delivered into the Energy Centre, generally by refuse collection vehicles and deposited into the bunkers.

##### *Bunkers (2)*

There are five bunkers, each about 25 m deep and 14 m<sup>2</sup>.

##### *Overhead Grab Cranes (3)*

There are three grabs which lift the waste from the bunkers and place it into one of the five feed chutes. The boilers are fed at a rate of 15 tons per hour.

##### *Boiler Feed Chute (4)*

The waste is fed to the boiler grates at a controlled rate by the hydraulic feeder ram which controls the rate at which is fed to the boiler grates.

##### *Boiler grate (5)*

Waste is burnt on the grate at temperatures in excess of 1000 °C.

*Boiler (6)*

Above the grate is the tube area where the hot gas is used to generate superheated steam from 40 tons of water every hour. The steam from the boiler is used to drive turbines and generate electricity.

*Ash (7)*

Ash from the boiler grates is sent on to an on-site Ash recycle plant. The specialist processors remove any further metals for re-use and then grade and screen the ash for use as an aggregate for use in road building and construction.

*Economiser (8)*

To ensure that the maximum amount of energy is recovered from the waste, the hot gases from the boiler pass into the economiser where they heat the incoming boiler water.

*Precipitator (9)*

The gases, now cooled to about 180 °C, carry on into the first part of the gas cleaning plant, the precipitator. Wires and plates in the precipitator are charged with electrostatic electricity where they attract the dust out of the flue gas.

*Flue gas treatment plant (10)*

The purpose of the flue gas treatment plant is to clean the flue gas before it enters the atmosphere. The first part of the process cools the gas to 140 °C by adding water. Lime and activated carbons are then injected into the gas stream to neutralise any acidity and absorb other pollutants.

*Fabric Filter (11)*

All the gas is filtered through an extremely fine fabric to remove remaining dust and lime before passing to the 100 metre high chimney.

*Chimney (12)*

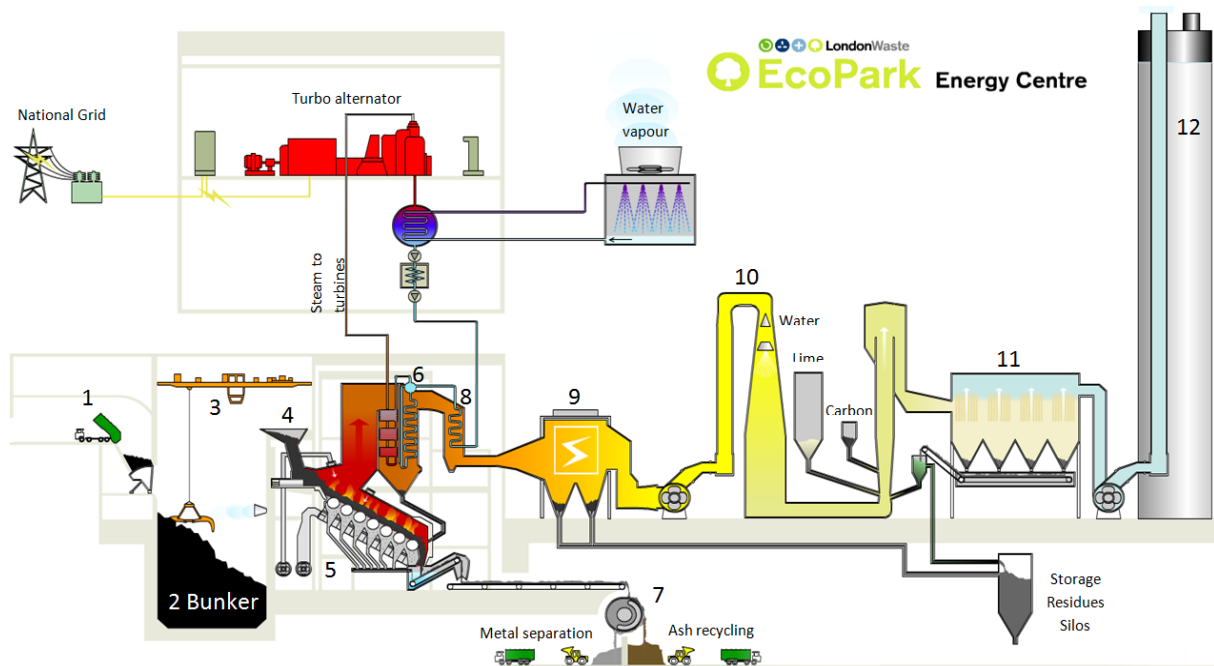
All the gases are continuously monitored to ensure compliance with very stringent regulations. A slight plume, which is only water vapour, may be visible under some conditions.

### Alternator (13)

After supplying the internal needs, more than 85 % of the electricity generated by the plant is exported to the National Grid. The export is up to 35,000 KW of power every hour.

The process scheme of the treatment is shown in **Figure 20**.

#### 3.13.3 Process scheme



**Figure 20: Process scheme of the LondonWaste Plant.**

*Source: Website of LondonWaste*

#### 3.13.4 Useful contact(s) for more information

LondonWaste Plant (United Kingdom)

Email address: [recycling@londonwaste.co.uk](mailto:recycling@londonwaste.co.uk)

University of Leeds (United Kingdom)

Email addresses: [A.B.Ross@leeds.ac.uk](mailto:A.B.Ross@leeds.ac.uk), [cndrr@leeds.ac.uk](mailto:cndrr@leeds.ac.uk), [M.A.Camargo-Valero@leeds.ac.uk](mailto:M.A.Camargo-Valero@leeds.ac.uk)



### **3.14 Removal of heavy metals from sludge and sediments**

#### **3.14.1 General description**

The CTP (Centre Terre et Pierre) is located in Tournai (Wallonia, Belgium). Its activities consist in treating ores, industrial minerals, recycling solid materials, contaminated soils, sediments and dredging spoils. The analysis lab of the CTP is able to achieve complete physical, chemical and mineralogical analyses of mineral materials. The Center is also an authorized laboratory for waste analysis by the Walloon Region. The Center contains an area of about 3400 m<sup>2</sup> equipped with different types of comminution and sorting devices able to treat up to several tonnes of materials.

The aim of the SOLINDUS platform is to validate recycling techniques applied to solid materials on a partly industrialized scale. The treatment presented in this section explains a method which leads to different fractions with defined and homogeneous particle size distribution, and complementary unit operations can be added to the original technique. This process can be used to remove heavy metals from silt like materials obtained after wet treatment of different types of sludge or soil, and therefore be used to purify the materials and increase their quality as fertilizers. Industrial sludge and sediments can be treated, but ashes should also be considered.

The treatment is mainly composed of 8 important steps:

- Removal of big particles (> 2mm),
- Removal of particles the size of which is superior to 250 µm,
- Removal of particles the size of which is superior to 63 µm,
- Removal of particles the size of which is superior to 15 µm,
- Purification of the muddy fraction,
- Flocculation/decantation of the clayey fraction,
- Dehydration of the different fractions,
- Water treatment (not described here).

The raw material is brought to a first trommel by hydraulic excavators, through a grid that retains blocks bigger than 20 mm. This trommel separates the material into two fractions on the basis of a size separation. Two fractions are obtained: a first fraction of wastes the size of which is superior to 4 mm, and a second fraction composed of wastes the size of which is inferior to 4 mm. Then, a vibrating sieve is used to obtain a finer fraction (size inferior to 2 mm). The two fractions composed of the biggest elements are put together to constitute the first waste fraction (Fraction 1, size superior to 2 mm).

Then, the finest fraction is homogenized and mixed with water before being sent to a curved sieve. This step leads to a second fraction (Fraction 2) mainly composed of sand particles (between 250 µm and 2 mm). A supplementary unit operation, which uses a magnetic separation, can be achieved on Fraction 2 if ferromagnetic materials are present. The materials are next sent to a vessel in which the pulp density is modified and adjusted to the right value.

The pulp, which is composed of particles the size of which is inferior to 250  $\mu\text{m}$ , is then sent to a hydro-cyclone combined with a screw classifier. This combined system leads to a fine fraction (particle size inferior to 63  $\mu\text{m}$ ) and Fraction 3, composed of fine sands. This Fraction 3 is next sent to supplementary steps: attrition (facultative) and spiral gravity separation. Then, the material is dehydrated by big bag filters.

The finest fraction is then composed of particles the size of which is inferior to 63  $\mu\text{m}$ . The pulp is sent to two parallel hydro-cyclones, which lead to a muddy fraction (particle size comprised between 15 and 63  $\mu\text{m}$ ) and a clayey fraction (size inferior to 15  $\mu\text{m}$ ). The muddy fraction is next sent to a purification step achieved in a flotation tank. The aim of that step is to separate metallic and organic pollutants, by a technique based on their hydrophobic nature. Different substances are added to the pulp during this process in order to collect the pollutants in the foam (supposed to contain metals and organic pollutants). The purified muddy fraction is then decanted and filtered, leading to Fraction 4.

The clayey fraction is sent to a flocculation/decantation system. The pulp is mixed with flocculation reagents in a tank to improve and accelerate the sedimentation process. The pulp, which has been thickened, is next sent to a filter press to be dehydrated. This final step leads to the finest Fraction 5.

### **3.14.2 Unit operations**

#### *Screening by a trommel (A)*

The first unit operation is a screening step achieved by a trommel, composed of a rotary drilled cylinder. Blades are located inside the cylinder and mix the material. An aspersion device is also included in the system to help de-agglomeration of the material. The device can treat a maximal input flow of 1 to 1.5  $\text{m}^3/\text{h}$ , with a percentage of DM comprised between 50 and 60 %. Three fractions are obtained (particle size superior to 20 mm, manually removed from a grid at the feed of the trommel, inferior and superior to 4 mm which is the size of the holes in the inner cylinder of the trommel).

#### *Screening by a vibrating sieve (B)*

The second unit operation is another screening step achieved in a vibrating sieve. Water is brought to the material in order to facilitate the mass transfers. The device can treat a maximal input flow of 1.5 to 2  $\text{m}^3/\text{h}$ , with a percentage of DM comprised between 30 and 40 %. The output flow contains about 20 % of DM. Two fractions are obtained (particle size inferior and superior to 2 mm).

#### *Mixing step (1) (C)*

A mixing step is used to homogenize the material, added with water to obtain a pulp. The maximal input flow can reach a value of 2  $\text{m}^3/\text{h}$ .

*Screening by a curved sieve (D)*

This separation device is composed of small metallic blades separated by gaps of 500  $\mu\text{m}$ . The maximal input flow can reach a value of 5  $\text{m}^3/\text{h}$ , with a percentage of DM comprised between 10 and 20 %. Two fractions are obtained (particle size inferior and superior to 250  $\mu\text{m}$ ).

*Magnetic separation (E)*

A magnetic separator can be included in the treatment if necessary. It consists of a rotary device equipped with a permanent magnet. The magnetic particles are retained by the magnet before being released in a zone in which the magnetic field is weaker. The device can treat an input flow of 5  $\text{m}^3/\text{h}$  with a percentage of DM comprised between 10 and 20 %.

*Mixing step (2) (F)*

A second mixing step is used to reach a specific value of density. The percentage of DM must be comprised between 5 and 10 % in the output flow. Water is added in the tank to dilute the pulp. The device can treat an input flow of 5  $\text{m}^3/\text{h}$  with a percentage of DM comprised between 10 and 20 %.

*Screening by a combined system (hydro-cyclone/screw classifier) (G)*

A combined device composed of a hydro-cyclone and a screw classifier is used to treat the fraction the particle size of which is inferior to 250  $\mu\text{m}$ . This system leads to two fractions: the fine sands composed of particles with size comprised between 63 and 250  $\mu\text{m}$ , and the fine fraction composed of the smallest particles (size inferior to 63  $\mu\text{m}$ ). The device can treat an input flow of up to 12  $\text{m}^3/\text{h}$  with a percentage of DM comprised between 5 and 10 %.

*Attrition (facultative) (H)*

This unit operation can be added to the process if necessary and is applicable to fine sands (size comprised between 63 and 250  $\mu\text{m}$ , G). This system is located at the end of the screw classifier and is composed of blades creating strong currents. Those currents allow cleaning the particle surfaces and remove hydrocarbons, metal oxides, etc. The machine can treat a maximal input flow of 1  $\text{m}^3/\text{h}$  with a percentage of DM comprised between 50 and 70%.

*Screening by a hydro-cyclone and spiral devices (I)*

This step is applicable to the fine sands obtained in (G). A hydro-cyclone is used to ensure a particle size comprised between 63 and 250  $\mu\text{m}$ . Then, two spiral separators, placed in series, generate a fine water blade to separate the particles according to their specific weight, the heaviest particles (minerals) staying close to the axis of the spiral are collected by the inner valve at the bottom of the spiral, when the lightest particles (organic matter) are collected by the outer valve. Small valves

collect the different fractions. The finest and lightest particles tend to go to the spiral extremity because of the turbulences combined with the centrifugal force. The system can treat an input flow of 5 m<sup>3</sup>/h with a percentage of DM comprised between 5 and 10%.

#### *Filtration (J)*

The finest fractions obtained by the action of the spiral separators are dehydrated by big bag filters.

#### *Concentration of the heavy fraction by a hydro-cyclone and filtration (K)*

The heavy fraction collected by the spiral separators is next treated on a vibrating screen for dehydration. This combined device can treat a maximal input flow of 1 m<sup>3</sup>/h with a percentage of DM comprised between 10 and 20 %.

#### *Mixing step (3) (L)*

The finest fraction obtained in (G) by the action of the hydro-cyclone combined with the screw classifier (particle size inferior to 63 µm) is sent to a mixing vessel. This vessel is used to homogenize the material and dilute it with water. The maximal input flow which can be treated is 10 m<sup>3</sup>/h with a percentage of DM comprised between 5 and 10 %.

#### *Screening by parallel hydro-cyclones (M)*

The finest fraction which has been homogenized is next sent to two parallel hydro-cyclones. This device leads to two fractions: a muddy fraction composed of bigger particles (size comprised between 15 and 63 µm) and a clayey fraction composed of small particles (size inferior to 15 µm). The system can treat a maximal input flow of 15 m<sup>3</sup>/h with a percentage of DM comprised between 5 and 10 %.

#### *Purification of the muddy fraction by a hydro-cyclone (N)*

The muddy fraction coming from the previous step (M) is next sent to another hydro-cyclone before being treated in the flotation device.

#### *Purification by flotation (O)*

The aim of the flotation device is to remove the metallic and organic pollutants present on the muddy particles. Reagents are prepared separately before being added to the flotation tank. Air is injected in the tanks, and different types of reagents can be added: activating reagents, foaming reagents, etc. Two different tanks of 750 L are placed in series, and the foam containing the concentrated pollutants is collected at the surface. The maximal input flow can reach 1.5 m<sup>3</sup>/h, with a percentage of DM comprised between 20 and 30 %. Reagents added are chosen to be selective

towards the pollutants or nutrients to be removed and need a preliminary case by case study at laboratory scale.

#### *Decantation step (P)*

The resulting foam coming from the flotation process and the clean muddy fraction are next sent to the decantation device. The system is composed of two tanks of 4.9 m<sup>3</sup>. The first decantation tank treats the polluted foam (containing the metallic elements, or micronutrients), while the second one treats the clean fraction.

#### *Filtration (Q)*

Both fractions obtained in (P), after the decantation step, are next sent to big bag filters.

#### *Flocculation and decantation of the clayey fraction (R)*

The natural decantation of the clayey fraction is very slow and requires flocculation reagents to be accelerated. Those reagents are prepared in a separate mixing tank by dissolution of the powder. Then, the flocculation agents are added in pulp to the clayey fraction. The material mixed with the flocculation reagents are sent to a decantation tank of 35 m<sup>3</sup>. A maximal input flow of 10 m<sup>3</sup>/h with a percentage of DM of about 5 % can be treated in this device.

#### *Dehydration of the clayey fraction (S)*

The flocculated particles are dehydrated by a filter press. The device is equipped with 30 units, and the internal pressure can reach a maximal value of 15 bar, allowing to reach a final DM of 70% without any other pressing-aid additives. One dehydration cycle takes between 1 and 2 hours per ton of final material obtained. This final step allows recovering the finest fraction of the raw material in the shape of compressed cakes, easy to handle.

The scheme of the process is shown in **Figure 21**.

3.14.3 Process scheme

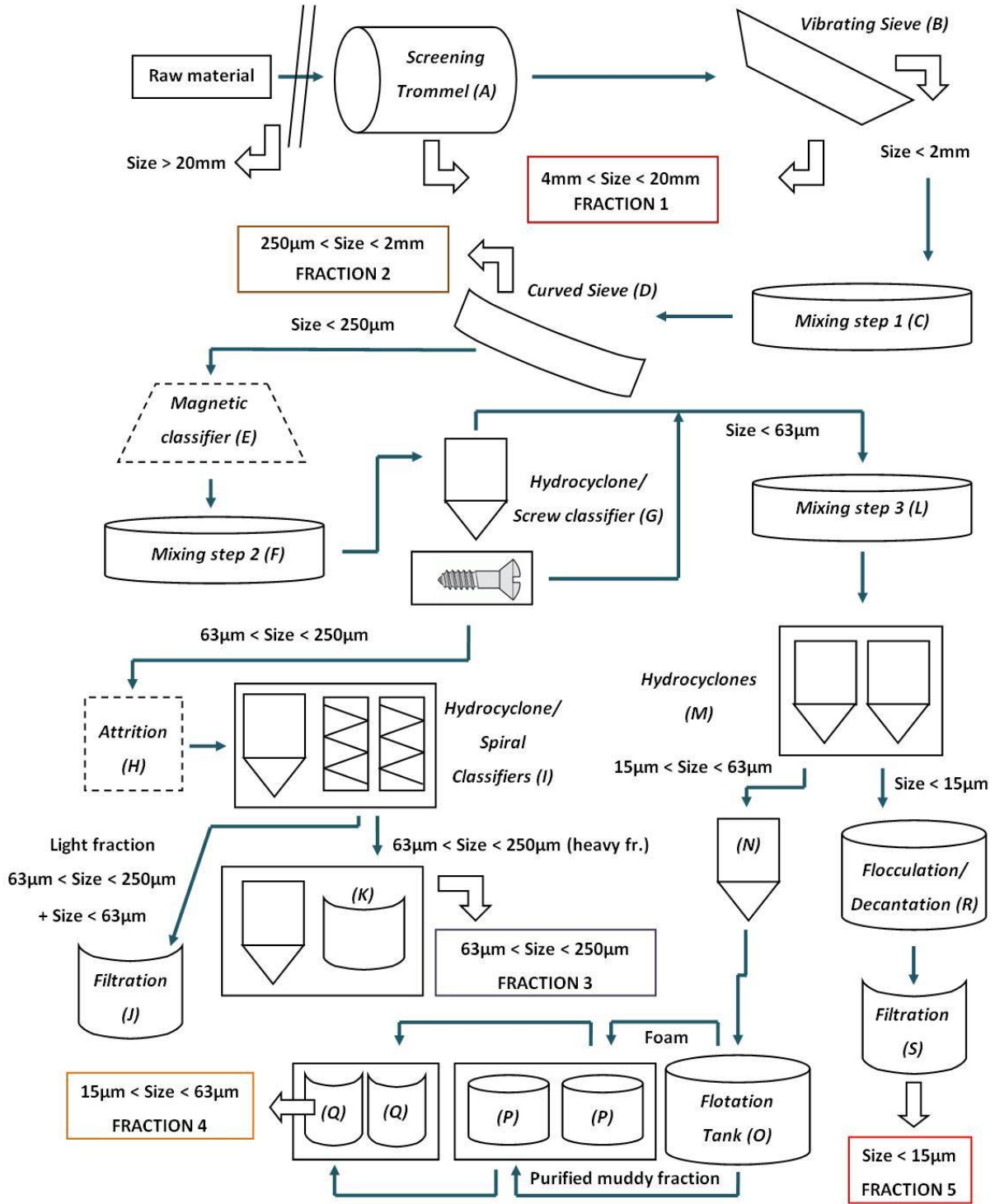


Figure 21: Scheme of the process used by the “Centre Terre et Pierre” to purify sludge and sediments.

Source: Centre Terre et Pierre (Tournai, Belgium)

#### **3.14.4 Additional comments**

Some unit operations can be added to the process if necessary. The magnetic separation (E) and the attrition step (H) are facultative. A water treatment process, which has not been described here, is also included in the system. The pilot plant is currently under extension to integrate other unit operations such as jig separation (heavy/light fraction separation combined with granulometry separation in wet conditions) and will be fully operational in February 2016.

All those data were provided by the “Centre Terre et Pierre” in Tournai (Belgium).

#### **3.14.5 Useful contact(s) for more information**

Centre Terre et Pierre (Belgium)

Email addresses: Herve.BREQUEL@ctp.be ; Benoit.GRYMONPREZ@ctp.be

### ***3.15 Removal of metallic compounds from ashes (IPALLE, Belgium)***

#### **3.15.1 General description**

The waste incinerator of Thumaide is managed by the inter-municipal organization IPALLE (Wallonia, Belgium). Its activities consist in valorizing different types of materials through incineration. The plant accepts bulky wastes, industrial and household wastes, medical and hospital wastes, plastics, cardboard, sewage sludge, etc. The residue obtained after incineration is clinker and its composition is quite variable because of the heterogeneity of the input flows. The plant treats about 300,000 tons of material every year.

The aim of the valorization plant of clinker is to separate the different fractions according to the size, the magnetic and metallic characteristics. Then, it is possible to send the different fractions to the corresponding recycling techniques.

The treatment is mainly composed of 4 types of steps:

- Screening steps,
- Magnetic separations,
- Metallic separation based on an eddy current separator,
- One mixing step.

The raw material is brought to a first screening sieve to separate the input flow into two fractions: a first fraction of wastes the size of which is superior to 100 mm, and a second fraction composed of wastes the size of which is inferior to 100 mm.

The biggest fraction is next sent to a magnetic separator, leading to a fraction of big magnetic particles (size > 100 mm) and a fraction of big non-magnetic particles (size > 100 mm).

The finest fraction is composed of the finest particles (size inferior to 100 mm). This flow is sent to a screening trommel which leads to two fractions: the finest fraction composed of particles the size of which is inferior to 20 mm and the biggest fraction composed of particles the size of which is comprised between 20 and 100 mm.

The finest fraction is sent to another magnetic separator which leads to a magnetic and non-magnetic fraction of fine particles. The fine magnetic fraction is sent to a mixing tank, while the non-magnetic flow is next sent to an eddy current separator. This plant allows separating the metallic compounds included in the material. The eddy current separator leads to a non-metallic flow of fine particles and a second fraction of non-magnetic metals (size inferior to 20 mm).

The flow composed of the intermediate particles (size comprised between 20 and 100 mm) obtained by the size separation achieved in the trommel is next sent to a magnetic separator. This device leads to a magnetic and a non-magnetic fraction. The magnetic fraction is mixed with the finest particles in the mixing tank cited before. This mix is then sent to another magnetic separator which leads to two different flows: the fine magnetic particles (size inferior to 100 mm) and the fine non-magnetic particles (size comprised between 20 and 100 mm).

Finally, the non-magnetic fraction obtained by the magnetic separation which follows the trommel screening is added with the fine non-magnetic particles cited before. Those two combined flows are composed of intermediate non-magnetic particles (size comprised between 20 and 100 mm).

### **3.15.2 Unit operations**

#### *Primary screening sieve (A)*

The raw material is first sent through a primary sieve which leads to two different flows. Those two fractions consist of a fine fraction (size < 100 mm) and a big fraction (size > 100 mm). The input flow is composed of about 67 % of household wastes, 23 % of industrial wastes, 7 % of sewage sludge and 2 % of hospital wastes.

#### *Magnetic separation (1) (B)*

A magnetic separator is used on the biggest particles coming from the screening sieve. This device leads to a magnetic fraction of big particles and a non-magnetic fraction of big particles (size superior to 100 mm).

#### *Screening by a trommel (C)*

A screening trommel is used to separate the particles composing the finest flow coming from the primary sieve (size inferior to 100 mm). This screening device leads to a fine fraction (size < 20 mm) and a bigger fraction (size comprised between 20 and 100 mm).



*Magnetic separation (2) (D)*

A second magnetic separator is used on the finest fraction (size < 20 mm). The input flow is divided into a magnetic flow (next sent to a mixing tank (G)) and a non-magnetic flow which is sent to an eddy current separator.

*Eddy current separator (E)*

The principle of the eddy current separator is based on the magnetic properties of the elements but is more complex than the one of a common magnetic separator. Eddy currents are due to a magnetic flux at a high frequency. A rotating device equipped with permanent magnets allows creating specific magnetic fields. The magnets show alternating magnetic poles. The rotation of the device causes a variation in the magnetic field which causes a repulsion of the metallic elements. The device leads to a flow of fine non-metallic particles and a flow of fine metallic elements (particle size inferior to 20 mm).

*Magnetic separation (3) (F)*

The intermediate fraction (size comprised between 20 and 100 mm) obtained in (C) is next sent to another magnetic separator. The device leads to one flow of fine magnetic particles and one flow of fine non-magnetic particles (size comprised between 20 and 100 mm).

*Mixing step (G)*

The aim of the mixing tank is to homogenize the magnetic fractions obtained in (D) and (F). Both fractions are mixed together in the tank before being sent to (H).

*Magnetic separation (4) (H)*

This final magnetic separator creates two flows: the magnetic fraction of the fine particles (size inferior to 100 mm) and the non-magnetic fraction of fine particles. This flow is added with the one coming from (F). A blower device is then used to remove the finest particles, leading to a non-magnetic fraction of particles the size of which is comprised between 20 and 100 mm.

The process scheme is shown in **Figure 22**.

### 3.15.3 Process scheme

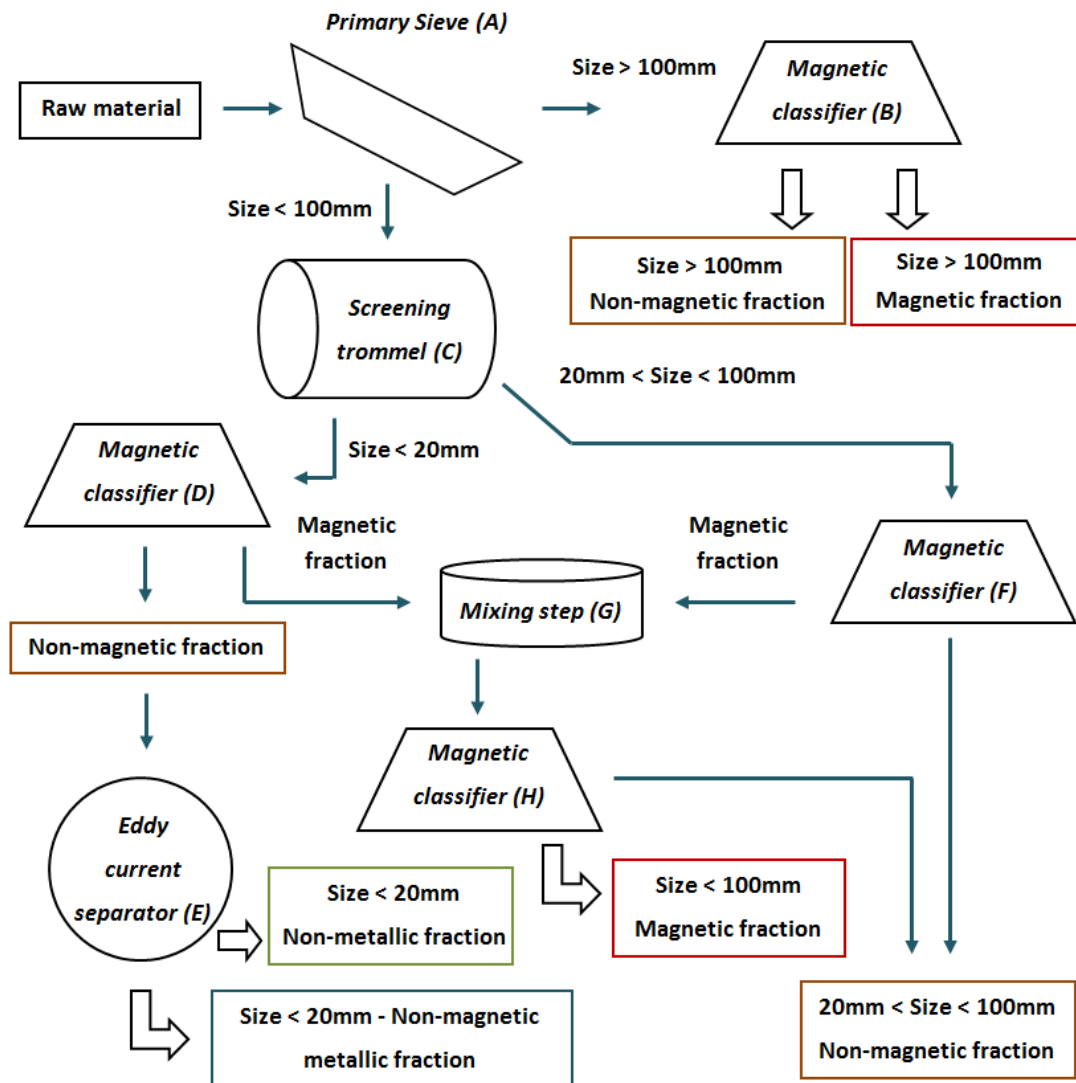


Figure 22: Scheme of the process used by IPALLE to purify ashes.

Source: IPALLE (Belgium)

### 3.15.4 Additional comments

This plant is used to separate the different fractions in clinker. It allows separating magnetic and non-magnetic elements but does not consider macronutrients (phosphorus, nitrogen and potassium).

All those data were provided by the inter-municipal organization IPALLE (Belgium).

**3.15.5 Useful contact(s) for more information**

IPALLE (Belgium)

Email address: [laurent.dupont@ipalle.be](mailto:laurent.dupont@ipalle.be)

## **4 List of useful contacts**

### **BELGIUM**

#### **Ecowerf**

Aarschotsesteenweg 210, 3010 Kessel-Lo

Contact: see the website *www.ecowerf.be*

#### **DLV InnoVision ESV**

Rijkkelstraat 28, 3550 Heusden-Zolder

Contact: Lies Bamelis, *lies.bamelis@dlv-innovision.be*

#### **Gembloux Agro-Bio Tech – University of Liège**

Passage des Déportés 2, 5030 Gembloux

Contacts: Frank Delvigne, *f.delvigne@ulg.ac.be* ; Cédric Tarayre, *cedric.tarayre@ulg.ac.be*

#### **Intercommunale du Brabant Wallon (IBW)**

Rue de la Religion 10, 1400 Nivelles

Contacts: Vincent Gooris, *vgooris@ibw.be* ; François Dedoyard, *fdedoyard@ibw.be*

### **IPALLE**

Centre de valorisation des déchets de Thumaide

Rue de Ribonfosse 9, 7971 Thumaide

Contact: Laurent Dupont, *laurent.dupont@ipalle.be*

**NuReSys**

Roosevelttlaan 108/1, 8790 Waregem

Contact: Carl Dewaele, cd@nuresys.be

**Société publique de la Gestion de l'Eau (SPGE)**

Avenue de Stassart(NR) 15, 5000 Namur

Contact: Christian Didy, Christian.DIDY@spge.be

**University of Ghent, Faculty of Bioscience Engineering**

Coupure Links 653, 9000 Gent

Contacts: Erik Meers, Erik.Meers@UGent.be ; Evi Michels, Evi.Michels@UGent.be

**Vlaamse Compostorganisatie (VLACO)**

Stationsstraat 110, 2800 Mechelen

Contacts: Elke Vandaele, elke.vandaele@vlaco.be ; Wim Vanden Auweele, wim.vanden.auweele@vlaco.be

**FRANCE**

**Sydeme-Méthavalor**

Rue Jacques Callot 1, 57600 Morsbach

Contact: see the website [www.sydeme.fr/site/equip\\_methanisation1.php](http://www.sydeme.fr/site/equip_methanisation1.php)

**THE NETHERLANDS**

**Nijhuis Water Technology**

Innovatieweg 4, 7007 CD Doetinchem

Contact: Frank Delgorge, f.delgorge@nijhuis-water.com

**UNITED KINGDOM**

**LondonWaste EcoPark**

Advent Way, N18 3 AG London

Contact: [recycling@londonwaste.co.uk](mailto:recycling@londonwaste.co.uk)

**Severn Trent Water Ltd**

PO Box 5310, CV3 9FJ Coventry

Contact: see the website [www.stwater.co.uk](http://www.stwater.co.uk)

**South East London Combined Heat and Power**

SELCHP Energy Recovery Facility, Landmann Way Off Surrey Canal Road, SE14 5RS London

Contact: see the website [www.selchp.com](http://www.selchp.com)

**Thames Water**

Clearwater Court, Vastern Road, Reading, RG1 8DB West Berkshire

Contact: see the website [www.thameswater.co.uk](http://www.thameswater.co.uk)

**University of Leeds**

Faculty of Engineering, LS2 9JT Leeds

Contacts: Miller A. Camargo-Valero, [M.A.Camargo-Valero@leeds.ac.uk](mailto:M.A.Camargo-Valero@leeds.ac.uk) ; Andrew B. Ross, [A.B.Ross@leeds.ac.uk](mailto:A.B.Ross@leeds.ac.uk)

**EUROPE**

**European Sustainable Phosphorus Platform (ESPP)**

Contact: [info@phosphorusplatform.eu](mailto:info@phosphorusplatform.eu)

## 5 Bibliography

- Abu-Orf, M., Stinson, B., Davies, G., Goss, T., Marija, P., Amad, S., Taylor, R., Belschner, D., Hartz, F. & Hentz, L. (2011). Energy Recovery from Residuals ; Comparing Anaerobic Digestion with Combined Heat and Power to Drying Gasification. *Proceedings of the Water Environment Federation 2011* : 550-572.
- Adam, C., Eicher, N., Hermann, L., Herzel, H., Mallon, J., Schaaf, M., Stemann, J. (2015). Comparative review of ash processes.
- Akinola, O. (2013). Overview of Phosphorus Recovery and Recycling From Selected Waste Streams - Protecting Phosphorus as a Resource. MSc, Imperial College London.
- Britton, A., Koch, F. A., Mavinic, D. S., Adnan, A., Oldham, W. K. & Udala, B. (2005). Pilot-scale struvite recovery from anaerobic digester supernatant at an enhanced biological phosphorus removal wastewater treatment plant. *Journal of environmental engineering and science* 4 : 265-277.
- Clearfleau Ltd, (2013). Nestlé: Anaerobic Treatment and Energy Generation.
- Clearfleau Ltd, (2015). Sweet success for Nestle's on-site anaerobic digestion plant.
- Cooper, J. & Carliell-Marquet, C. (2013). A substance flow analysis of phosphorus in the UK food production and consumption system. *Resources, Conservation and Recycling* 74 : 82-100.
- Cordell, D., Drangert, J.-O. & White, S. (2009). The story of phosphorus: global food security and food for thought. *Global environmental change* 19 : 292-305.
- Cornel, P., Schaum, C. (2009). Phosphorus recovery from wastewater: needs, technologies and costs. *Water Sci. Technol.* 59 : 1069–1076.
- DEFRA, (2011). Anaerobic digestion strategy and action plan. In: Department for Environment, Food and Rural Affairs (ed.). London, UK: Department for Environment, Food & Rural Affairs.
- Desmidt, E., Ghyselbrecht, K., Zhang, Y., Pinoy, L., Van der Bruggen, B., Verstraete, W., Meesschaert, B. (2015). Global phosphorus scarcity and full-scale P-recovery techniques-a review. *Crit. Rev. Environ. Sci. Technol.* 45 : 336–384.
- Di Iaconi, C., Pagano, M., Ramadori, R., Lopez, A. (2010). Nitrogen recovery from a stabilized municipal landfill leachate. *BioResource Technology* 101 (2010): 1732-1736.
- DIRKSE, E. (2015). Biogas upgrading using the DMT Carborex® PWS Technology.
- Driessen, W. (2009). Sustainable Treatment of Reject Water and Industrial Effluent by Producing Valuable Products. 14th European Biosolids and Organic Resources, 9-11 September 2009, Leeds, UK. AquaEnviro.
- Driessen, W. & Reitsma, G. (2014). One-Step ANAMMOX Process [Online]. UK Water Projects Online. Available at [http://www.waterprojectsonline.com/case\\_studies/Technologies/anammox\\_I&T.pdf](http://www.waterprojectsonline.com/case_studies/Technologies/anammox_I&T.pdf).

Driessen, W. (2014). PHOSPAQ<sup>®</sup>™ Process - Recovery of phosphorus by formation of struvite [Online]. UK Water Projects Online. Available at [http://www.waterprojectsonline.com/case\\_studies/Technologies/PHOSPAQ<sup>®</sup>\\_I&T.pdf](http://www.waterprojectsonline.com/case_studies/Technologies/PHOSPAQ<sup>®</sup>_I&T.pdf).

Durose, N. & Jeffcoat, T. (2014). Stoke Bardolph STW Centrate Scheme- first UK installation to utilise the Phospaq, UASB+ and Anammox technologies in a single process solution [Online]. UK Water Projects Online.

EcoWerf, year not specified. EcoWerf Afvalverwerking. Online <http://www.ecowerf.be/nl/getpage.asp?i=9#5>.

Environment Agency, (2012). Review of best practice in treatment and reuse/recycling of phosphorus at Wastewater Treatment Works. In: Environmental Agency (ed.). Bristol, UK.

Ewert, W., Hermanussen, O., Kabbe, C., Mèlè, C., Niewersch, C., Paillard, H., Stössel, E., Wagenbach, A., Stemann, J. (2014). Description of sludge related processes.

Gueterbock, R. (2014a). The benefits of on-site AD (with Nestle Fawdon AD plant case study). In: ASSOCIATION, A. D. A. B., ed. UK AD & Biogas 2014 Conference, Birmingham, England. Anaerobic Digestion and Bioresources Association.

Gueterbock, R. (2014b). Smaller Scale, On-site Anaerobic Digestion – For Food & Beverage Sectors. In: ALL-ENERGY, ed. All-Energy Conference, Glasgow, Scotland. All-Energy.

Hadden, D. (2009). Severn Trent First in Europe to Recycle Nutrients into “Environmentally Friendly” Commercial Fertilizer [Online]. VANCOUVER, CANADA: OSTARA<sup>®</sup> Nutrient Recovery Technologies Inc. Available at <http://www.OSTARA<sup>®</sup>.com/news/news-releases/2009/severn-trent-first-europe-recycle-nutrients-%E2%80%9Cenvironmentally-friendly%E2%80%9D-comme>.

Kepp, U., Machenbach, I., Weisz, N. & Solheim, O. (2000). Enhanced stabilisation of sewage sludge through thermalhydrolysis-three years of experience with full scale plant. *Water Science & Technology*, 42 : 89-96.

Kim, D., Ryu, H., Kim, M., Kim, J., Lee, S. (2007). Enhancing struvite precipitation potential for ammonia nitrogen removal in municipal landfill leachate. *J. Hazard. Mater.* 146 : 81–85.

Langerak, J., Lems, R., Giménez Dominguez P., Dirkse, E.H.M. (2013). Biogas upgrading: Membrane separation take over. The success story of Poundbury continues. Available at [http://www.dirkse-milieutechniek.com/dmt/do/download/\\_/true/212310/Poundbury\\_Article\\_for\\_Manchester\\_V2JL\\_30\\_10\\_2013\\_1.pdf](http://www.dirkse-milieutechniek.com/dmt/do/download/_/true/212310/Poundbury_Article_for_Manchester_V2JL_30_10_2013_1.pdf).

Lems, R., Dirkse, E.H.M. (2010). Small scale biogas upgrading: Green gas with the DMT Carborex<sup>®</sup> MS system. 15th European Biosolids and Organic Resources Conference, Leeds, UK. AquaEnviro.

Lermen, A. (2013). Best practice example of an existing bio-methane gas grid injection plan. In: GRIDS, G. G. (ed.).



Li, X.Z., Zhao, Q.L. (2001). Efficiency of biological treatment affected by high strength of ammonium-nitrogen in leachate and chemical precipitation of ammonium-nitrogen as pretreatment. *Chemosphere* 44 : 37–43.

LondonWaste, year not specified. LondonWaste. Online <http://www.londonwaste.co.uk/>.

Moerman, W., Carballa, M., Vandekerckhove, A., Derycke, D., Verstraete, W. (2009). Phosphate removal in agro-industry: Pilot- and full-scale operational considerations of struvite crystallization. *Water Res.* 43 : 1887–1892.

Morgenschweis, C. (2011). The Pearl® technology [Online]. Available at <http://grontmij.com/highlights/water-and-energy/Documents/The-Pearl-Technology.pdf>.

NuReSys, (2015). The Technology [WWW Document]. Available at [http://nuresys.be.apache22.hostbasket.com/?page\\_id=11](http://nuresys.be.apache22.hostbasket.com/?page_id=11).

Ofwat, (2005). Water Framework Directive – Economic Analysis of Water Industry Costs In: Ofwat (Water Services Regulation Authority) (ed.). England: Ofwat - The Water Services Regulation Authority.

Oloibiri, V.A. (2013). Ozonation of biologically treated landfill leachate. Ghent University.

OSTARA®, (2013). UK's First Commercial Nutrient Recovery Facility. Thames Water's Slough Sewage Treatment Works [Online]. Slough, UK: OSTARA®. Available at [http://www.OSTARA.com/sites/default/files/pdfs/OSTARA-THAMES\\_case\\_study.pdf](http://www.OSTARA.com/sites/default/files/pdfs/OSTARA-THAMES_case_study.pdf).

OSTARA®, (2014). Pearl® 2000 Nutrient Recovery Process [Online]. Available at [http://www.ostara.com/sites/default/files/pdfs/E-Pearl2000\\_brochure.pdf](http://www.ostara.com/sites/default/files/pdfs/E-Pearl2000_brochure.pdf).

Panter, K. (2001). Getting the Bugs Out of Digestion and Dewatering with Thermal Hydrolysis. *Proceedings of the Water Environment Federation* 2001 : 54-64.

P-REX, (2015). Pearl Struvite crystallisation in sludge liquor [Online]. P-REX Project - Practical implementation of phosphorus recovery and recycling from wastewater stream in Europe. Available at [http://p-rex.eu/uploads/media/PREX\\_Factsheet\\_PEARL.pdf](http://p-rex.eu/uploads/media/PREX_Factsheet_PEARL.pdf).

Remy, M. (2014). Integrated Solution for Nutrient Removal. LIFT Phosphorus Recovery Focus Group Meeting. Portland, Oregon.

Ross, D., Shrive, C., Chauvin, D., Harnum, J. & Constantine, T. (2010). The Power of Sludge Maximizing Energy Recovery at the Woodward Avenue WWTP in Hamilton, Ontario. *Proceedings of the Water Environment Federation* 2010 : 1141-1149.

Sartorius, C., Horn, J. Von, Tettenborn, F. (2012). Phosphorus Recovery from Wastewater—Expert Survey on Present Use and Future Potential. *Water Environ. Res.* 84 : 313–322.

Schoumans, O.F., Bouraoui, F., Kabbe, C., Oenema, O., van Dijk, K.C. (2015). Phosphorus management in Europe in a changing world. *Ambio* 44 : 180–192.

## Techniques for nutrient recovery from household and industrial wastes

SELCHP, year not specified. Virtual Tour. Online <http://www.selchp.co.uk/about-selchp/virtual-tour/>.

Tillier, R. (2013). Oxford STW Bio Thelys® thermal hydrolysis plant provides green energy from sewage sludge [Online]. UK Water Projects 2013. Available at [http://www.waterprojectsonline.com/case\\_studies/2013/Thames\\_Oxford\\_2013.pdf](http://www.waterprojectsonline.com/case_studies/2013/Thames_Oxford_2013.pdf).

Vlaco vzw, (2015). Vlaco vzw: Professionele verwerking. Online [www.vlaco.be](http://www.vlaco.be).

Vale, P. (2013). Phosphorus Recovery from Wastewater. END-O-SLUDG Conference. Sludge and Phosphorus Management in Europe: Present and Future., London.

Wentworth, J. (2014). Phosphate Resources. In: Parliamentary Office of Science and Technology (ed.). The Parliamentary Office of Science and Technology.

Wild, R. (2014). Full Scale Phosphorus Recovery in Severn Trent Water. A UK Nutrient Platform? Leeds, UK.