



## **BIOREFINE**

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

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

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## 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

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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

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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 environmental damage and losses in nutrients. An advanced system of domestic waste collection, sorting and recycling has been applied for years in most European countries, leading to a gradual shift to sustainable resource management. Furthermore, industry is making efforts to gain a green image and invest in recycling and recovery techniques.

The Interreg IVB project BioRefine aims at facilitating the shift to a circular, bio-based economy in North Western Europe by using an action-oriented approach consisting in providing applied technological solutions for improved recycling and recovering 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 to solids and liquids of 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**

The vegetable, fruit and garden (VFG) waste left over by 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 collected selectively and used for the production of heat and electricity through anaerobic digestion. From an energetic point of view, this is the most effective route, since both energy as heat and electricity and a valuable residual product, digestate, are developed. Digestate can be composted and results in a sufficiently hygienized product. In Flanders, the quality of the compost obtained is certified by the Flemish Composting Organization (Vlaco vzw), which means that quality is ensured and so, 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 effective composting. 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 inside 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 an incomplete oxidation of the carbon compounds, causing the formation of fatty acids and other organic acids. This pH decrease causes the process to slow down. By turning over the pile and if necessary moisturizing it, more oxygen is brought into the system and the water content is optimized, causing decomposition. A major advantage of high temperature in combination with high moisture content is that weed seeds lose their germinating power. In this way, a 'hygienized' product is obtained. In general, the composting of green waste takes place in open air, while the composting of vegetable, fruit and garden waste takes place in an enclosed space (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 mixing process of organic and mineral compounds. Depending on the process, the post-ripening phase lasts from 3 weeks to 3 months. The last phase, called post-treatment, includes the refinement of the compost, which consists in sifting unusable parts and splitting the compost into different granulometric fractions depending on the end-use. In practice, this is done 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 monitored with great accuracy. 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 ensure 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 are those which have 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.

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- The smallest particles (size of about and less than 1 mm) are the actual compost. At this stage, the compost is not ready for use, 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 developed a separate collection strategy, so there is no direct interference with other (non-organic) household wastes at this stage.

The presence of the VGF-biomass during this storage step is rather limited in time: in order to obtain an optimal composting process and 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 transportation between the different treatment steps.



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### *Rotating sieve (B)*

The sieve in the pre-treatment stage will do a first screening of the particles based on their size. A mesh-size of around 16 mm is usually used. 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 in 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 moving 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 cling to. An increase of the surface-volume ratio is obtained by crushing the bigger particles at the inlet.

### *Wooden branches remover (E)*

This is a claw-shaped device that removes the branches that fell through the sieve from the biomass. The wood that is recovered here can be chopped and used as structure material in the composting unit or to fill the bio-filters for the odour treatment.

### *Composting (F)*

Dependent on the type of biomass that is composted, one can decide between open-air composting and indoor composting. In the VGF's composting applications, only indoor composting is in use.

There are different ways to actually implement indoor composting, but the 2 most popular ones are done either in big halls or in tunnels. EcoWerf's choice fell on indoor composting. The biomass will remain for about 5 weeks in the "composting zone" in which it is turned around on a weekly basis so as to allow "passive" aeration.

In order to obtain a highly effective bacterial activity, it is essential to use optimal process parameters: the right moisture content, oxygen level and temperature are of the utmost importance. In order to keep the moisture content at a high level, fluid is sprayed over the composting material – this can be fresh water, but whenever it is 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 greatly impacts the temperature of the composting biomass, the type of ventilation will depend on the temperature: if the biomass temperature is too

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high, outside air will be ventilated through the composting hall. If it is too low, the inside air will be recirculated and used for aeration.

The air inside the composting hall has about 45°C and relative moisture of 100%. During the process, there will/can be an accumulation of odour in the air, which makes it necessary for it to be treated before being discharged to the open air. This is done by a bio-filter system 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 the separation of the actual compost from the inoculation material. All particles exceeding 10 to 15 mm in diameter are seen 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 will be mixed together with the fresh incoming compost.

The smaller particles (< 10 to 15 mm) are considered to be actual compost, and will go through a maturation phase in order to ensure the stability of the material.

### *Maturation (J)*

The final step of the composting process is the maturation phase, which lasts about 5 weeks. Here, the composting process slowly goes on in the most resistant parts of the biomass. This can be done either indoors or outdoors, though it is more common for it to be done in a covered area. The necessity of turning over the material remains for the sake of aeration. Some additional aeration and moistening might even be required to ensure 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: EcoWurf

### 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/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 further 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 is very similar 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 tons of waste per year (385,000 inhabitants). About 32,000 tons of that waste consist of VGF waste disposed of by the inhabitants of surrounding regions, 5,000 tons of organic waste come from restaurants and similar businesses and the remaining 5,000 tons are green wastes. In the installation, 1 ton of VGF is converted to 100 m<sup>3</sup> of biogas (which corresponds to 70 litres of gasoil) and 200 kg compost.

#### *“Multiflux” sorting*

The collection of the waste is slightly different from the traditional collection process: inhabitants have to put their wastes in plastic bags of different colours. Green bags are meant for biological waste (VGF), orange bags are for plastics and metals and blue bags are for all other types of domestic wastes. All these bags are collected simultaneously, which contributes to reducing collection expenses, since waste is collected only once instead of 3 times.

When all the bags are delivered to the site, they are sorted optically and directed to the sites they are meant for: the green bags are sent to the biomethane recovering unit, the orange bags are sent to “recyclable waste” stock (recycling is done on 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 other waste, the preparation of the bio-waste for use in the biogas production starts. As mentioned 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 contents are spread on a moving sieve, while the plastic bags are removed by a wind-shifter. This way all the bags are collected and can be collected. All the material that gets through the sieve will be directed straight to the intermediate storage unit. The material that is oversized will first go through a shredder. The materials are also removed by magnets located above the conveyor belts.

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- *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 unit.

- *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 go through the process, in which the different flows and the recycled flow from the digestate will be mixed together.

### *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 into biogas in the digesters, it is important to obtain a feeding mix that meets the process requirements of the digester. To have an optimal biogas production, several conditions must be fulfilled:

- The incoming biomass (and consequently also the content of the digester) must show an optimal dry matter (DM) content. This is essential in order to ensure a good mixing and dynamics within the digester. As this is a “dry digester” type, it can take a higher DM content, which means that some problems might come up if the material is too dry.
- There must be some inoculation of the “fresh” biomass with a recycle-flow coming from the digester. This contributes to 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 (= recycled flow) which ensures 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 in order to lower the DM content. If there is too little liquid waste to obtain a good DM-content, it is possible to add some fresh water.

From this point, the mixture (= fresh input material + water + recycled flow) is directed to 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 digester, which has the advantage of being able to operate with a higher DM-content: digestate of 25 to 35 % DM against up to 15 % DM in a “wet digester”. The need to add water is therefore limited in this system.

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At Méthavalor, there are 3 parallel horizontal digesters. Each digester treats about 15,000 ton/year. Multi-line work provides optimal flexibility and capacity throughout the year.

Within the digester, the biomass is converted into biogas through the anaerobic process. On average, a biogas production of 110 to 120 Nm<sup>3</sup> per ton of VGF material is achieved. There are seasonal variations in the biogas-production: in winter, the material coming from households does not contain garden waste, which generates a higher biogas production. In summer, a bigger fraction of the incoming VGF is composed of garden waste (grass, weeds, 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 recovering.

### *Digestate treatment*

The raw digestate coming from the digester is processed in order to separate the liquid from the thick fraction. This is done by using a 2-step separation system. Digestate first goes through 3 screw presses working in parallel. The second step consists in having 2 centrifuges 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 either in bulk or in small bags.

### *Biogas valorisation*

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

#### *- Cogeneration*

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 directed to the grid. The heat produced by this cogeneration unit (about 2 MWth) is used to heat the digesters. It can also contribute to heating other applications either on the site or elsewhere. One Nm<sup>3</sup> of biogas corresponds to about 2.4 kWe and 2.8 kWth when burnt in a cogeneration unit.

#### *- Biomethanisation*

The part of the biogas that is not burnt in the cogeneration unit will be “upgraded” to a level similar to the one 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 by 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 can smell the gas in case of accidental release into the air. On the Méthavalor site, 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 in the digesters.

### 3.2.2 Unit operations

#### *“Multiflux” sorting (A)*

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

#### *Bag Opener (B)*

All the organic waste coming from households is delivered in plastic bags which are taken to the ripper head on conveyor belts. The ripper head consists of ripper tines. The ripper head (rotor) holding the tines rotates in the opposite direction to the flow of material.

#### *Plastic Removal (C)*

Plastic (from the bags and similar objects) is removed by a wind-shifter.

#### *Sieve (D)*

As with the standard composting process, the particles that go into the system have to be small enough to ensure 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 less than 16 mm. All the particles that fall through the sieve go straight to the intermediate storage unit. The bigger parts go through the crusher. In this case, the sieving device is part of 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 subdivide into smaller particles that can be stored in the intermediate storage unit for further processing and bigger ones that will be sent to the crusher again.

*Intermediate storage (H)*

The intermediate storage unit is a place in which all incoming organic flows (except the liquid ones) can be kept until further treatment. Given the fast decomposition of the material, it is essential (e.g. for the biogas production) for the retention time in this intermediate storage phase to be 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 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 dry digesters (type Kompogas) are used. These reactors are all plug-flow digesters that work non-stop, which makes it more convenient to manage both the manpower involved and the downstream located biogas-recovering equipment. The retention time of the organic material varies from 14 to 20 days. A low-speed agitator prevents the sedimentation of dense media materials and will take the material to the exit of the digester. The temperature inside the digesters is 50 – 55 °C, which corresponds to thermophilic conditions. The advantages of this higher temperature (compared to the one measured in 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 is required.

*First separation (K)*

A first division of the digestate is done with 3 screw presses. In this process, about 25 – 40 % of the DM are removed from the digestate. The thick fraction is sent to composting whereas 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 and therefore a release of ammonia. This factor must be taken 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 phase the DM-removal effectiveness needs to be higher, 2 parallel centrifuges have been installed. The removal potential 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 the same way as in the stages described before. The fully matured compost is sold in bulk or in bags.

### *Cogeneration unit (N)*

Part of the biogas produced in the digester is transformed into heat and electricity in a cogeneration unit or in a combined heat and power plant (CHP unit). The total capacity of Méthavalor is 1.7 MWe. The heat produced is used to heat the digesters and other equipment or even buildings in the district. 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 of these exhaust gases at the outlet of the engine varies from 400 to 450 °C. About 20 – 25 % of the incoming energy is converted into heat. The lower temperature results from 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 is part of the cooling system, the cooling away of this heat is crucial for the smooth running of the CHP-engine. In case the heat is not consumed, 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 all over the plant – the remaining part is sent to the electricity grid. About 40-45 % of the energy generated by biogas is converted into electricity in the CHP-unit. Working with 2 CHP-engines (700 kWe and 1000 kWe) has the advantage that in case of maintenance of one of the devices, the other one can ensure enough 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 it contains. This is done by cooling, 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 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. In this process, a pressure of about 10 bar is required. The rise (in pressure) from 16 mbar to 10 bar is obtained with the help of a biogas compressor.

*Pressure Swing Adsorption (PSA) (R)*

Pressure Swing Adsorption (PSA) is a dry method used to separate gases thanks to physical properties. The raw biogas is compressed and fed into an adsorption column. In this column, CO<sub>2</sub> (carbon dioxide) is retained but methane (CH<sub>4</sub>) is not. If the column is saturated with CO<sub>2</sub>, the pressure is released and the CO<sub>2</sub> will be desorbed and led 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 alternately be closed and opened. The Méthavalor PSA-installation has a capacity of about 100 Nm<sup>3</sup>/h (input biogas flow).

*Filtration (S)*

Just before the biogas can be turned into engine fuel, a removal of all remaining impurities is necessary.

*Odourisation (T)*

Methane (CH<sub>4</sub>) as such is odourless and cannot be smelled by humans. Therefore, in order to prevent unnoticed accidental releases, the bio-methane can be made detectable thanks to odourising agents.

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

### 3.2.3 Process scheme

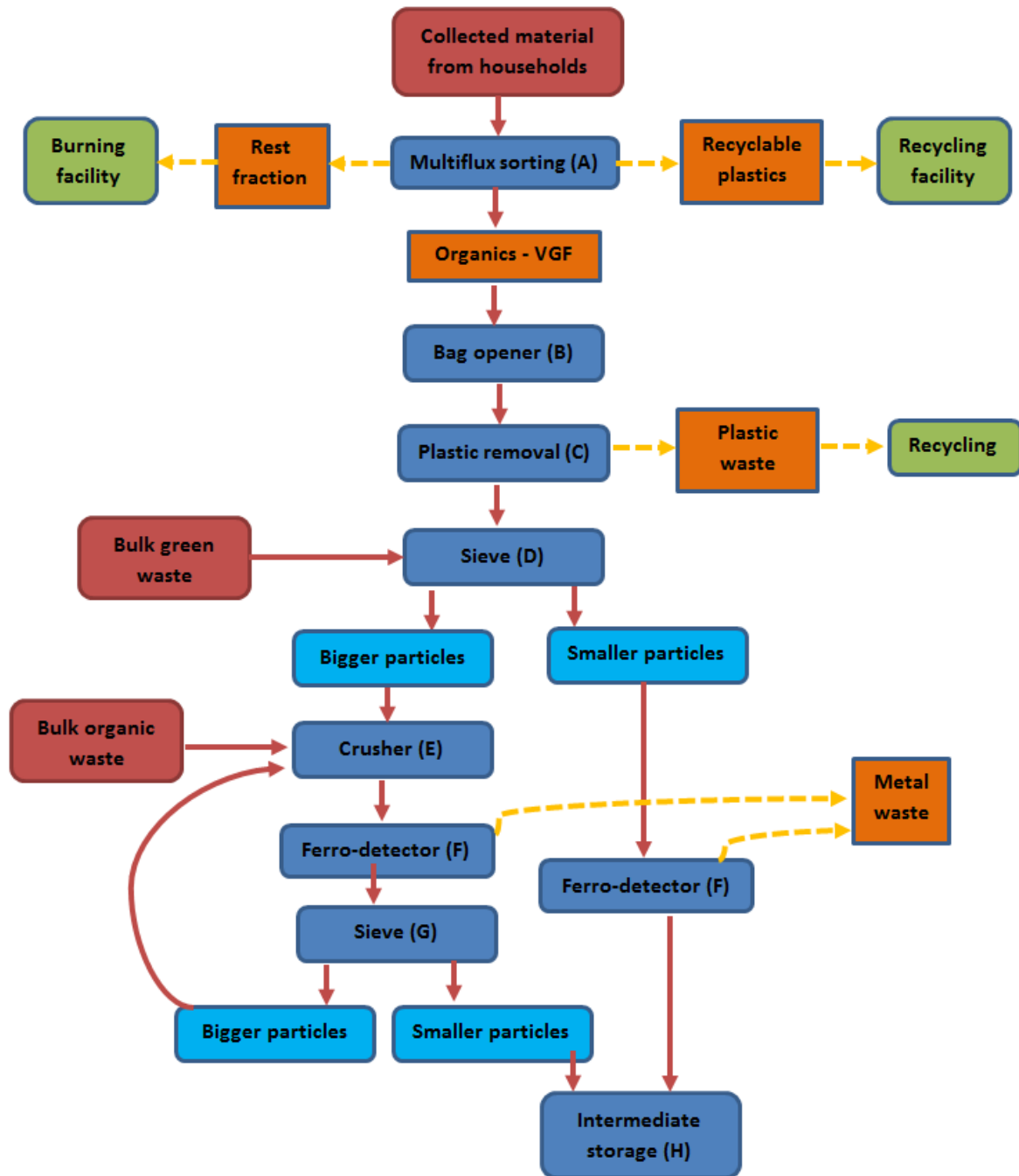


Figure 3: Process scheme of Méthavalor (part 1).

Source: Sydeme-Méthavalor

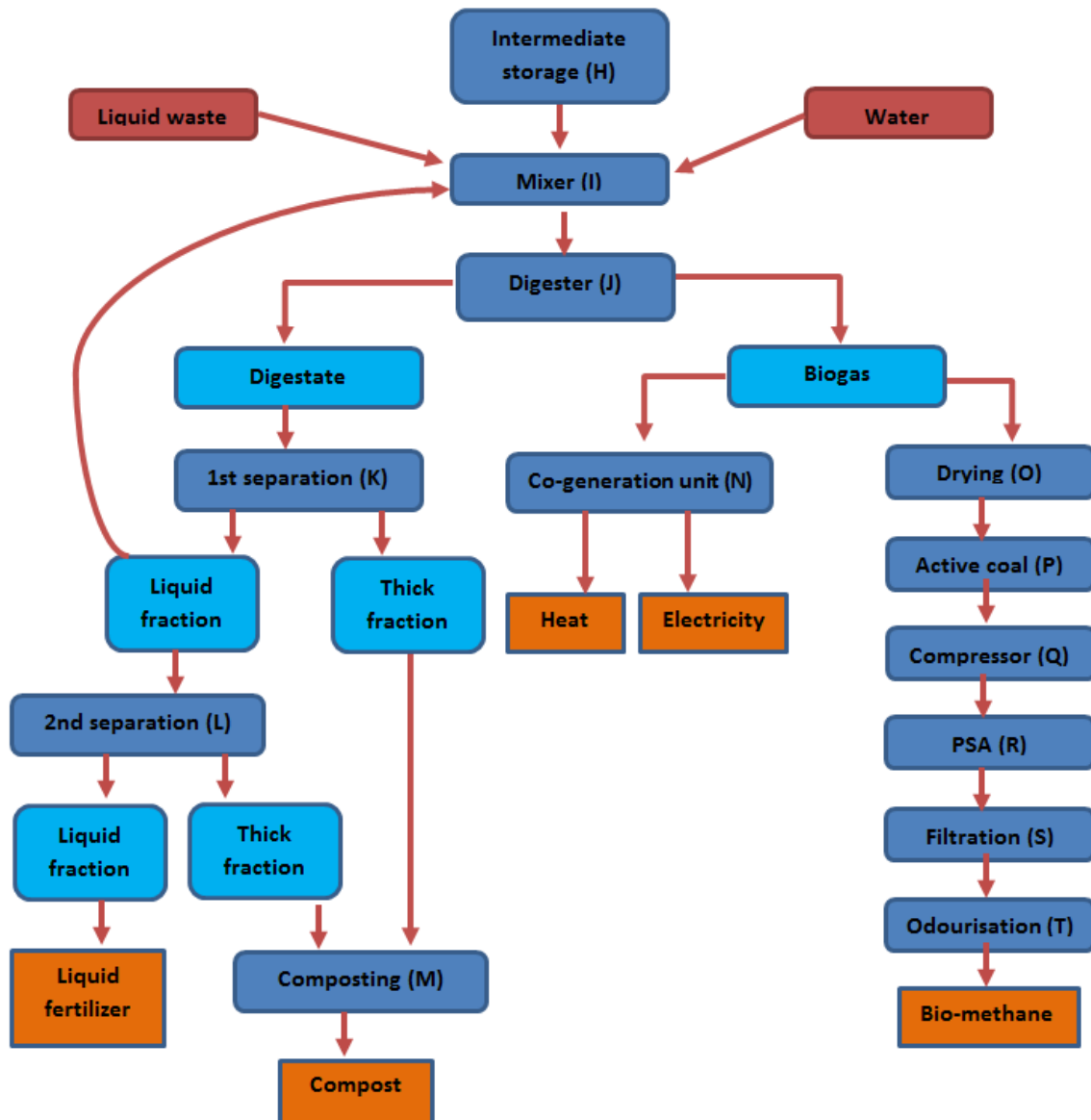


Figure 4: Process scheme of Méthavalor (part 2).

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 further information**

DLV Innovision (Belgium)

Email address: [lies.bamelis@dlv-innovision.be](mailto:lies.bamelis@dlv-innovision.be)

Sydeme-Méthavalor (France)

Email address: see 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 generating biomethane connected to Grid Plant in England was started at Rainbarrow farm, in Cornwall. The anaerobic digester at Rainbarrow farm is fed with maize, grass, potato waste, whey and small amounts of food waste (chocolate and muesli) from local factories. The plant uses around 41,000 tons of maize grass and potato waste from local farmers as well as organic waste (e.g. chicken manure) from local farms and factories such as Dorset Cereals and the House of Dorchester Chocolate Factory (Lermen, 2013).

About 850 standard cubic metres/hour ( $\text{Sm}^3/\text{h}$ ) of biogas production can be achieved in the Rainbarrow plant. The gas produced (with approximately 53 %  $\text{CH}_4$ ) is shared between the energy generator and the 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 to supply the installation and the rest is exported.

Up to 650  $\text{Sm}^3/\text{h}$  of biogas is led to the DMT Carborex® MS biogas upgrading plant, which cleans out the  $\text{CO}_2$  from the gas stream with a multistage system of membranes so as 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 biogas potential. At this stage, a specific gas odour is also added to the biomethane in order to match the 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. Moreover, the plant produces 8,000 tons/year of digestate which can be used as a fertiliser (Langerak, 2013).

### **3.3.2 Unit operations**

The Rainbarrow multi-stage system makes use of highly selective membranes making it possible to optimize methane production (98%  $\text{CH}_4$ ), reduce propane addition and obtain pure  $\text{CO}_2$  (>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 goes over 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. Since biogas usually contains small amounts of hydrogen sulphide, an oil-free compressor is needed. The compressed biogas is cooled with water obtained via a cooling system.

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

After the cooling phase, carbon dioxide and hydrogen sulphide are removed in a scrubber. The scrubber is designed for mass and heat transfer. The gases are absorbed together with the water at a low and constant temperature. The recirculation water is fed into the absorber at the top, while the biogas flows through the absorber in the opposite direction. They come into contact in the absorber and the carbon dioxide and hydrogen sulphide in the biogas are reduced. Carbon dioxide and hydrogen sulphide dissolve better than methane in water. Some methane will also be absorbed, but this can be recycled in the gas-freeing phases.

### *Gasses' removal from circulation water*

Used circulation water with dissolved gases goes through a flash vessel at a 2-bar pressure in order to reduce the methane losses. The water is partly degassed and the gas from the flash tank is recirculated to the inlet of the upgrading plant. The gas inside the multi-stage membrane system separates CO<sub>2</sub> from CH<sub>4</sub> thanks to different permeation rates. 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> goes through the various pressure stages for methane separation. In the meantime, the recirculation water coming from the absorber is recycled by freeing gas, while water pressure is reduced from 10 to 2-4 bar so as to release more gases. The gas recovered then goes through the pressure stages.
- The gas resulting from the lowest gas-freeing circuit with high concentration in CO<sub>2</sub> either goes through the pressure stages again or is used as industrial raw gas.
- The recirculation water coming from the methane recovery tower is sent into an air-stripping unit in order to release CO<sub>2</sub> and H<sub>2</sub>S. In the air-stripping tower, the air coming from outside is blown into a desorption tower where the recirculation water flows down the other way. Most of the CO<sub>2</sub> and H<sub>2</sub>S is 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) in order to reduce H<sub>2</sub>S contamination biologically. The BTF is a biological filter for the treatment of wastewater and air and consists of a cylindrical tank filled with

## Techniques for nutrient recovery from household and industrial wastes

plastic materials which act as biofilm carriers. The wastewater is fed into the filler at the top, whilst the air flows through the filter. Intensive mixing takes place in the filter and the contaminations in the air and water are reduced by the biofilm.

### *Biogas drying*

An absorption dryer is installed behind the water absorption column to extract water from the upgraded biogas. The dryer is self-regenerating and consists of two columns containing a drying agent. The post-absorption upgraded biogas is dried and polished prior to delivery to the gas grid by vessels filled with a drying agent and activated carbon. The drying vessels self-regenerate by guiding approx. 5-10 % of the dried gas through the regenerating column.

### *Biogas purification*

Before the dried gas is led into the column, it goes through a heat exchanger. The regeneration pressure is approximately 200 mbar, which means that the gas is quite fit to absorb the water in the drying agent. Granular Activated Carbon (GAC) vessels purify the upgraded biogas from H<sub>2</sub>S, siloxanes and traces of HC. In order to optimize the process, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>O and H<sub>2</sub>S are measured continuously. A programmable system controls the process according to the gas analyses results.

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



### 3.3.3 Process scheme

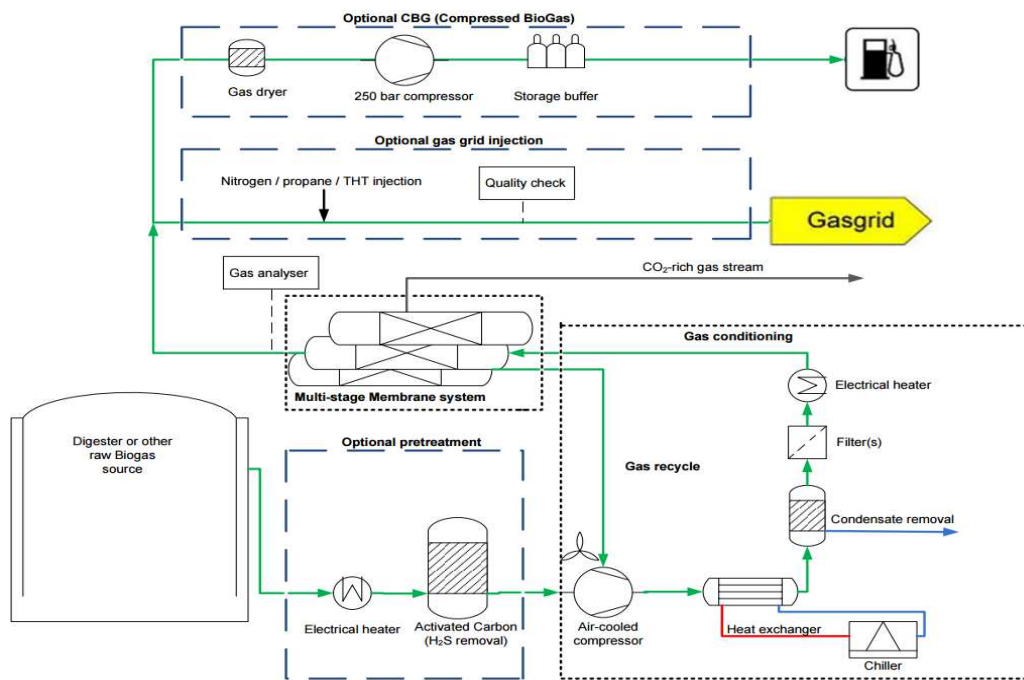


Figure 5: Process scheme of the DMT Carborex MS system.

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

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

University of Leeds (United Kingdom)

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## 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 aiming at reducing the carbon footprint from the factory, and was started in August 2013 with a production of 300 kWe.

The anaerobic digestion plant treats liquid effluents, 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 uses a wide range of techniques developed by Clearfleau (see **Erreur ! Source du renvoi introuvable.**), including several steps.

#### *Feedstock supply*

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

#### *Anaerobic Reactor*

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

#### *Biogas Handling*

The 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 AD plants produce renewable electricity from Combined Heat and Power (CHP) engines along with surplus heat. The electricity generated can be used on site (to replace bought-in power) or sold to the national power grid.

#### *Process Control*

In the middle of the plant, the control system includes simulation tools of all the key elements of the process linked to the site's supervisory control and data acquisition system.

The project is beginning to lower the site's CO<sub>2</sub> emissions and helping to control energy costs. It is part of an investment programme aiming at noticeably reducing its environmental footprint and enhancing sustainable production (Clearfleau, 2015; Gueterbock, 2014a; Gueterbock, 2014b; Clearfleau, 2013). The process scheme is shown in **Figure 6**.

### 3.4.3 Process scheme

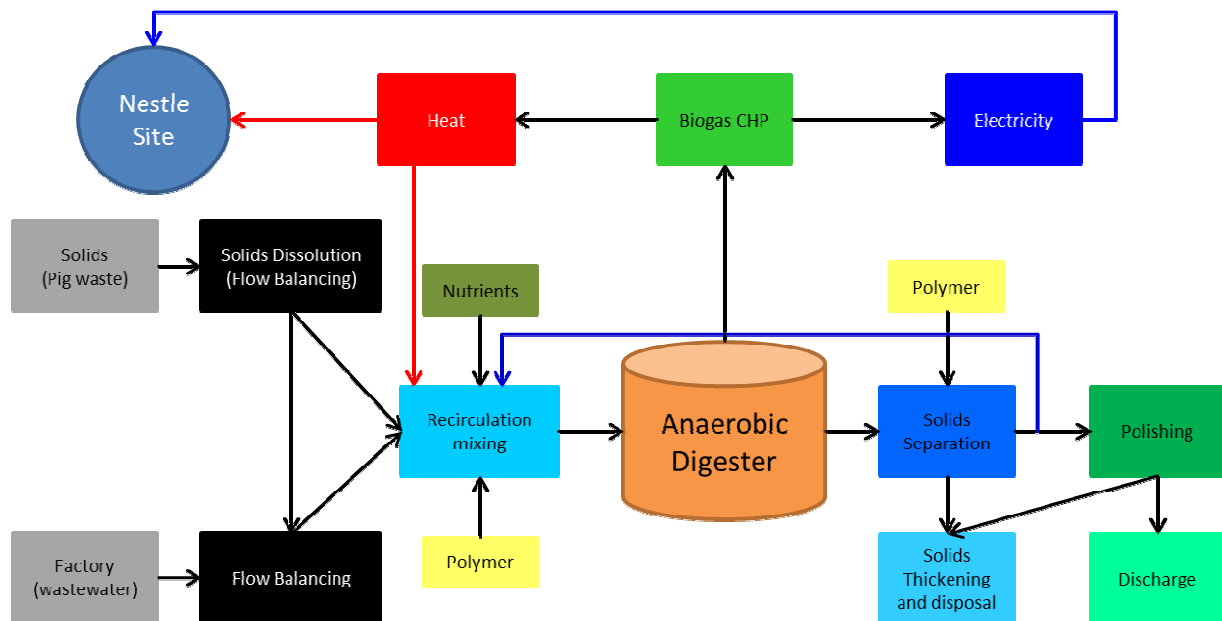


Figure 6: Nestlé's Fawdon Anaerobic Digestion Process.

Source: Gueterbock R., (2014 a)

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

University of Leeds (United Kingdom)

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## 3.5 Nutrient recovery from landfill leachate

Municipal landfill leachate results from the percolation of rainwater through solid waste and is seen as a wastewater type with one of the greatest environmental impacts because of high concentrations of ammonium, salts and organic matter. The conventional nitrification–denitrification is not very suitable for leachate treatment. 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) and precipitation (Oloibiri, 2013). The limitation of this way of recovering 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 subject to full-scale implementation.

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

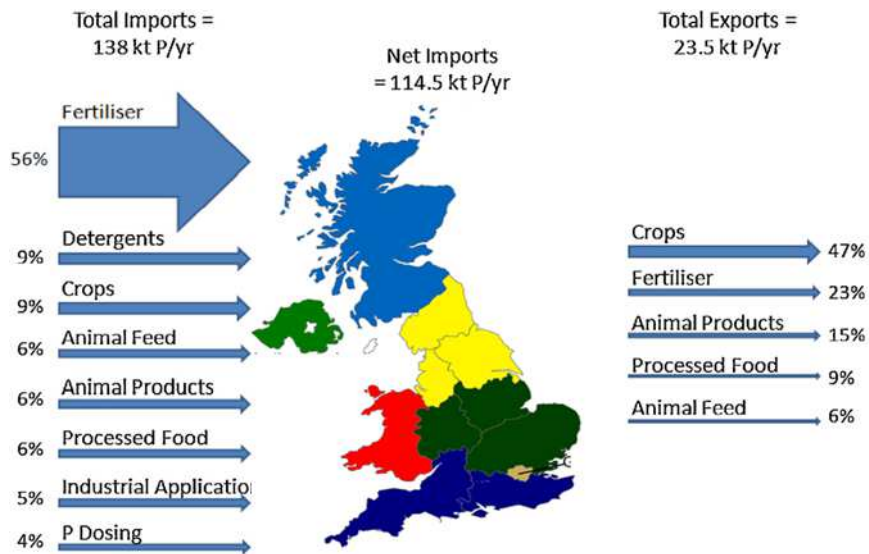
#### **3.6.1 Potentialities of sewage sludge in the United Kingdom: a case study**

Phosphorus (P) is a nutrient indispensable to the growth of plants and the production of food. Modern agriculture uses mineral fertilizers which are derived from phosphate rock and need to be applied regularly to stimulate production. Since phosphate rocks are non-renewable, there is growing concern over a 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 more and more in addition to being located in few countries (Morocco, China, USA and Western Sahara). The discharge of treated or untreated wastewater into bodies of water with high nitrogen and phosphorus concentrations has also caused eutrophication. Owing to this, it is necessary to recover P from waste streams and reuse it to various purposes.

Since the UK relies on imported phosphorus, it is crucial to optimize its use and find out ways of recovering it most effectively. **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



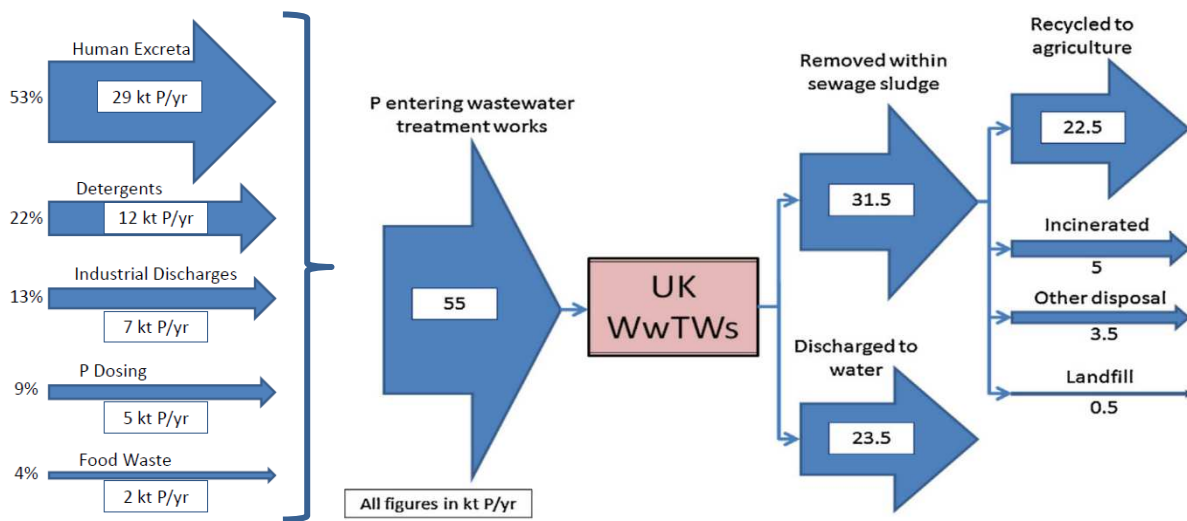
**Figure 7: Global overview of UK imports and exports.**

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

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

The dried solids resulting from the sewage sludge generated by the wastewater treatment contain P and N and are used in the UK agricultural process. These fertilisers have the advantage of releasing P more slowly than standard fertilizers and manures, which makes them more effective. Around 1 million of tons of dry solids are applied on land each year with the advantage of being inexpensive and more profitable for environment than incineration or landfill (Environment Agency, 2012).

Another way to remove P and N is the chemical addition of  $\text{FeCl}_3$ , a conventional and well-known technology widely used in the UK (95 % of the wastewater treatment plants in the UK use this method). The main disadvantages are that it needs other processes, e.g. tertiary filtration. The use of  $\text{FeCl}_3$  also involves a mix with the sludge, which could prove expensive due to the addition of the flocculating agent (cost estimated at £3.3 million/year for Wales). A last problem lies in the fact that P is considered a pollutant and not a resource (Environment Agency, 2012; Vale, 2013).



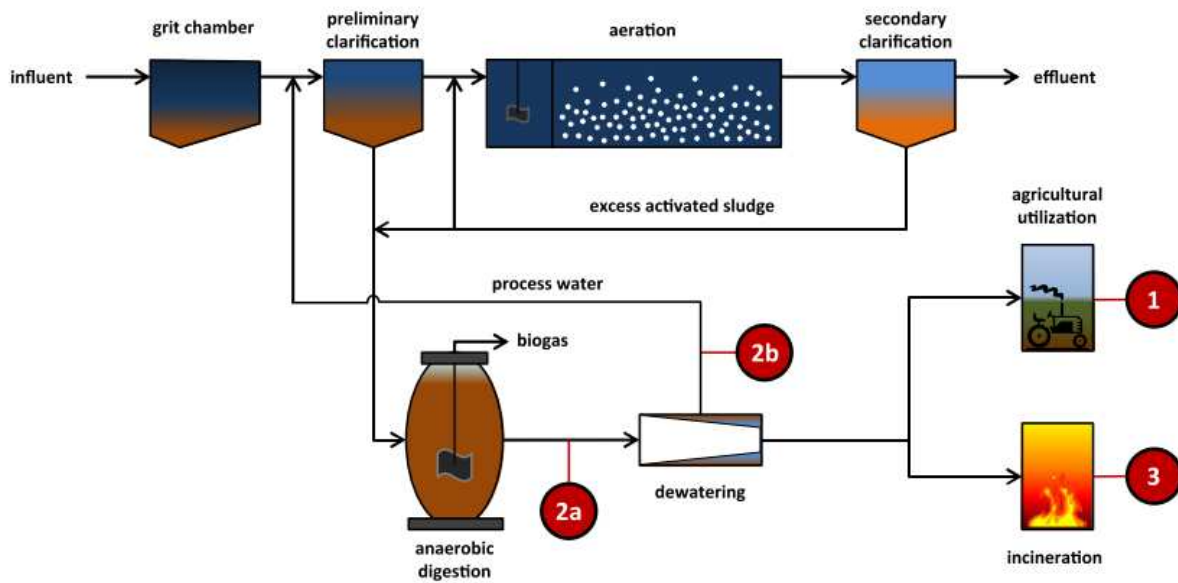
**Figure 8: Phosphorus flows through UK wastewater treatment plants.**

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

Phosphorus and Nitrogen recovery as struvite (magnesium ammonium phosphate) is a new trend in resources recovery from wastewater and involves the addition of  $MgCl_2$  at high pH for the production of struvite salts. Struvite recovery is only practicable at high P concentrations and with small water volumes. Profitability is only possible with plants exceeding 75,000 population equivalents (one population equivalent corresponds to a five-day biochemical oxygen demand ( $BOD_5$ ) of 60 g per day) and P concentrations higher than 75 mg/L. To reach these levels, Biological Nutrient Removal is advisable. 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 rising P concentration in UK rivers and pollution. It can also result in the production of struvite-type material which is rich in nutrients and can be sold as a fertiliser. It also contributes to lessening struvite-related damage to equipment. Besides, struvite has been classed as a product rather than waste by the UK regulations and consequently has a high market value (Ofwat, 2005).

### 3.6.2 Wastewater treatment plants as phosphorus sources

The 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, from 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 than in the liquor phase (<50-60 %) (Cornel and Schaum, 2009). However, most current 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 in 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 had been removed chemically with iron or aluminium salts, the phosphates would remain have remained bound 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), just like in 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. In a 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 used in agriculture as it is (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*

The phosphorus contained in sewage sludge ash can also be treated chemically or thermally. 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 availability of phosphorus for plants. 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 metal chlorides which vaporize and are captured during 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**

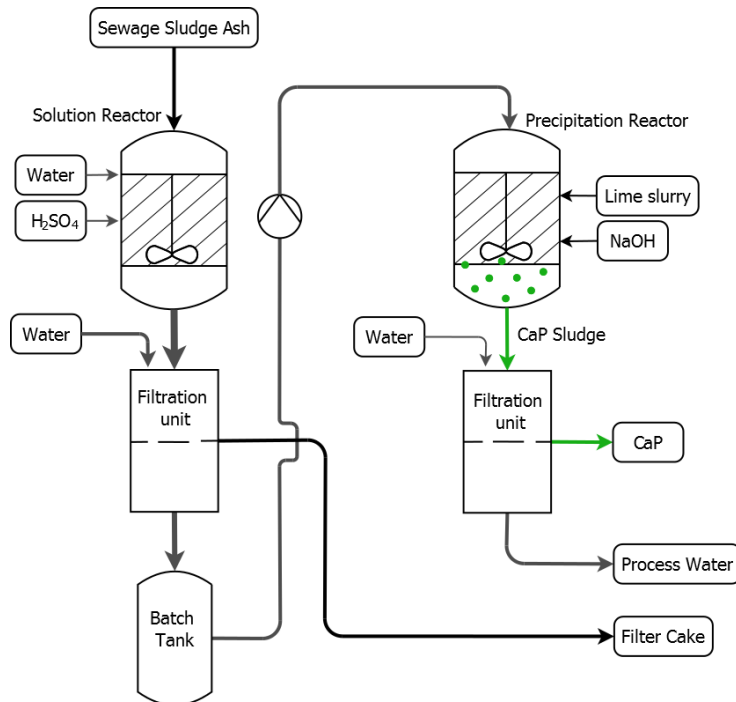
#### **3.7.1 General description - Leachphos process**

The Leachphos process as described by the P-REX project partners Adam et al. (2015) consists of two sequential steps: a leaching one and a precipitation one (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 of. 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 as well as aluminium phosphate. First results indicated that the P compounds are present in an amorphous form. Once the product has been purified, the liquid stream requires an additional treatment involving a pH increase (obtained by adding lime) and a sulphidic metal precipitation (obtained 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 removed almost completely. Afterwards, the pH is adjusted to 7 and the wastewater is discharged into a WWTP or a collecting water body.

### 3.7.2 Process scheme - Leachphos process



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

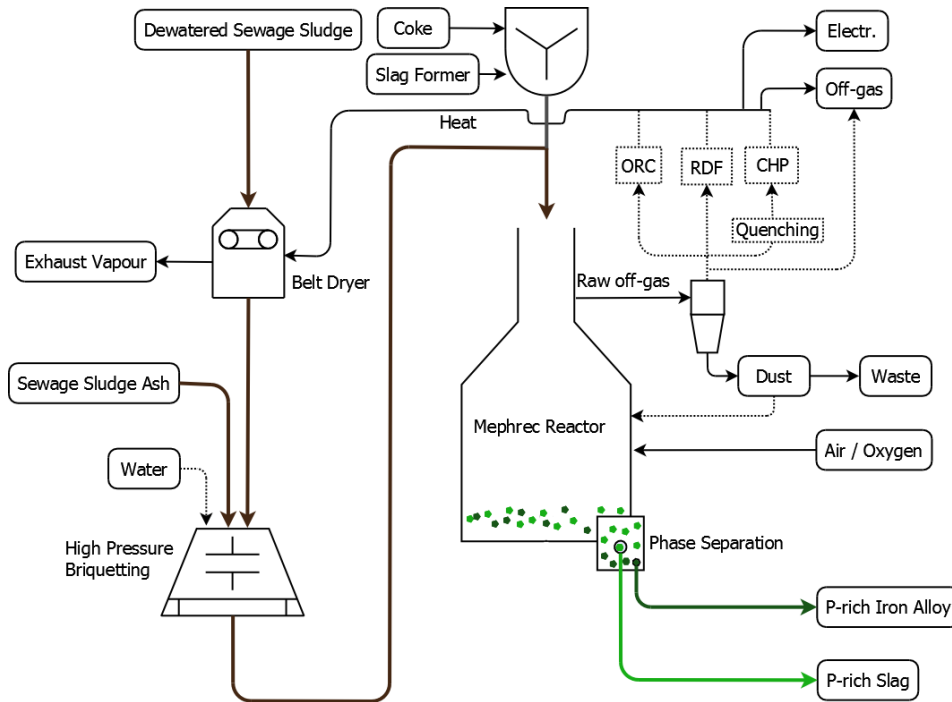
Source: Adam C. et al., (2015)

### 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, 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 weighed, mixed and added at the top of the Mephrec reactor by means of a bucket system. This implies that a quasi continuous 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 melt metal and the melt slag are separated by the action of gravity. The liquid metal melt is tapped discontinuously. The slag melt continuously flows out of the siphon straight into a water basin. Thanks to the scraper in the water basin, a uniform grain size is obtained. The process step aiming at transforming the P-rich slag into a marketable fertilizer includes granulation

and ideally the addition of other nutrients to produce complex fertilizers. The produced iron alloy is enriched with phosphorus and can 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 further 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 have started the construction of a full-scale P and N recovery plant in Stoke Bardolph, Nottingham (UK) - using the PHOSPAQ®™ process - 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 struvite produced 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 removed from the water phase, and are fit for agricultural use (fertilizer) (Driessen, 2014). Severn Trent Water has come to an agreement with a fertilizer producer who will blend the struvite with nitrogen to produce fertilizer with the required nutrient balance (Hadden, 2009).

The treatments used in wastewater treatment plants usually involve:

- A preliminary treatment - so as to remove grit and gravel as well as screen 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 get rid of 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*

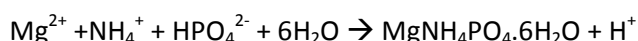
Severn Trent Water's Stoke Bardolph STW, Nottingham, UK use PHOSPAQ®, UASB<sup>+</sup> and ANAMMOX® techniques in a combined process. The sludge dewatering liquors are first treated in a phosphate removal reactor (PHOSPAQ®™), while the sludge stream is treated in a UASB<sup>+</sup> reactor for biogas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

The PHOSPAQ® process is used to recover phosphate from effluents such as struvite. Phosphate is becoming limited and PHOSPAQ® is considering a technology less expensive than the one consisting in dosing iron salts. Furthermore, the struvite obtained is an excellent fertilizer containing N, P and Mg (Durose and Jeffcoat, 2014).

In the BIOPAQ® UASB bioreactor, organic compounds are transformed into biogas by bacteria in anaerobic conditions. The main advantages of this process are the production of power-generating biogas, a high effectiveness in 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 offers several advantages such as low energy use, non-clogging of pipes 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).

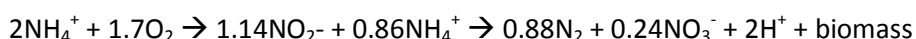
The PHOSPAQ®™ reactor works with a continuous aeration and stirring system with magnesium addition for the formation of struvite. The chemical reaction can be described as follows (**Equation 1**):



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

For the stimulation of struvite crystallization, pH must be raised to 8/8.5 by stripping the carbon dioxide (CO<sub>2</sub>) (≈ 90 Nm<sup>3</sup>/h; 60 kWh/d) and adding magnesium oxide (MgO, 125 kg MgO/d) in a 50 m<sup>3</sup> reactor (7 m in height, 3 m in diameter). The addition of MgO instead of MgCl<sub>2</sub> is preferred because it is more economical and helps to raise 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).

Furthermore, 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, the one-step ANAMMOX® reactor converts ammonium and nitrites by associating nitrification and the ANAMMOX® process linked bacteria without requiring an external carbon supply and a low oxygen consumption as shown in the equation below (**Equation 2**):



**Eq.2: Removal of ammonia and nitrite using the ANNAMOX® process**

A red granular biomass is generated owing to specific enzymes. The reactor is continuously aerated and can be controlled by measuring nitrite and ammonium.

The 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 in height, 3.5 m in diameter, with a load of 2.2 kg N/m<sup>3</sup>·d, 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 95 % phosphate recovery (73 kg/d) and 75 % ammonium removal rates.

### **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 then takes the wastewater to a sewage treatment plant.

##### *Screening (2)*

The first stage of wastewater treatment is the removal of large objects such as face wipes, sanitary items, rocks, plastics, etc. that may block or damage equipment, or be unsightly if allowed back into the catchment water surface. 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 on 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 out of 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 in the water. The products from the aerobic sewage treatment are carbon dioxide, water and nitrogen gas. The effluent flows out of the tanks to be directed to further settling tanks.

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

The treated wastewater is taken to a final settlement tank, where the bacteria sink to the bottom. The sludge on 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 out of the settlement tank for disposal, although additional treatment is sometimes needed before disposal.

##### *Polishing (6)*

To meet some standards relating to specific pollutants and the 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 treated wastewater depends on the legal constraints of the country concerned.

*Sludge thermal treatment (8)*

The sludge collected 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. The hydrothermal process is energy-effective, reaches high digestion levels and raises 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, the 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 a 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 straight into the national gas grid (Tillier, 2013).

*Anaerobic Digestion (AD) (9)*

After going through the hydrothermal process, the 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 to power engines for CHP, burnt to produce heat, or can be cleaned and used as natural gas or as a vehicle fuel. In addition to that, digestate can be used as a fertilizer or soil conditioner. AD is no new technology and has been widely used in the UK for the treatment of sewage sludge for over 100 years (DEFRA, 2011). Around 660,000 dry tons of separated, treated solids return to 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 the sake of stirring and aerating with CO<sub>2</sub>. CO<sub>2</sub> bubbling increases the pH to about 8.0-8.5.

*Magnesium addition (2)*

When pH is about 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 an internal separator especially designed for the retention of struvite crystals. The average size of the struvite crystals collected from the PHOSPAQ<sup>®</sup> reactors is 0.7 mm (Driessen, 2014). Big struvite crystals can settle and are collected 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 struvite crystallization.

### *Extraction (4)*

Struvite is extracted from the bottom of the reactor and then dewatered. It is dewatered by a belt-filter or a screw press down to 55 - 65 % dry struvite. During storage, the DM content increases to 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 in order to facilitate the conversion into 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 ensure a 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

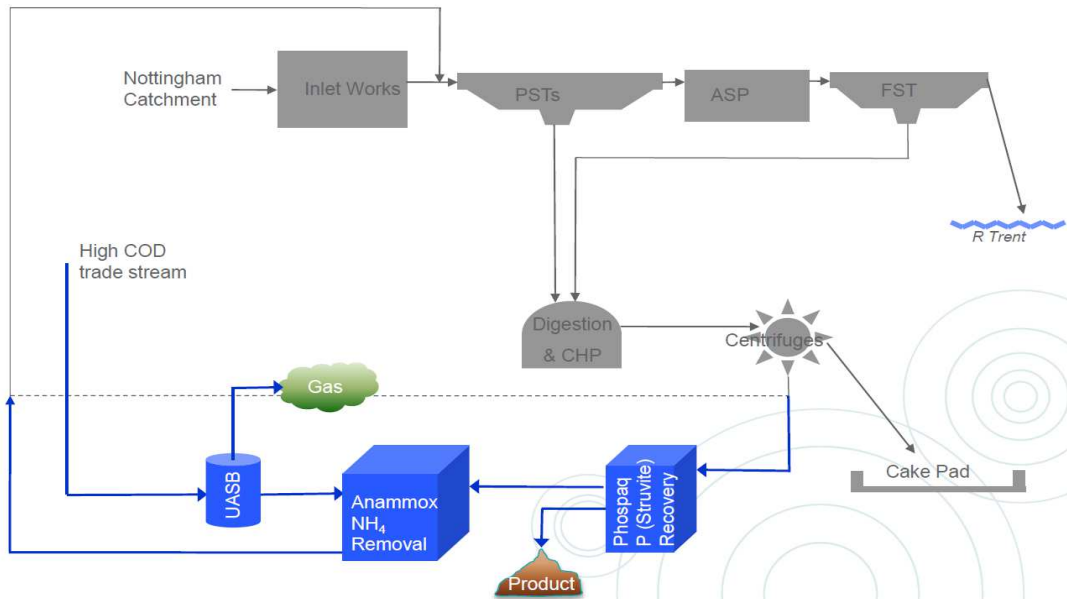


Figure 12: Full scale Phosphorus Recovery system used by Severn Trent Water.

Source: Wild R., (2014)

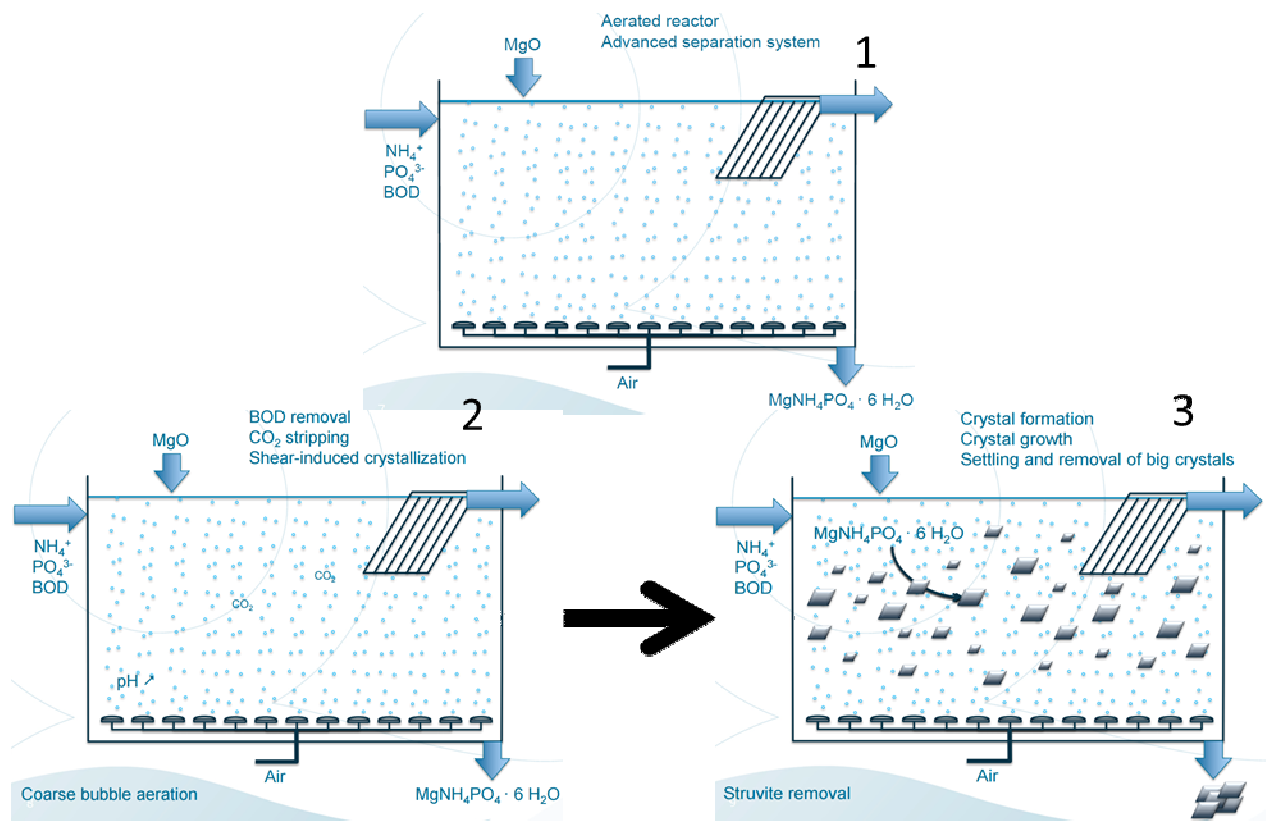


Figure 13: Principle of a PHOSPAQ® reactor.

Source: Remy M., (2014)



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

P-REX Project

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

### **3.9.1 General description**

Severn Trent Water and Thames Water (White Slough treatment plant, Berkshire, United Kingdom) are currently using the fluidized bed reactor Pearl® process from OSTARA®. The final product from Pearl process is known as Crystal Green® and is pelletized and ready for usage (Akinola, 2013; OSTARA®, 2013; Wentworth, 2014). Struvite usage is preferable to the use of bio-solids from treated sludge since it allows up to 40 % more P to be recovered (Vale, 2013). The removal of struvite makes it possible to recover phosphorus and other nutrients from wastewater and recycle them into an environment-friendly, high-quality commercial fertilizer free from harmful chemicals. For example, in the UK, the Pearl® struvite product contains very low heavy metal concentrations but it is still a bit expensive (at ≈ £1000/ton) for use in agriculture (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, P and N recovery can be achieved via OSTARA® process by a slow-release fertilizer called Crystal Green® (MAP). Severn Trent Water's Derby Sewage Treatment Works began operating an OSTARA® pilot plant in 2009 for a biological phosphorus removal and the recovering of valuable materials from wastewater (Hadden, 2009, Vale, 2012). OSTARA® Pearl reactor adopts the same chemical principle for the formation of struvite: continuous aeration, high pH and magnesium addition.

OSTARA®'s struvite recovery process claims to be able to both lower operating costs in the wastewater treatment plants and meet environmental regulations. Moreover, the recovery of pollutants (P and N) that are recycled into environment-friendly and slow-release fertilizer is another advantage (Hadden, 2009). Among the Crystal Green® fertilizer advantages are: certified product that can be used in horticulture and especially agriculture, 100 % sustainable and renewable production process, small fraction of heavy metals, more effective nutrients uptake by plants, low

overflow to surface waters due to P and N slow release, freedom from dust, right particle size and no chemical coatings (Morgenschweis, 2011). Crystal Green® pellets are periodically collected 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 vary from 200 to 1,000 tons per year, i.e. enough to fertilize 1,000 to 5,000 soccer play grounds.

The advantages of the OSTARA® process are: P removal higher than 85 %, process stability, up to 40 % N, 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*

The liquor resulting from sludge dewatering is sent to the Pearl process unit (fluidized bed reactor) for struvite crystallization. A magnesium chloride solution is fed into the reactor to maintain a molar ratio of Mg:PO<sub>4</sub>:P equal to 1.3:1 inside the reactor (Britton et al., 2005).

#### *pH control*

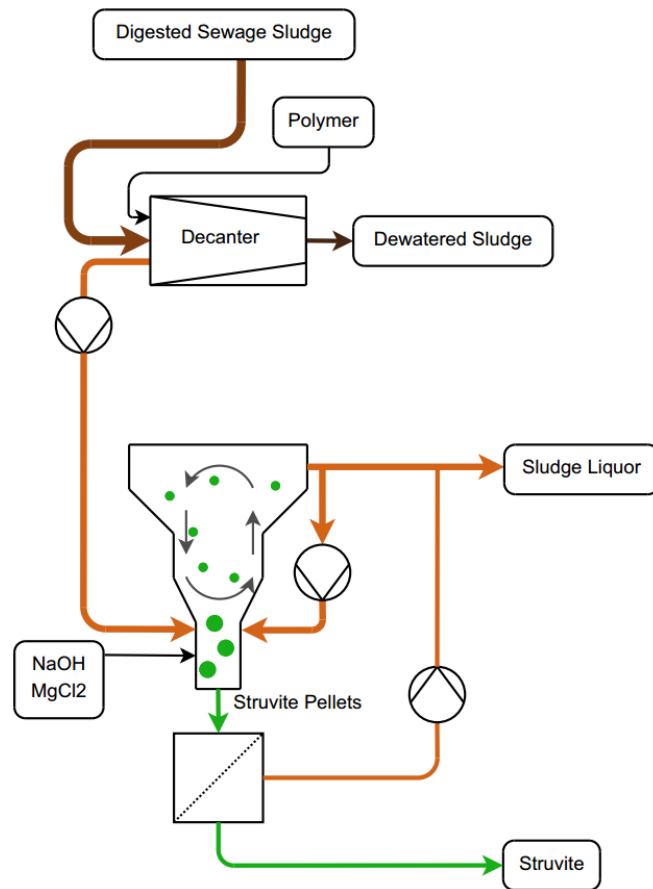
Struvite formation is influenced by pH, so NaOH can be added to improve nutrient removal performance. A reactor recycle pump controls hydraulic conditions and fluidization energy inside the bed. The saturation point of a solution is strongly influenced by pH, which should ideally be kept between 7 and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

#### *Pellets formation*

Fertilising pellets are first microscopic struvite crystals (created in the reactor). They then grow as layers of struvite deposit on the particle surface. The result is extremely pure. These crystalline struvite pellets are collected from the reactor when they are big enough for sale as a fertiliser. The crystals collected are then air-dried in a final step (OSTARA®, 2014). The pellets contain more than 99.9% pure struvite and have the right size and hardness to be used as a fertiliser.

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 further information

P-REX Project

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

#### **3.10.1 General description**

Phosphorus can be recovered as struvite from industrial wastewater by the NuReSys® (Nutrient Recovery System) technique, which is used on a full scale in a German dairy and in 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®, (2015)

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

After treating the wastewater 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 rise (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 ensure 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

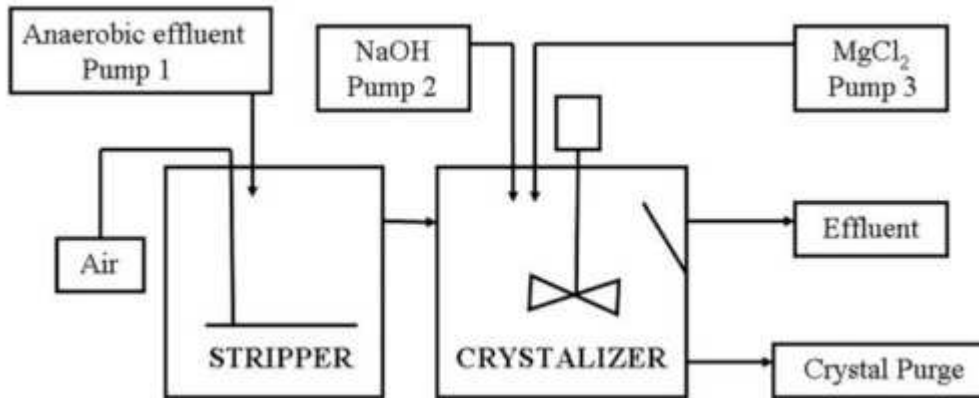


Figure 16: Schematic overview of the NuReSys® phosphorus recovery process.

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

### 3.10.4 End-product

The end-product 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**), a clean product that can safely be used as a slow release phosphorus fertilizer or soil amendment in agriculture and horticulture (NuReSys, 2015). Part of the struvite produced is exported to France for use in wine growing while another part is mixed with compost (Desmidt et al., 2015).



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

Source: NuReSys, (2015)

### **3.10.5 Useful contact(s) for further 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 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 consists of three parts:

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

After that, 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)*

The sewage sludge coming from the different treatment steps (primary, secondary and tertiary sludge) is collected in two thickening ponds. The concentration in DM is more or less 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 caused by specific microorganisms. The degradation process is composed of three main phases: hydrolysis-fermentation, acetogenesis and methanogenesis. The products of this anaerobic digestion are digestate, water and biogas made up of bio-methane and carbon dioxide. The digestion tank can take an input flow of about 14,000 kg of DM and produces about 5,000  $\text{Nm}^3$  of biogas per 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 further part is used to provide the plant with electricity through a cogeneration device. The cogeneration motor is powerful (366 kWh) and decreases the emissions of greenhouse gases from the plant. This device made WWTP eligible for green certificates.

*Liming step (D)*

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

*Thermal drying (E)*

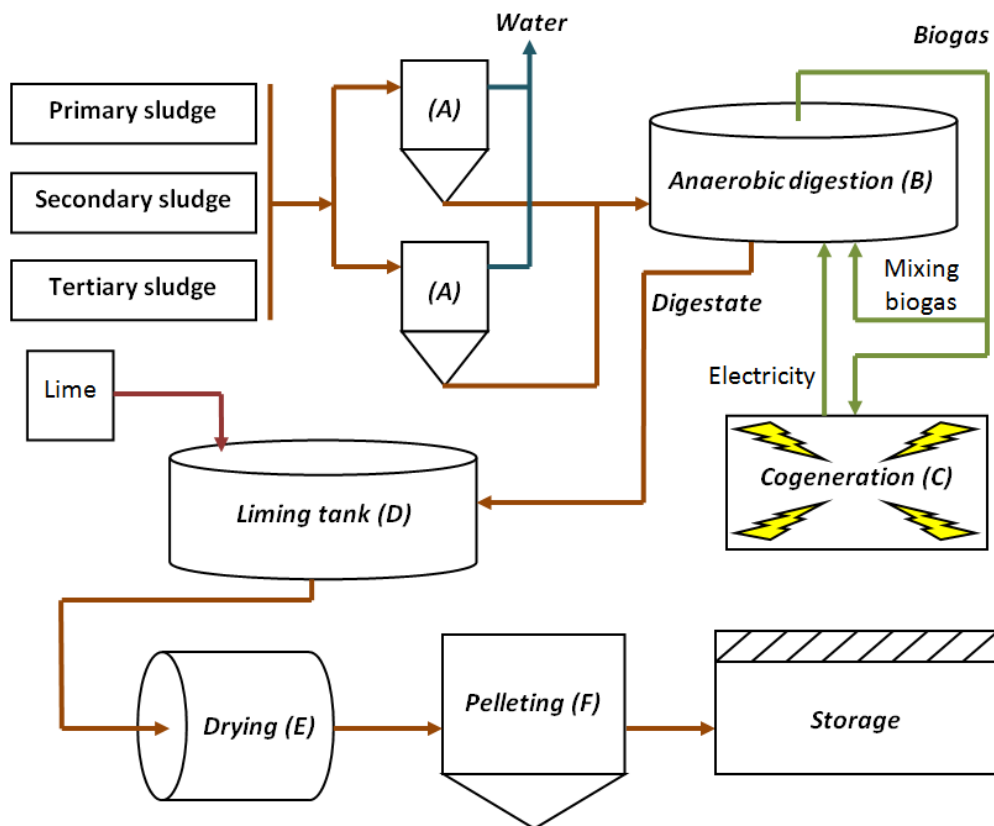
The thin layer thermal dryer is 10.5 metres long and 1.2 metre wide and can take about 100 kg of matter. The dryer has a double envelope into which a heat transfer fluid (250-260 °C) brings energy to evaporate the water contained in the limed digestate. The sludge is distributed over the thin layer by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

*Pelleting (F)*

The pelletizing phase consists in making pellets of dried digestate. Those pellets are taken 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 further information

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

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### **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 businesses. The 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 sloping grate where it is constantly turned over so as 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 purified ash is recycled as material for road building or construction use.

The 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 the National Grid.

The gases from the boiler go through a complex flue gas cleaning process, involving the injection of a 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 potential remaining dioxins.

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

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

The exhaust steam from the turbine is recycled as water (returning into the process) by air-cooled condensers. 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 'acceptable' and 'unacceptable' waste. 'Acceptable' waste is household 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 when processed and disposed of. Those include bulky items, waste oil and other items of 'unacceptable' waste.

Acceptable wastes include leaves, twigs, grass and offcut from plants, paper, plastics, ferrous and non-ferrous metals, glass and other materials present in household refuse. In order to avoid errors, Hazardous Waste as defined by the Hazardous Waste Directive (Council Directive 91/689/ECJ) is seen as unacceptable 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, plaster plates,
- 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, motorcycles, motor engines, transmissions, rear ends, springs, fenders and major parts of motor vehicles, trailers, agricultural equipment, boats and ships, 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' such as fridges, freezers, 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 so as to cool the low pressure steam from the turbine exhaust. Cooling condenses the steam back to water which 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 in order to produce electricity. The electricity leaves via 11,000 volt cables lying across the floor.

#### *Tipping Hall (3)*

Vehicles drive up a slope 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 are 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)*

By pulling down the handle on the right-hand side of the viewing port and looking up at 45 °C to observe the combustion of refuse, it is possible to see the ash falling into the cooling bath below.

#### *Steam Boiler (7)*

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

*Gas Treatment Scrubber (8)*

As the hot combustion gases pass 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 them, removing the acid ones and reaching the bottom, where it is removed in powder form. The incoming acid gas content is continuously measured to make sure 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 all 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 % of ferrous metal and up to 1.5 % of 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)*

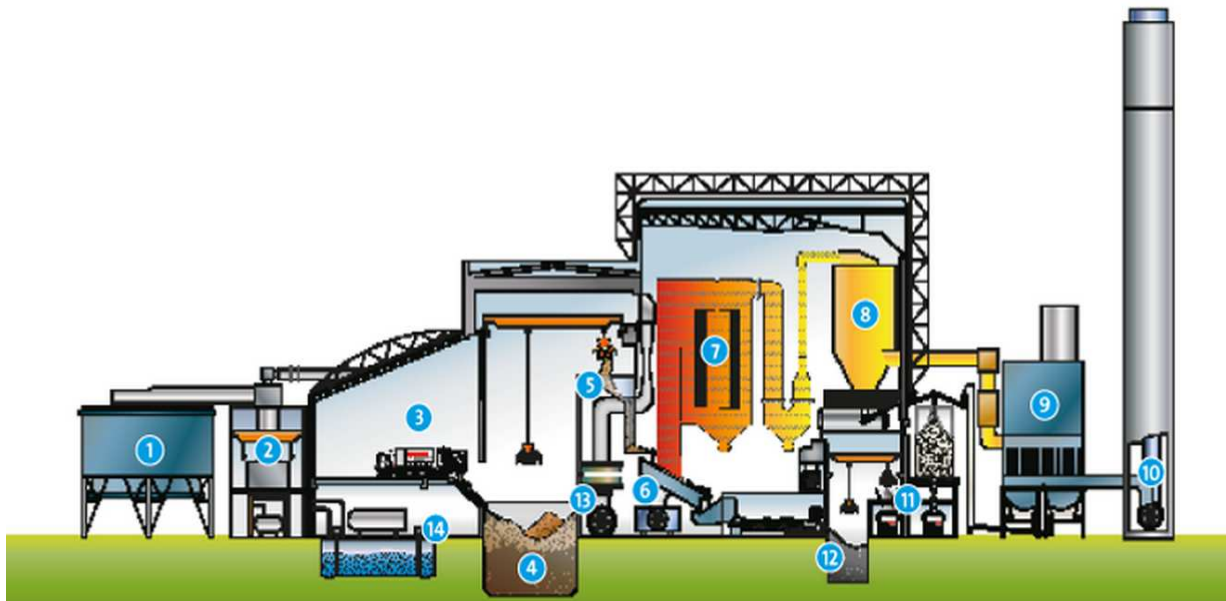
These large ducts draw air from above the waste pit through the concrete wall to the west. The air is fed into the furnace via fans from both below and above the flames. This air is vital to maintain the correct combustion of the waste. Drawing the air from around the waste pit also stops smells from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

### 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 intended 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 further information

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University of Leeds (United Kingdom)

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### **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 power all the EcoPark centres. From 1994, when LondonWaste Ltd was awarded the NLWA contract, till 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 to 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 put onto the boiler grates at a pace controlled by a hydraulic ram.

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

Waste is burnt on the grate at temperatures over 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 to an on-site ash recycling plant. The processors remove any further metals for re-use and then grade and screen the ash for use as an aggregate 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 flow 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 neutralize 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 flowing through the 100 metre high chimney.

*Chimney (12)*

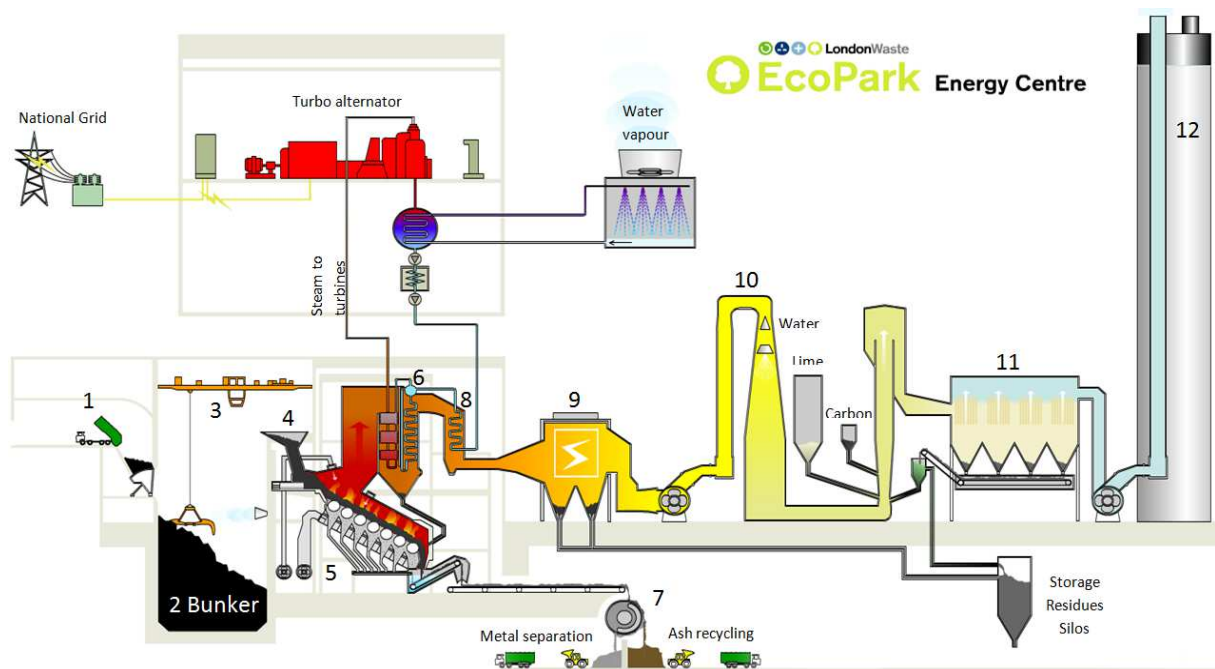
All the gases are continuously monitored to ensure compliance with very strict regulations. A slight plume, which is only water vapour, may be visible under some conditions.

*Alternator (13)*

After supplying the internal needs, more than 85 % of the electricity generated by the plant are exported to the National Grid. The export reaches 35,000 KW of power per 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 further information**

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University of Leeds (United Kingdom)

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### **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, and 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 3,400 m<sup>2</sup> center is equipped with different types of comminution and sorting devices able to treat up to several tons 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 stages:

- 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 taken to a first trommel by hydraulic excavators through a grid that retains blocks bigger than 20 mm. This trommel divides the material into two fractions depending on their sizes. Two fractions are obtained: one made of wastes the size of which is superior to 4 mm, and one composed of wastes the size of which is inferior to 4 mm. After that, a vibrating sieve makes it possible to obtain a finer fraction (size inferior to 2 mm). The two fractions composed of the biggest elements are put together to make up the first waste fraction (Fraction 1, size superior to 2 mm).

The finest fraction is then homogenized and mixed with water before being sent to a curved sieve. This results in a second fraction (Fraction 2) mainly composed of sand particles (between 250 µm and 2 mm). A further unit operation consisting in magnetic separation can be achieved in Fraction 2 if it contains ferromagnetic materials. The materials are then 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 third fraction then goes through further stages: attrition (optional) and spiral gravity separation, after which 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 generates a muddy fraction (particle size from 15 to 63  $\mu\text{m}$ ) and a clayey fraction (size inferior to 15  $\mu\text{m}$ ). The muddy fraction is next purified in a flotation tank so as to separate metallic and organic pollutants with 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, giving 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 stage provides the finest fraction of all, called Fraction 5.

### 3.14.2 Unit operations

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

The first unit operation is a screening phase achieved with a trommel composed of a rotary drilled cylinder. The blades inside the cylinder mix the material. An aspersion device is also included in the system to facilitate the 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 feeding end 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 stage achieved on 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 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 stage (1) (C)*

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

*Screening on 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 5  $\text{m}^3/\text{h}$ , with a percentage of DM varying from 10 to 20 %. Two fractions are obtained (particle size inferior and superior to 250  $\mu\text{m}$ ).

*Magnetic separation (E)*

A magnetic separator can be integrated into the process 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 from 10 to 20 %.

*Mixing stage (2) (F)*

A second mixing stage is needed to reach a specific density. The percentage of DM must be 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 varying from 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 generates two fractions: the fine sands composed of particles with sizes 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 from 5 to 10 %.

*Attrition (optional) (H)*

This unit operation can be added to the process if necessary and is applicable to fine sands (size 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 to clean 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 varying from 50 to 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 varying from 63 to 250  $\mu\text{m}$ . Two in-line spiral separators generate a fine water blade to separate the particles according to their weights. The heaviest particles (minerals) staying close to the axis of the spiral are collected by the inner valve at the bottom of the spiral while 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 varying from 5 to 10%.

#### *Filtration (J)*

The finest fractions obtained thanks to 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 varying from 10 to 20 %.

#### *Mixing stage (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 varying from 5 to 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 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 from 5 to 10 %.

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

The muddy fraction resulting from the previous stage (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 fed into the flotation tank. Air is injected into the tanks and different types of reagents can be added: activating reagents, foaming reagents, etc. Two in-line tanks of 750 L allow the foam containing the concentrated pollutants to be collected at the surface. The maximal input flow can reach 1.5 m<sup>3</sup>/h, with a percentage of DM

varying from 20 to 30 %. The reagents are chosen according to their 'ability' to select the pollutants or nutrients to be removed and need a targeted preliminary study carried out in a laboratory.

#### *Decantation stage (P)*

The foam resulting from the flotation process and the clean muddy fraction are next sent to a decantation device consisting 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 dissolving the powder. The flocculation agents are then added to the clayey fraction in pulp form. The material mixed with the flocculation reagents is 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 consists of 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 additives. One dehydration cycle takes between 1 and 2 hours per ton of final material obtained. This final phase allows to recover the finest fraction of the raw material in the shape of compressed cakes which are easy to handle.

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



#### **3.14.4 Additional comments**

Some unit operations can be added to the process if necessary. The magnetic separation (E) and the attrition stage (H) are optional. A water treatment process - which is not described here - is also part of the system. The pilot plant is being extended in order to integrate other unit operations such as jig separation (heavy/light fraction separation combined with granulometry-oriented separation in wet conditions) and will be fully operational in February 2016.

All this data was kindly provided by the “Centre Terre et Pierre” in Tournai (Belgium).

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

Centre Terre et Pierre (Belgium)

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### ***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 recovering different types of materials through incineration. The plant processes bulky wastes, industrial and household wastes, medical and hospital wastes, plastics, cardboard, sewage sludge, etc. The post-incineration residue 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 clinker-generating plant is to separate the different fractions according to their sizes as well as their magnetic and metallic characteristics. It is possible to identify the techniques best suited to the various fractions.

The treatment consists of 4 main kinds of processes:

- Screening stages,
- Magnetic separations,
- Metallic separation based on an eddy current separator,
- Mixing step.

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

The biggest fraction is next sent to a magnetic separator, producing 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 provides two fractions: the smaller one composed of particles the size of which is inferior to 20 mm and the bigger one made up of particles the size of which is varies from 20 to 100 mm.

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

The flow composed of medium-sized particles (size from 20 to 100 mm) resulting from the size-bound separation achieved in the trommel is next sent to a magnetic separator. This device generates two fractions, a magnetic one and a non-magnetic one. The magnetic fraction is mixed with the finest particles in the mixing tank. This mix is then sent to another magnetic separator which creates two different flows: the fine magnetic particles (size inferior to 100 mm) and the fine non-magnetic particles (size between 20 and 100 mm).

Finally, the non-magnetic fraction resulting from the magnetic separation following trommel screening is mixed with the above-mentioned non-magnetic fine particles. Those two combined flows are composed of medium-sized non-magnetic particles (size 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 of a big one (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 processes the biggest particles coming from the screening sieve, which results in a magnetic fraction of big particles and in a non-magnetic fraction of big particles (size superior to 100 mm).

#### *Trommel screening (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 produces a fine fraction (size < 20 mm) and a big(ger) one (size comprised between 20 and 100 mm).



*Magnetic separation (2) (D)*

A further magnetic separator is used for 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 it is more complex than the one of a common magnetic separator. The swirl is due to a high-frequency magnetic flux. A rotating device equipped with permanent magnets makes it possible to create specific magnetic fields. The magnets have 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 creates both a flow of fine non-metallic particles and one of fine metallic elements (particle size inferior to 20 mm).

*Magnetic separation (3) (F)*

The intermediate fraction (size between 20 and 100 mm) obtained in (C) is then sent to another magnetic separator. The device generates a flow of fine magnetic particles and one of fine non-magnetic particles (size 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 fine particles (size inferior to 100 mm) and the non-magnetic fraction of fine particles. This flow is mixed with the one coming from (F). A blower is then used to remove the finest particles, generating a non-magnetic fraction of particles the size of which varies from 20 to 100 mm.

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

### 3.15.3 Process scheme

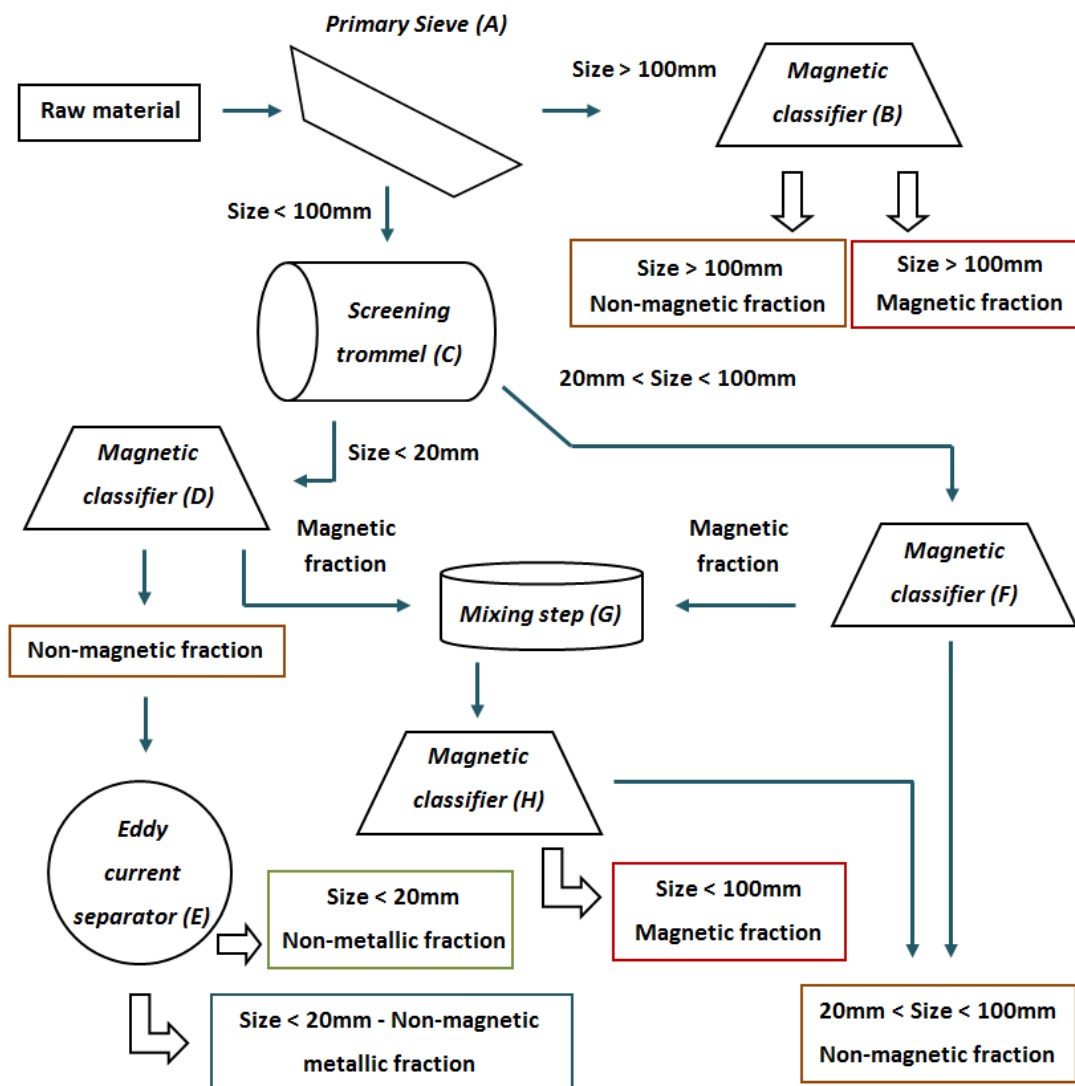


Figure 22: Scheme of the process used by IPALLE to purify ashes.

Source: IPALLE (Belgium)

### 3.15.4 Additional comments

This plant is used to sort the different clinker fractions. It separates the magnetic elements from the non-magnetic ones but disregards macronutrients (phosphorus, nitrogen and potassium).

All this data was kindly provided by the inter-municipal organization IPALLE (Belgium).

**3.15.5 Useful contact(s) for further 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

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

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

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

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#### **IPALLE**

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**NuReSys**

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Contact: Carl Dewaele, cd@nuresys.be

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

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

Coupure Links 653, 9000 Gent

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**Vlaamse Compostorganisatie (VLACO)**

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

**FRANCE**

**Sydeme-Méthavalor**

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**THE NETHERLANDS**

**Nijhuis Water Technology**

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**UNITED KINGDOM**

**LondonWaste EcoPark**

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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**

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**EUROPE**

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