

Good Practices in Sludge Management



Introduction

Efficient municipal waste water treatment produces vast amounts of sludge. For example, in the countries located wholly or partly on the Baltic Sea watershed the amount of sewage sludge generated is about 3.5 million tonnes of dry solids annually – this is expected to increase to almost four million tonnes by 2020. Sludge management is an integral part of any modern municipal waste water treatment plant: it is important not to lose the nutrients in the sludge, to make use of its material and energy, and to dispose of it efficiently and sustainably.

Sewage sludge is a product of municipal waste water treatment; however, sludge treatment issues are often neglected in comparison with water-related parameters such as the outgoing load and the degree of removal of different waste water compounds. Sludge is a potential threat for the environment; for example, foaming sludge can be lost from the treatment process or sewage sludge may be even deliberately disposed of into watercourses.

The practical and technical challenges of sludge handling are:

- stabilising – sludge is not inert and can have an unpleasant odour;
- reducing the water content and sludge volume to the minimum;
- utilising the energy potential when economically possible;
- reducing the amount of harmful micro-organisms if people, animals or plants are in contact with the sludge; and
- recovering phosphorus for agriculture.

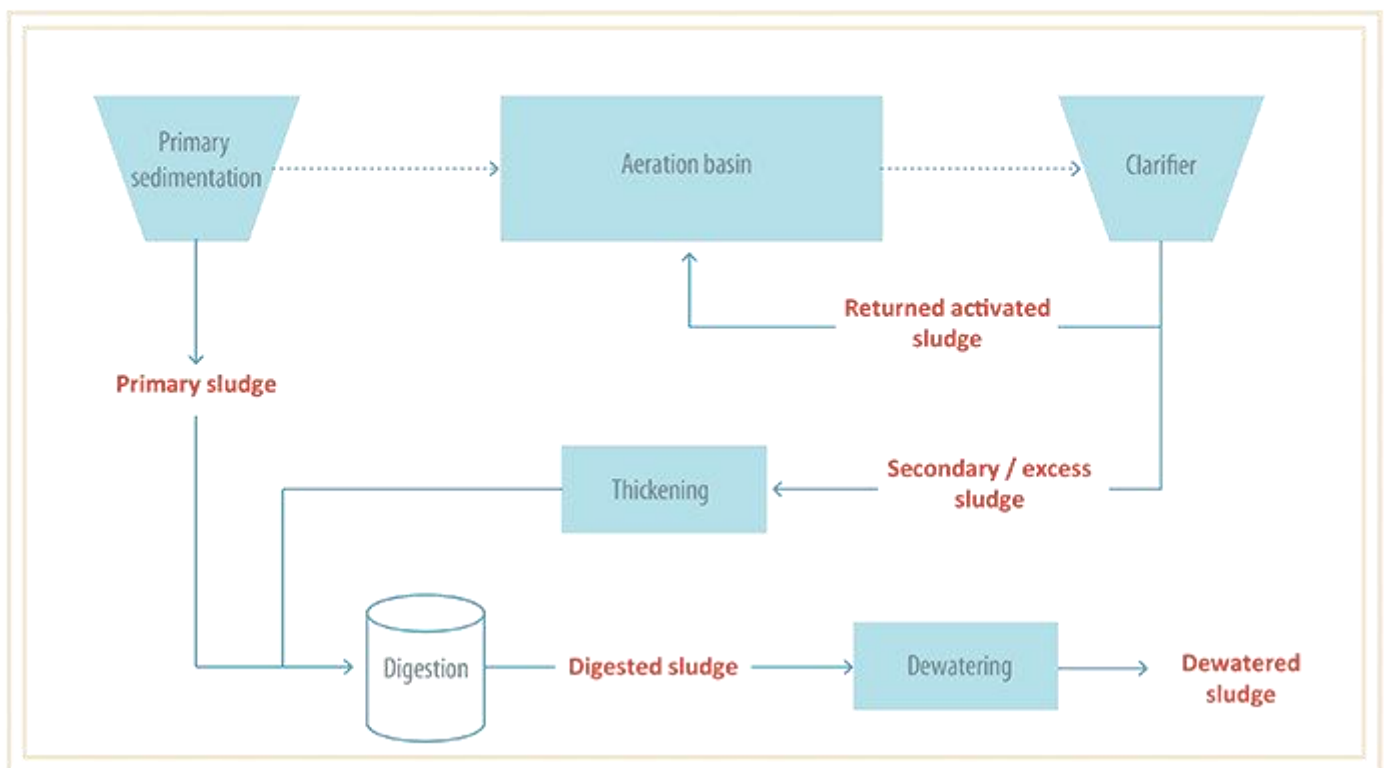
Sewage sludge treatment is more than only thickening, digestion, dewatering and disposal. It has consequences for the whole treatment plant:

- With sludge-originated biogas, it is possible to increase energy production (electrical and thermal) to over 100% of the power needed in the plant. Energy production and energy efficiency are thus very important issues. It is also possible to increase biogas production with certain pre-treatment methods.
- The retention time in primary sedimentation has a direct positive effect on the biogas production. On the other hand, a higher retention time decreases the BOD

load in the biological treatment; this decreases the denitrification capacity and may require an additional carbon source. Other possible effects are better dewaterability and lower disposal costs.

- In digestion, nitrogen is reduced to ammonia, which is in high concentration in the reject water that is separated from the sludge in dewatering. Better digestion causes a higher reject water load. If the nitrogen removal capacity of the waste water treatment plant is too low, additional reject water treatment methods can be applied.
- Biological phosphorus removal reduces the dewaterability up to 10 % (Kopp, 2010). Some plants have problems to operate a stable biological phosphorus removal or have other operational problems (e.g. bulking sludge). Chemical phosphorus removal, in turn, increases the amount of sludge.

Figure 2-1. Different types of sludges generated in urban waste water treatment plant processes.



Different types of sludge generated in an urban waste water treatment plant process.

Country	2005 / 2006	2010	2020
	(tDS/a)	(tDS/a)	(tDS/a)
Belarus*	50 000	50 000	70 000
Denmark	140 021	140 000	140 000
Estonia	n.d.	33 000	33 000
Finland	147 000	155 000	155 000
Germany	2 059 351	2 000 000	2 000 000
Latvia	23 942	25 000	50 000
Lithuania	71 252	80 000	80 000
Poland	523 674	520 000	950 000
Russia*	180 000	180 000	200 000
Sweden	210 000	250 000	250 000
Total	3 405 240	3 433 000	3 928 000

Total sludge volumes in tonnes of dry solids per year (tDS/a) of different countries of the Baltic Sea Region reported to the EU Commission and estimated to develop by respective Member States (Milieu, WRc and RPA, 2008).

- Non-EU countries; and hence no data available in Milieu et al., 2008 report, order of magnitude estimated by Pöyry Finland Oy for PURE, based on population connected to municipal systems in the Baltic Sea Region.

Sludge thickening

The sludge that comes out of waste water treatment has a water content of between 97 % and 99.5 %. In sludge thickening, the dry solids (DS) content of sludge is increased by reducing the water content with low energy input. Sludge thickening can be applied both as a pre-treatment for digestion as well as a pre-treatment for dewatering in waste water treatment plants that operate without digestion.

With gravity and mechanical thickening, it is possible to treat primary sludge, excess sludge or a mixture of both. Thickening excess sludge has a high priority because after secondary sedimentation, the DS content of the sludge is about 0.5–1.0 %, while primary sludge from primary sedimentation tanks can have a DS content of up to 4.0 %. In sludge thickening – like in sludge dewatering – inorganic or organic flocculant aid chemicals (usually polymers) are used. With all thickening and dewatering methods they are, however, not absolutely necessary.

Gravity thickening

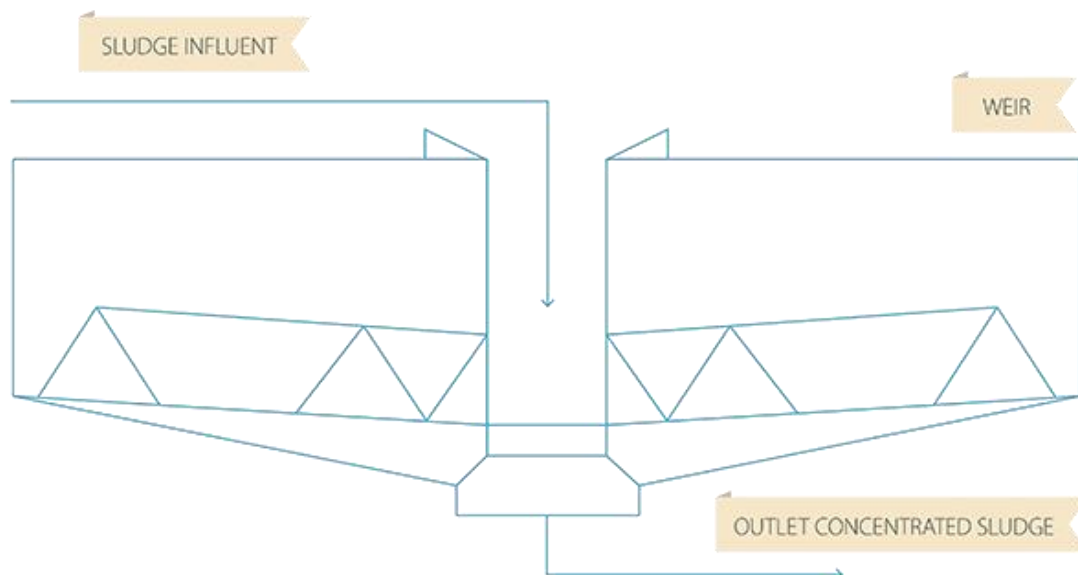
Gravity thickening is the easiest way to reduce the water content of sewage sludge with low energy consumption. Sludge is pumped directly to a circular tank equipped with a

slowly rotating rake mechanism, which breaks the junction between the sludge particles and therefore increases settling and compaction. With gravity thickening, the total sludge volume can be reduced by even 90 % from the original volume; this method consumes very little energy. Another target of gravity thickening is the significant hydraulic buffering capacity (up to 3 days) between the waste water stream and the sludge handling process.

	Without flocculant aids	With flocculant aids (polymers)
Primary sludge	5–10 % DS	-
Mixture of primary and excess sludge	4–6 % DS	5–8 % DS
Excess sludge	2–3 % DS	3–4 % DS

Results as dry solids (DS) contents of gravity thickening with or without flocculant aids (DWA-M 381E, 2007),(Burton et al., 2003).

Figure 4-2. Schematic diagram of a gravity thickener.



Schematic diagram of a gravity thickener.

Gravity thickeners are in use in nearly all large and medium-size waste water treatment plants in the Baltic Sea Region, for example in Tallinn, Tartu and Pärnu in Estonia; Espoo, Turku and Oulu in Finland; Stockholm in Sweden; Riga in Latvia; Vilnius and Kaunas in Lithuania; Warsaw and Gdansk in Poland; St. Petersburg in Russia; Copenhagen in Denmark and also Berlin and Hamburg in Germany.

The gravity thickener can be either replaced (e.g. in Lahti, Finland or Kohtla-Järve, Estonia) or complemented with other thickening equipment, which is usually needed if there is also anaerobic treatment of sludge at the plant. Sometimes, gravity thickening (or any other thickening) is not used in medium-size or small treatment plants in Estonia, Latvia, Poland and Germany, for example. In these cases, the type and capacity of the sludge dewatering equipment is designed to take into account that there is no preceding thickening stage.

Mechanical thickening

Mechanical thickening is usually used for thickening excess sludge. The mixture of sludges is often thickened mechanically at plants with a small primary sedimentation unit or when the sludge is not treated in the digestion process. Mechanical thickening needs flocculant aid and electrical energy, and can be operating continuously. It is typical for large and medium-size waste water treatment plants and as pre-treatment for direct dewatering without digestion. Mechanical thickening equipment options include screw, drum, belt and centrifuge.

Technology	Screw thickener	Drum thickener	Belt thickener	Centrifuge
DS content	4–7 %	5–7 %	5–7 %	5–7 %
Polymer consumption	2–6 g/kg DS	2–6 g/kg DS	2–6 g/kg DS	1–1.5 g/kg DS
Energy consumption	Low	Low	Low	High
Maintenance	Low	Low	Low	Low
Capacity and remarks	20–100 m ³ /h	10–70 m ³ /h	24–180 m ³ /h	5–200 m ³ /h, use without polymers possible

Comparison between different mechanical thickeners. DS = dry solids.

PURE partner	Method of thickening for excess sludge	Achieved DS	Flocculation aid consumption
Kohtla-Järve	Belt thickeners	6 %	4.0 g/kg DS
Riga	Centrifuge	5–7 %	2–4 g/kg DS
Jurmala	Drum thickener	4–7 %	3.5 g/kg DS
Gdansk	Screw thickener	6 %	3.4 g/kg DS
Szczecin Pomorzany	Belt thickener	6 %	3-5 g/kg DS
Szczecin Zdroje	Drum thickener	6.5 %	6.5 g/kg DS
Lübeck ZKW	Belt thickener	5–6 %	1.5 g/kg DS

PURE partner thickening method comparison. DS = dry solids.

Stabilisation

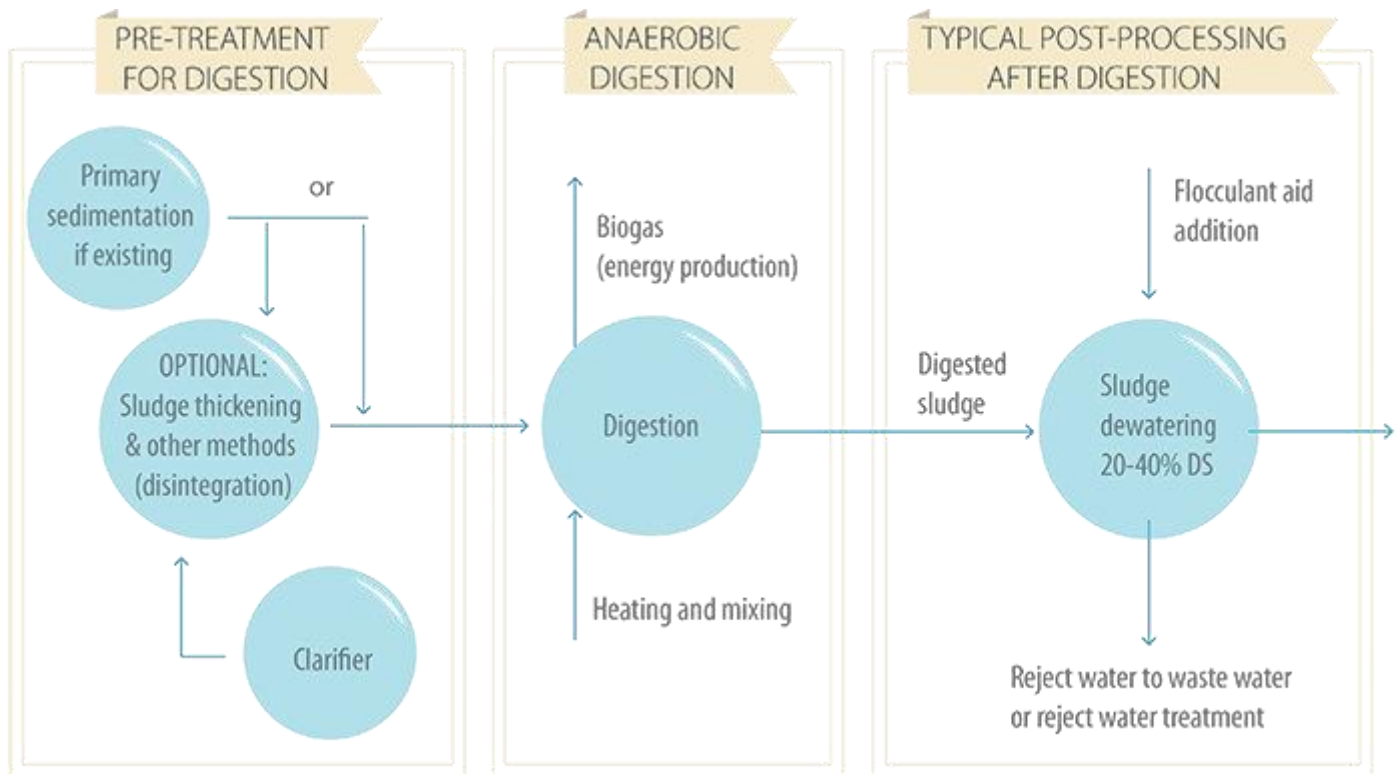
The aim of stabilisation is the reduction of biological and chemical reactions to a minimum. Anaerobic digestion is one of the oldest and still most commonly used processes for sludge stabilization. The first anaerobic digestion tanks were introduced over a hundred years ago in the United States. Concentrated organic and inorganic sludge matter is decomposed microbiologically in the absence of oxygen and converted to methane and inorganic end products. The main benefits from digestion are the stabilisation of sewage sludge, volume reduction and biogas production.

The anaerobic digestion process is operated either in the mesophilic (around 35–40 °C) or thermophilic (53–57 °C) temperature ranges. Thermophilic temperature has been extensively tested with sewage sludges from municipal waste waters in laboratory, pilot and full scale for more than 30 years – unfortunately without success. Accordingly, the presentation here focuses on the mesophilic temperature range only. Its main advantages are good process stability and supernatant quality with reliable operation experience. It is possible to reduce the sludge volume considerably and gain biogas for energy supply. It has to be taken into account that digestion produces a significant amount of reject water that increases the nitrogen and COD loads in the waste water treatment plant.

Anaerobic digestion process in the sludge handling chain.

Digestion takes place in one or several reactors, which can be fed in parallel or in a row with a typical retention time of between 20 and 25 days. The minimum retention time is around 14 to 15 days – lower retention time normally reduces the gas production, although some treatment plants are operating with retention times under 14 days without any reduction of gas production. In these cases, the sludge is very well biodegradable. Primary sludge is easier to digest and easier to dewater compared to excess sludge that

consists of bacteria from the activated sludge process. The digestion of excess sludge requires a longer detention time. A mixture of primary and excess sludges should reach a dry solid (DS) content of between 4–7 % before digestion, and the most common pre-treatment method is thickening. Increasing the DS content causes lower energy consumption for heating and a reduced digestion time.



The digestion reactor is always equipped with a mixing and a heating device to guarantee good mixing and constant temperatures. Temperature variation or poor insulation reduces biogas production. Mixing the digester contents enhances its operation by reducing thermal stratification, dispersing the incoming sludge for better contact with the active biomass, and reducing scum build-up. Mixing also dilutes any inhibitory substances or adverse pH and temperature feed characteristics, thereby increasing the effective volume of the reactor.

A benchmark for digesters is the amount of degradation of organic matter in the sludge. A degradation of 50 % of organic matter is considered as good performance. The operation of an anaerobic treatment process requires more biotechnical skills than the operation of other sludge handling equipment like thickening or sludge dewatering. Unless special attention is paid to it, this technology is a potential source of malodorous air emissions; and since the biogas is also explosive, special safety control measures must be carried out.

This technology is widely used in the Baltic Sea Region at medium-size and large waste water treatment plants. Also, some small plants are planning to build a digester. As the break-even point to build a digester has shifted, it may be also economical for smaller plants. Sometimes, several smaller municipalities have agreed to build a common digestion plant to serve them.

In Estonia, digestion has been installed in Tallinn and Kuresaare, with a digestion plant under construction Tartu. In Latvia, there are digesters in Riga and Limbazi. In Sweden and in Finland, digestion is installed in bigger cities like Stockholm, Gothenburg, Helsinki, Tampere, Espoo, Kuopio, Jyväskylä and Hämeenlinna. In Poland, there are digestion plants in Gdansk, Lublin and Szczecin. See Table 5 2 for PURE partner comparisons in the use of digestion (together with dewatering).

Biogas is taken from the top point of the digester. It is removed from the digested sludge by air stripping in the gas removal unit before the sludge is fed further to the intermediate storage. It has an average content of 58–64 % of methane (CH_4), 30–40 % of carbon dioxide (CO_2), and a small amount of water and hydrogen sulphide (H_2S). In special cases, for example where the food industry's share in the waste water is high or when co-fermentation is done, the methane (CH_4) content can be up to 70 %. The calorific value of methane (100 %) is 10 kWh/m^3 and of biogas between $5.8\text{--}6.4 \text{ kWh/m}^3$.



Gas flare, gas storage tank and digesters in Lübeck, Germany. Photo: Entsorgungsbetriebe Lübeck.

Biogas is renewable energy. The combined heat and power plant (CHP) unit uses the biogas to produce electrical energy, most often with gas motors or micro turbines. Modern CHPs have an efficiency factor over 40 % for electrical energy production. The surplus heat of the machine and of the exhaust gas can be used to heat the sludge that is fed to digestion, to heat the operation building, and dry the sludge. If a district heating system exists, it is also possible to sell the heat to a nearby heat supplier.



Energy central with CHP, gas flare and heating system in Riga, Latvia. Photo: SIA Rigas Udens.

Sludge can be stabilised – as an alternative to anaerobic digestion – by long-term aeration that biologically destroys volatile solids. Long-term (or extended) aeration takes place in aeration tank and can therefore also be referred to as 'simultaneous aerobic digestion'. Also, aerobic stabilisation methods operating at higher temperatures and in separate tanks have been developed. Aerobic digestion produces sludge suitable for various disposal options.

Sludge dewatering

The sludge dewatering process is relatively simple: increasing the dry solids content of the sludge with different types of equipment. This unit process always requires the use of at least some flocculant aid that keeps the excess sludge flocculated in the dewatering unit. Sometimes, coagulation chemicals such as iron or aluminium salts are also added in order to enhance the efficiency of flocculant aids (polymers) and reduce the consumption of them in sludge dewatering. Some research projects are developing dewatering methods without any chemicals; however, the separation effect and reliability are not yet sufficient.

After dewatering, the dry solids content of the sludge is usually between 19 % and 30 %. Depending on the dewaterability, it is possible to reach a dry solid content of up to 40 %. With chamber filter presses, for example, this higher dry solid content is reachable by conditioning with lime. The maximum dry solid content can be determined in a laboratory. After reaching the maximum DS content with dewatering, the water left in the sludge is bound in the cells and can only be reduced with sludge drying.

Centrifuges and belt filter presses are currently the most popular dewatering methods in municipal waste water treatment plants due to their good operation and cost efficiency. Chamber filter presses are expensive compared to other presses, and are therefore used more in large applications elsewhere – in the mining industry, for instance. Hydraulic presses, originally developed for the food industry with high hygienic demands, are also expensive. Screw presses are most suitable and used for sludges containing fibre material from the pulp and paper industry. Today, there are also some screw press applications in the Baltic Sea Region, especially in small and medium-size municipal treatment plants. There are several innovative methods under development, for example 'Rofitec' or reed beds.

Good to know: Biological phosphorus removal reduces the dewaterability of the sludge. Chemical phosphorus removal can thus be economically realistic as it reduces the sludge's disposal and transport costs. On the other hand, biological phosphorus removal allows the recovery of phosphorus from the waste water more easily (see [Recovery of phosphorus from sludge handling](#)). Also, the amount of sludge is smaller with biological phosphorus removal than with chemical precipitation.

Decanter centrifuge

The *decanter centrifuge* with its continuous feed and sludge output is the standard centrifuge type. High g (corresponding to the high multiples of the force of gravity, g) centrifuge models are favoured to achieve high dry solids content. The key elements are the bowl, which includes cylindrical and conical sections, the conveyor screw inside the bowl and the drive units to rotate them. The casing surrounding the bowl acts as a protective and noise suppression barrier, and channels the dewatered sludge cake and separated clarified liquid – or centrate – out from the unit.

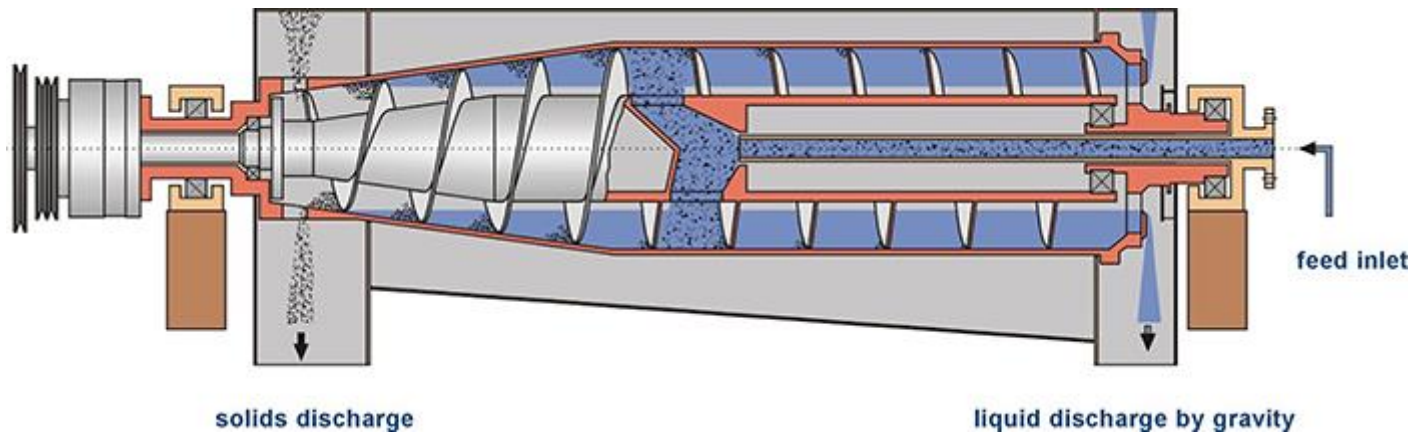
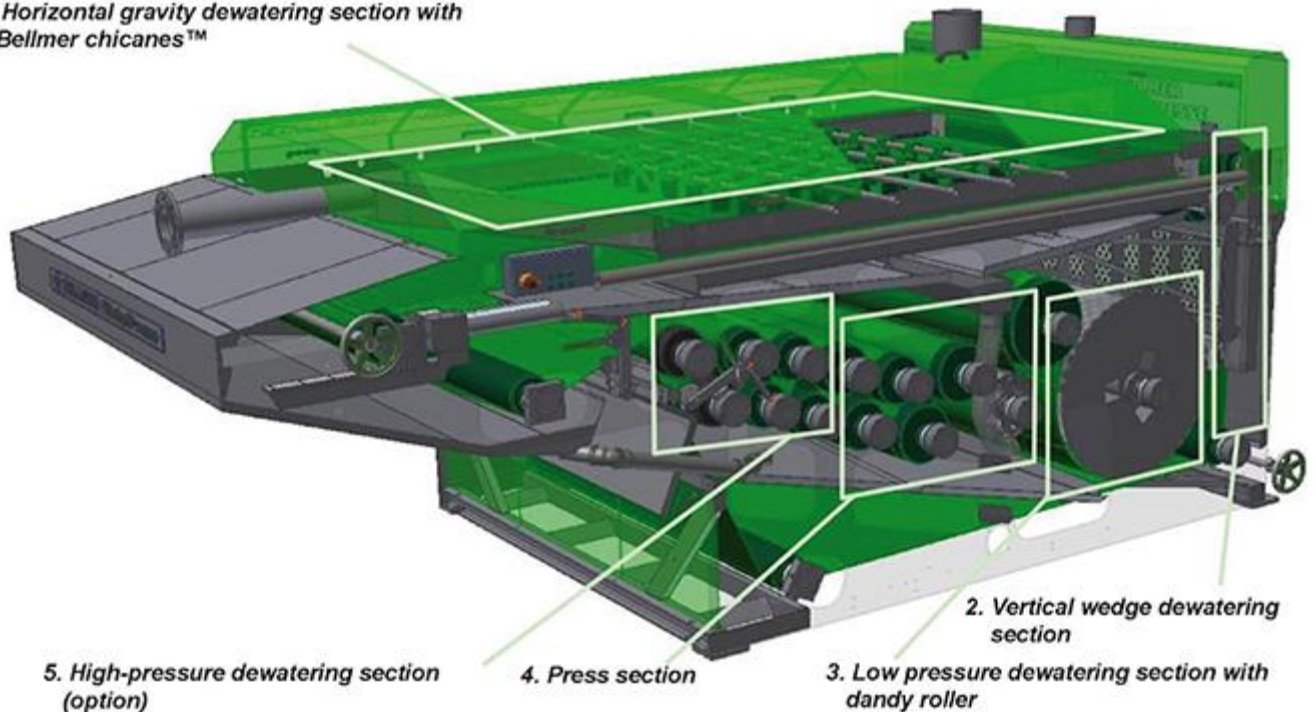


Diagram of a decanter centrifuge. Picture: Company Flottweg SE.

Belt filter press

The key elements of a *belt filter press* are the frame that supports the integrated sludge feed, the upper and lower belt systems for gravity drainage and pressing, the belt guidance and wash systems and the sludge discharge. Modern models often include an integrated enclosure to suppress the splashing of sludge and filtrate and the release of vapour, mist and malodorous gases. A proper design can also include a separate local air exhaust hood above the belt filter press unit.

1. Horizontal gravity dewatering section with Bellmer chicanes™



Scheme of a belt filter press. Picture: Company Bellmer GmbH.

Chamber filter press

A *chamber filter press* consists of a series of filter chambers containing filter plates supported in a frame. The sludge is fed in a batch manner. Loaded filter chambers are forced together with hydraulic rams. The sludge is squeezed in few seconds by up to 60 bar pressure in the press. The dewatered sludge is then discharged from chambers by opening the filter plate and shaking cloth or plate. The chambers and filter cloth are washed regularly to ensure continuous good filtration results and a longer durability of the cloths. An improved version of the chamber filter press is the *membrane filter press*, which reaches a DS content that is 2–3 % higher due to an additional membrane between the filter cloth and the filter plate.



Chamber filter press in Lübeck, Germany. Photo: Entsorgungsbetriebe Lübeck.

Hydraulic press

The hydraulic press belongs to the innovative solutions of sludge handling and it can be considered to be worth considering for municipal sludge dewatering, especially in special

cases where the dewatering properties are poor and/or high dry solids content is needed. The hydraulic press application was developed for the solid-liquid separation of biological substances. There are several installations of one supplier in Germany, Austria and Switzerland, and one installation in the Baltic Sea Region, the Käppala waste water treatment plant in Stockholm.



Hydraulic presses. Photo: Company Bucher Unipektin AG, Switzerland.

Innovative methods: With the KEMICOND treatment, the hydraulic press reaches up to 50 % DS in the waste water treatment plant in Stockholm. Even though this procedure is performed with the hydraulic press, it would be possible with all other dewatering devices as well.

Summary of the main dewatering methods

	Centrifuge	Belt filter press	Chamber filter press		
			Polymer conditioning	Lime	
Dewatering result: - aerobically stabilised - digested sludge	18–24 %	15–22 %	18–24 %	28–35 %	20–35 % 1
	22–30 %	20–28 %	22–30 %	30–40 %	- -
Flocculant aid consumption	4–14 g/kg DS	4–12 g/kg DS	5–12 g/kg DS	Lime 15–25 kg/m ³ and iron	5–12 g/kg DS
Energy consumption	High	Low	Medium	Medium	Medium
Automatic and continuous	Yes / Yes	Yes / Yes	No / No	No / No	Yes / No
Investment costs	Medium	Medium	Very high	Very high	Very high
Applications	Large, medium-size, small plants (mobile unit)	Large, medium-size, small plants (mobile unit)	Large plants	Large plants	Large plants
Examples of use in the Baltic sea region	FI (Helsinki, Tampere), EE (Tallinn, Kohtla-Järve), RU (St. Petersburg), LV (Riga, Jurmala), DE (Hamburg), PL (Warsaw, Gdansk, Szczecin)	EE (Tarto, Viljandi), FI (Pälkäne), PL (Szczecin-Pomozany), DE (Lüneburg)	Some plants in Northern Germany	DE (Kiel, Lübeck)	SE (Stockholm Käppala)

Overview on dewatering methods and their use in the Baltic Sea region. DS = dry solids.

PURE Partner	Sludge type	Dewatering device	BioP	DS	Flocculation aid consumption
Kohtla-Järve	No digestion	Centrifuge	Yes	22 %	8 g/kg DS
Riga	Digested sludge	Centrifuge	Yes	19 %	8 g/kg DS
Jurmala	No digestion	Centrifuge	Yes	18 %	5.4 g/kg DS
Gdansk	Digested sludge	Centrifuge	Yes	19.7 %	11.4 g/kg DS
Szczecin Pomorzany	Digested sludge	Centrifuge	Yes	20 %	8–12 g/kg DS
Szczecin Zdroje	Digested sludge	Belt filter press	Yes	19 %	5.3 g/kg DS
Lübeck ZKW	Digested sludge	Chamber filter press	No	37 %	500 g/kg DS (lime)

PURE partner comparison of digestion and dewatering. BioP = biological phosphorus removal; DS = dry solids.

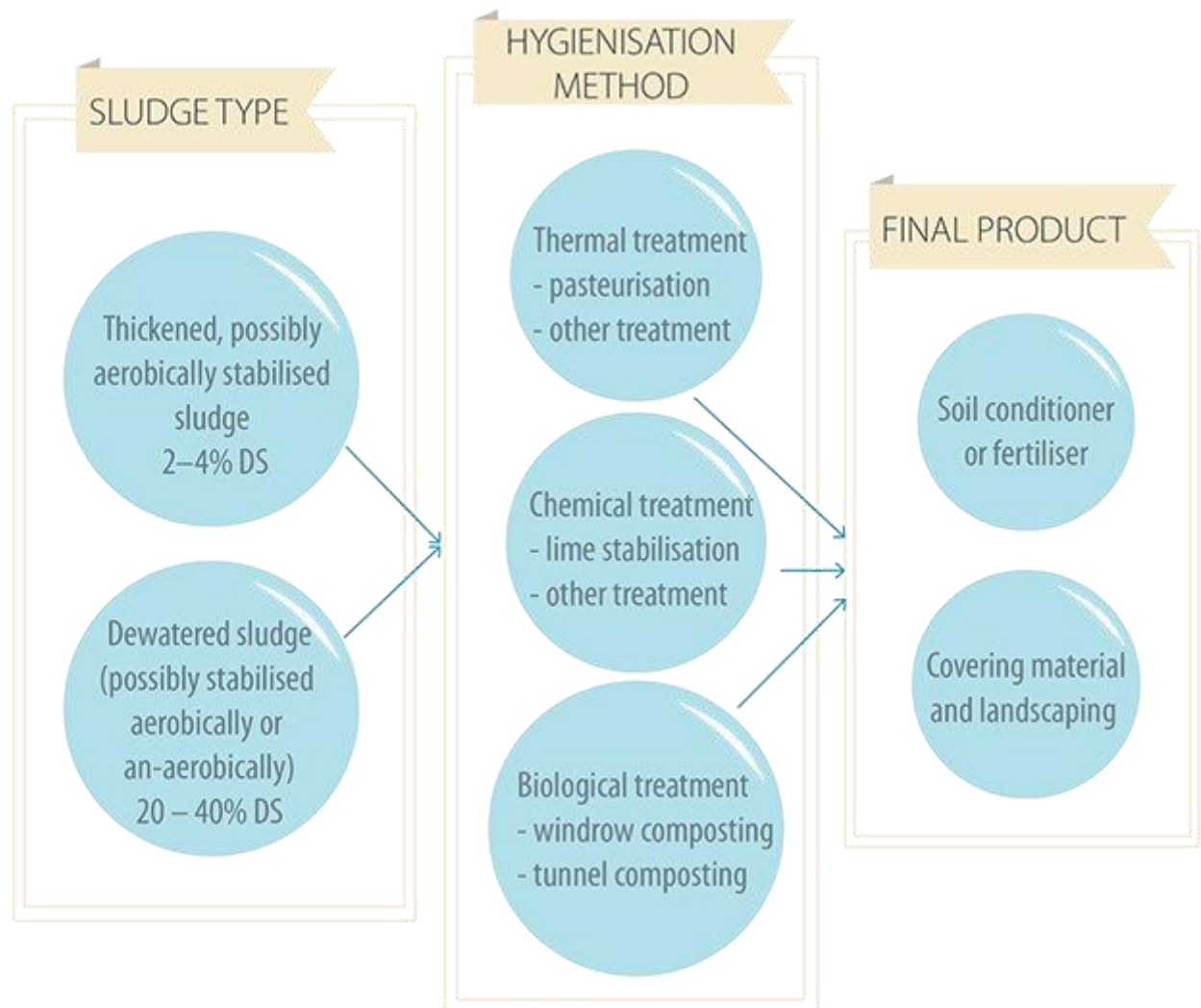
Sludge hygienisation

Municipal sewage sludge hygienisation or disinfection is a procedure to reduce the content of pathogenic bacteria in the sludge below a certain level, which is accepted by the competent authorities. The need for hygienisation depends on the sludge disposal method and is important for agricultural disposal and for disposal to landscaping. Guidelines have been issued by the WHO, as well as German and Swedish authorities although parts are only available in German and Swedish (SNV, 2003, Umweltbundesamt, 2009 and WHO, 2003).

Hygienisation can usually be achieved with two different types of treatments:

- elevation of sludge temperature above 55–70 °C for a certain period of time; and
- elevation of the pH value of the sludge above 12 for a certain period of time.

During the treatment, the bacteria should be eliminated and verified with the relevant measurements.



The principles of sludge hygienisation.

Thermal treatment

In thermal disinfection, the temperature of the sludge is raised to a level at which the bacteria are destroyed. Thermal hygienisation is recommended and sometimes required if animal remains and slaughterhouse waste are treated in the digester together with the municipal sewage sludge.

There are several methods that provide high temperatures for hygienisation:

- (pre-)pasteurisation;
- thermal conditioning;
- drying;
- anaerobic thermophilic stabilisation;
- aerobic thermophilic stabilisation;
- aerobic thermophilic pre-treatment; and
- composting.

Pasteurisation is the most commonly used method for thermal hygienisation. It was developed in the 1860s and commonly used for food preservation. In waste water treatment plants, primary and excess sludge are heated in a hygienisation tank to a temperature of more than 65 °C but less than 100 °C. The retention time has to be 30 minutes at 65 °C, 25 minutes at 70 °C and 10 minutes at 80°C. The legal framework of each country specifies the conditions for the pasteurisation



Pasteurisation plant in Kohtla-Järve, Estonia. Photo: OÜ Järve Biopuhastus.

Chemical treatment

The hygienisation of sludge can be achieved with the help of calcium chemicals (CaO or Ca(OH)_2) by increasing and maintaining the pH value of sludge at a level of about 12 for as long as biological activity ceases. The minimum time for hygienisation is 2 hours. The dosing is usually regulated by measuring the pH value, and the consumption of lime depends on the hardness and other chemical properties of waste water.

Operation and maintenance of this treatment is relatively simple: chemical dosing equipment and a storage silo is needed together with a mixing unit for the sludge and chemicals. The following need to be taken into account when using lime for hygienisation:

- the total sludge amount increases and thus the disposal costs increase;
- pH value increases – lime-treated sludge is of good quality for agriculture;
- an acid washer may be required for air emissions of ammonia;
- chemical safety is important because of the high alkalinity; and
- the needed chemical dosing is up to 300–400 kg per tonne of DS.



Sewage sludge, conditioned with milk of lime and then dewatered. Photos: Entsorgungsbetriebe Lübeck.

Biological treatment

Composting is an aerobic bacterial decomposition process to stabilise organic wastes and produce humus (compost). Composting is a simple and proven technology to achieve hygienisation (60°C for 3–6 days) and to produce useful products like compost and fertilizers. The national legislation should be taken into account since in some countries, the required composting time can be significantly longer than six days.

For composting sludge, its dry solids content should be increased to at least 15 % DS so

that it can be handled as a solid. Thickening and dewatering primary and excess sludges are required to achieve this dry solids content. This method can also be used for anaerobically stabilised (digested) and thereafter dewatered sludge. Mixing with bedding materials, such as dry sawdust, may assist in achieving the required solids content as well as attaining the required carbon to nitrogen ratio for composting.

Composting technologies available in the Baltic Sea Region range from simple open windrow systems with a small effort in terms of process structures to fully enclosed composting plants with accelerated treatment processes, complete enclosure and a high quality treatment of exhaust air. The various technologies are largely proven and well understood in their capabilities and limitations. The most feasible for sludge handling are windrow composting and tunnel composting technologies. The operation and maintenance of both methods are relatively simple and only require a basic understanding of the biology and biochemistry of composting.



Composting of waste water sludge in Helsinki, Finland and Kohtla-Järve, Estonia.
Photos: HSY Water and OÜ Järve Biopuhastus.

Summary of hygienisation methods

Small WWTP	Medium WWTP	Large WWTP
Thermal treatment		
-	Pasteurisation	Pasteurisation
-	Aerobic thermophilic stabilisation	Aerobic thermophilic pre-treatment
-	-	Thermal conditioning
		Anaerobic thermophilic stabilisation
Drying (solar, see chapter 7)	Drying (solar)	Drying (thermal)
Chemical treatment		
Treatment of sludge of low DS with milk of lime	Treatment of sludge with low DS with milk of lime	
-	Conditioning with milk of lime in chamber filter press	Conditioning with milk of lime in chamber filter press
Use of burnt lime after dewatering (mobile)	Use of burnt lime after dewatering (mobile or stationary)	Use of burnt lime after dewatering
Biological treatment		
Composting in windrows with dewatering technique	Composting in windrows with dewatering technique	Composting in windrows with dewatering technique
-	Composting in tunnels with dewatering technique	Composting in tunnels with dewatering technique

Overview of different hygienisation methods. Depending on regulations and costs (energy, personnel, investment, chemicals) the classification may change (based on UBA 2009). DS = dry solids, WWTP = waste water treatment plant.

The practised hygienisation methods differ between the Baltic Sea Region countries. The most used methods are composting, lime treatment and pasteurisation. In Finland and Estonia, composting is state-of-the-art, while in Germany lime treatment is common. Some methods are not applied in the Baltic Sea Region, like solar drying and drying for agricultural use, aerobic thermophilic stabilisation and pre-treatment, and anaerobic thermophilic stabilisation. Thermal conditioning is used but seldom for hygienisation, because the energy demand is much higher when primary sludge is also treated. Among the PURE partners, hygienisation is in use in Kohtla-Järve, Estonia, and Lübeck, Germany

	Composting	Lime treatment	Pasteurisation
Investment costs	High	Low-medium	Medium
Energy demand	Low	Low	High
Chemicals demand	No	Yes	No
Structure material needed	Yes	No	No
Sludge dewatering needed	Yes	No	No
Space needed	High	Low	Low
Hygienisation result	Medium – good	Medium/Good	Very good

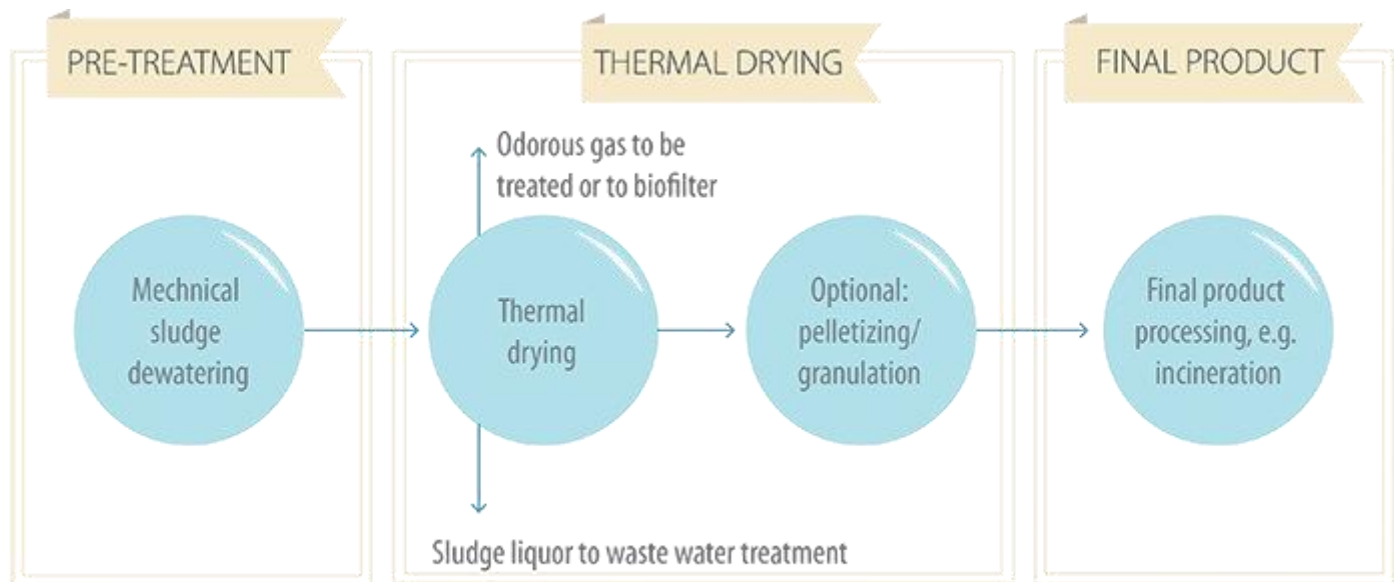
Comparison of the most common hygienisation methods in the Baltic Sea Region.

Sludge drying

Thermal drying is a technology that aims to significantly reduce the water content of sludge. Drying is mostly used in large waste water treatment plants to increase the heat value of sewage sludge for incineration. Also, drying for agricultural disposal is possible, but not often practised because of its high costs. The removal of water by evaporation from the treated and dewatered sludge increases the dry solids content of the sludge, and reduces both sludge volume and weight. Sludge drying is applied for dewatered (20–30 % DS) primary and/or excess sludges as well as digested sludge after dewatering. Due to the high investment costs, it is usually restricted to large plants. After drying, the solids content is between 50 and 90 %.

The thermal drying process typically includes material handling and intermediate storage; it is preceded with sludge dewatering and sludge silos, and requires heat generation and distribution equipment, a thermal dryer unit, a biological filter for exhaust gases, a post-processing unit like pelletizing, and storage for the final product.

Thermal drying is based on the use of heat to evaporate water from the sludge after dewatering. The energy input in dewatering is much lower than in drying, thus a high DS content after dewatering is required. Thermal drying processes are divided into two main categories – direct (convection drying) and indirect (contact drying) heating. This classification is based on how the thermal energy is applied to the sludge in order to increase the temperature.



Principles of thermal drying.

Direct drying

In *direct drying* of sludge, heat convection is achieved with direct contact with hot air or hot gases. The sludge's temperature is increased and water is evaporated. Typical direct drying equipment is a rotary drum dryer or belt dryer. Temperatures of about 450–460 °C (drum) or 120–160 °C (belt) are applied for about 5–10 minutes (drum) or 40–60 minutes (belt dryer).

Indirect drying

In *indirect drying*, a solid wall separates the sludge from the heat transfer medium, usually hot water, oil or steam. Typical, indirect drying equipment include vertical tray dryers and horizontal disc, paddle or spiral dryers as well as fluidised bed dryers. Temperatures of about 160–200 °C for steam as the heating medium and 190–240 °C for thermal oil are applied with disc dryer for 45–60 minutes, for example. The product temperature is 85–95 °C during the drying stage and exhaust air temperature is 95–110 °C.



Disk dryer in Gdansk, Poland. Photo: GIWK.

Summary of the main thermal drying methods

Technology	Features	Remarks
Direct heating (45 – 90 % DS)	Sludge is in direct contact with the heat transfer medium. Rotary drum or belt dryers are typical equipment.	Cost from EUR 0.5 to EUR 2 million. Installed power 150–200 kW. Consumption of electrical energy 70–100 kWh/t DS.
Indirect heating (45 – 90 % DS)	Sludge is not in direct contact with the heat transfer medium; e.g. tray, paddle or fluidised bed drying equipment is used.	Secondary heat can be utilised to save in energy costs. Maintenance of explosion risk zones needed.

Direct heating and indirect heating summary. DS = dry solids.

Thermal drying is a well-known and a proven technology in central Europe where it has been applied on both large and medium scales. The Baltic Sea Region has operational experience in thermal drying, for example in Copenhagen, Denmark; Hetlingen and Hamburg, Germany; and more recently in Finland (Ekokem, Riihimäki) and Poland (e.g. in Cracow, Gdansk, Łódź, Szczecin). Solar drying is used in Bredstedt (Germany).

Sludge incineration

Sewage sludge is a good fertiliser because of the high concentrations of phosphorus and nitrogen; however, it can also be a sink for contaminants. In addition to various organic substances, heavy metals may end up in the sludge and pollute the environment. This is why sludge incineration has become more common in recent years. It is also possible to receive a positive energy balance out of incineration and utilise the calorific value of sludge. The main driver for sludge incineration has, however, been the fact that the amount of sludge generated at municipal waste water treatment plants is very large compared to the land area available for the disposal or treatment (e.g. composting) of the sludge.

In the EU, the new Waste Framework Directive (Directive 2008/98/EC) is transposed or being transposed to the national legislation of the member states. The new directive will encourage the material recycling of sludge and limit the disposal of organic matter to landfills. The former requirement is likely to promote the disposal of sludge to agricultural land, provided that it is otherwise accepted by the farmers and competent environmental and agricultural regulatory authorities. The latter requirement will encourage or oblige the sludge producers to incinerate sludge unless it cannot be otherwise disposed of.



Incineration in Szczecin, Poland. Photo: ZWiK Szczecin.

Sludge can be either *co-incinerated* with other sources of energy, such as municipal solid waste or fossil fuels, or *mono-incinerated* using other fuels only as support. The design criteria for sludge incineration in different types of boilers depend on the mixture and heat values of different fuels. Sludge incineration is applied for digested, dewatered and possibly dried sludge. Sludge may be incinerated without drying and without digestion; however, in this case additional fuel is often required.

Co-combustion

The co-combustion of mixtures of different solid, liquid and gaseous fuels has been applied for decades and can thus be considered proven technology. The incineration of municipal or industrial waste water sludges is more common in Germany and Finland than the other countries in the Baltic Sea Region. Both grate-firing and fluidised bed technologies are applied with co-combustion.

Sludge and municipal solid waste co-incineration with grate firing are well-known and proven technologies in central Europe. This technology is not yet very widely applied in the Baltic Sea Region except for Germany, where co-incineration with coal has been practised in e.g. Bielefeld, Bremen Farge, Duisburg and Veltheim.

Mono-combustion

Mono-combustion is usually designed for the simple destruction of sludge without energy recovery because the net heat value of sludge does not produce excess energy. If the sludge is digested, the heat value is even lower. The typical heat value of the dry solids of sludge is about 3 MJ/kg DS. The mono-combustion therefore only consists of fuel reception, mixing and feeding systems, a furnace with burners of support and start-up fuels like oil, natural gas or coal, or biogas from digestion. Fluidised bed technology is, in practice, the only suitable technology for mono-combustion.

Sludge and solid waste incineration with fluidised bed technology are well known and proven technologies in industrial plants in the Baltic Sea Region. They have been applied in a few large waste water treatment plants for the mono-combustion of sludge, for example in Copenhagen, Denmark; St. Petersburg, Russia; and in Poland (e.g. in Cracow, Gdansk, Lodz, Pomorzany and Szczecin). Outside the Baltic Sea Region, this technology has been applied in the UK, the Netherlands, Switzerland, Austria, France and Italy.

Summary of incineration methods

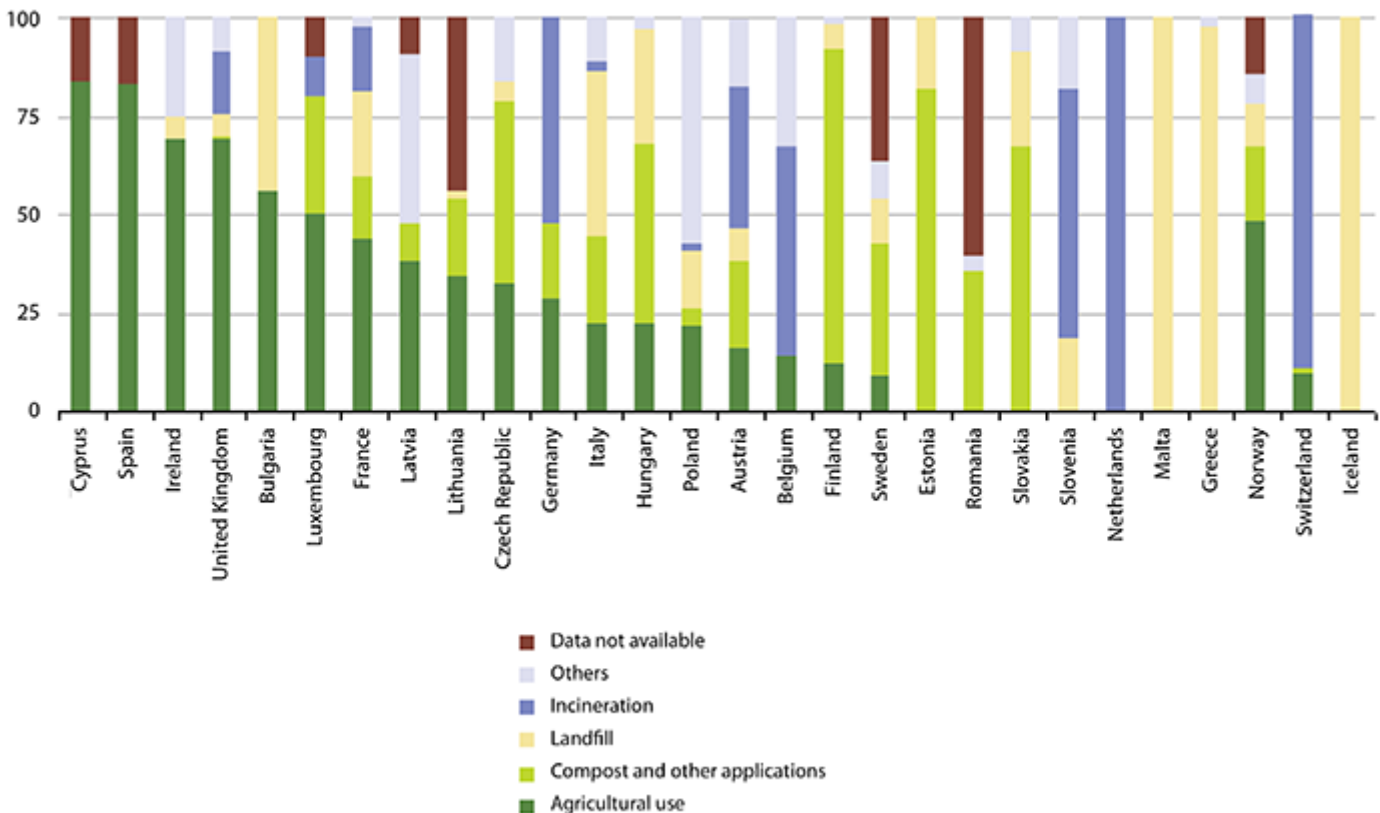
Technology	Features	Applicability	Remarks
Grate-fired combustion	Combustion in a furnace at 850–1 000 °C which consists of a grate floor and refractory lined furnace.	Not suitable for mono-incineration of sludge. Applicable for co-combustion of sludge, and the share of sludge < 20 %.	Investment costs EUR 60 million to EUR 100 million. Installed power 300–500 kW. Requires additional 4–5 persons with special competences; the plant is not normally operated by the waste water plant personnel.
Fluidised bed combustion	Combustion in a furnace at 850–950 °C which consists of a boiler floor made of fluidising nozzles, refractory lined furnace and sand bed.	Suitable for both mono-combustion and co-combustion of sludge.	Investment costs EUR 20 million to EUR 40 million. Installed power 400–600 kW. Requires additional 4–5 persons with special competences; with mono-incineration it can be operated by the waste water plant personnel.

Grate-fired and fluidised bed combustion.

Disposal of sewage sludge or ash from incineration

In the past, sewage sludge has been disposed to landfills, stored in huge sludge ponds, dried in the sun in arid climates or dumped to the oceans. More recently, beneficial uses for dewatered sludge and ash from sludge incineration have been developed. The more advanced methods of sludge or ash disposal are usually targeting to reuse the composted or digested sludge in agriculture as a fertiliser or in landscaping, or reuse phosphorus and/or nitrogen in agriculture as an additional fertiliser.

In Europe and in the Baltic Sea Region countries there are various sludge disposal strategies in use. Countries like the Netherlands, Belgium and Switzerland have forbidden or restricted the agricultural disposal of sewage sludge and is incinerated. Other countries like Finland, Estonia and Norway use composted sludge for green areas, for example. Some countries like Iceland, Malta and Greece are or have been completely disposing to landfill. In Russia and Belarus, collecting sludge to sludge pits or ponds is common.



Sewage sludge disposal from urban waste water treatment, by type of treatment, 2009* (% of total mass). Source: Eurostat.

- Belgium, Germany, Luxembourg, the Netherlands & Austria, 2008; the Czech Republic, Ireland, Latvia & Slovakia, 2007; Greece & Switzerland, 2006; Italy, Cyprus and the United Kingdom, 2005; France and Hungary, 2004; Iceland, 2003; Sweden, 2002; Finland, 2000; Denmark and Portugal, not available.

Use in agriculture

The use of municipal waste water sludge in agriculture has been practised in the Baltic Sea Region for at least 40 years. The interest for agricultural disposal of sludge varies from country to country. Also, within the borders of one country like Germany, the differences can be significant: in northern Germany, the share of agricultural disposal is over 60 %, whereas in the southern part of the country it is under 20 %. Pollutants, as well as the possibility of hygienic contamination, have raised scepticism among the agricultural sector, politicians and the public towards the agricultural use of sludge. New phosphorus recovery technologies are anticipated to allow the recycling of nutrients from sludge to agricultural use in the near future.

Disposal to landfill

In the European Union, a widely applied practice has been to dispose of the sludge that cannot be used in agriculture or landscaping to landfills. Landfills also require landscaping when a certain landfill area has reached its final height and sludge has been suitable material for this purpose. The only quality requirement for landscaping landfills with sludge is that it cannot be in liquid form, corresponding to the general restrictions to dispose of any liquid materials to landfills. The recent limitations or bans on the disposal of biodegradable material to landfills will also limit the disposal of sludge to landfills and the use of composted sludge as a landscaping material in the long run. This limitation does not exist in the non-EU-countries.

Disposal of sewage sludge ashes from mono-incineration

Sewage sludge ash is the product of sludge incineration. Only ashes from the mono-incineration of sludge and mixtures with other ashes with high concentrations of phosphorus and other nutrients can be used for further treatment and recycling. Ashes from co-incineration have a very low concentration of phosphorus and possibly too high contaminant levels if co-incineration takes place, for example, with municipal household waste – and are usually disposed to landfill. Sludge burned in a cement factory does not have a disposal problem because the ashes are bound in the product.

Summary of the disposal methods

- Several methods to dispose of sludge exist; the sludge disposal strategies followed by each country in the Baltic Sea region are not uniform.
- The agricultural use of sludge or incineration and the disposal of ashes allow the utilisation of sludge as a material or energy resource; these are quite common methods in the region.
- Composted or otherwise hygienised sludge is used in some countries in the region for green areas such as parks.
- The availability of nutrients in the sludge depends on the waste water treatment process in use.
- Contaminants present in the sludge restrict its use for agricultural purposes: although concentrations of heavy metals have been reduced in many countries, some new concerns have emerged.
- Ash from only mono-incinerated sludge is phosphorus-rich and contaminant-free enough to be used in agriculture.
- The availability of nutrients is low in ashes and requires additional treatment methods which are still under development work.
- Sludge pits and ponds are still used in some parts of the region; this is not a sustainable way of managing sludge, as its use as a material, together with the nutrients and energy potential are lost; also, leaking sludge storage areas pose a potential threat to the water environment.
- Using sludge for landfilling will be reduced in the coming years in the EU due to new regulations and an increasing interest to recycle the nutrients from sludge.

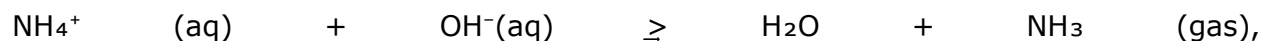
Reject water treatment

Internal reject waters from anaerobic digestion, overflow from the anaerobic digester, sludge dewatering or condensates from the thermal drying contain significant loads of nitrogen, phosphorus and suspended solids. Therefore, several treatment methods for reject water have been studied and introduced in many waste water treatment plants. Also, filtered liquor from the post-processing (composting) and storage fields of digested sludge is classified as reject water. External reject waters come, for instance, from regional treatment plants for waste or sludge.

Reject water after digestion is often very concentrated. Most of the reject water treatment methods target to reduce its nitrogen content as the waste water treatment process is sensitive to high loads of nitrogen, especially if not fed continuously. The reject water load can be reduced either with chemical and mechanical or biological treatment methods. The amount of reject water can be estimated if the quality and amount of the used feed sludge is measured and the digestion process is stable. Essential for the reject water quality is how well the sludge dewatering works and what kind of sludges are used.

Physical/chemical treatment process

There are different possibilities for the physical or chemical treatment of reject water. Most treatment processes are designed for nitrogen removal, e.g. the use of zeolite or ammonia stripping. The most common chemical treatment process for nitrogen removal is ammonia stripping. Ammonia can be removed from water by the balance reaction between ammonia nitrogen ($\text{NH}_4^+\text{-N}$) and ammonia (NH_3). The following balance reaction is utilised in ammonia stripping:



where (aq) means aqueous solution. The stripping takes place by increasing the pH value. The higher the pH, the more $\text{NH}_4\text{-N}$ is in ammonia form. At high pH (> 10) most of the ammonia nitrogen is in NH_3 form.

There are some references of stripping process in Finland at Biovakka Oy's sludge and biowaste biogas productions sites in Topinoja, Turku and Vehmaa. The Topinoja plant only treats municipal sludge from Turku's waste water treatment plant, while the Vehmaa plant treats municipal sludges with animal manure from large-scale agriculture. Ammonia stripping is a process that is mainly used in industry at processes with very high nitrogen loads. It is not very often used at waste water treatment.

Biological treatment processes

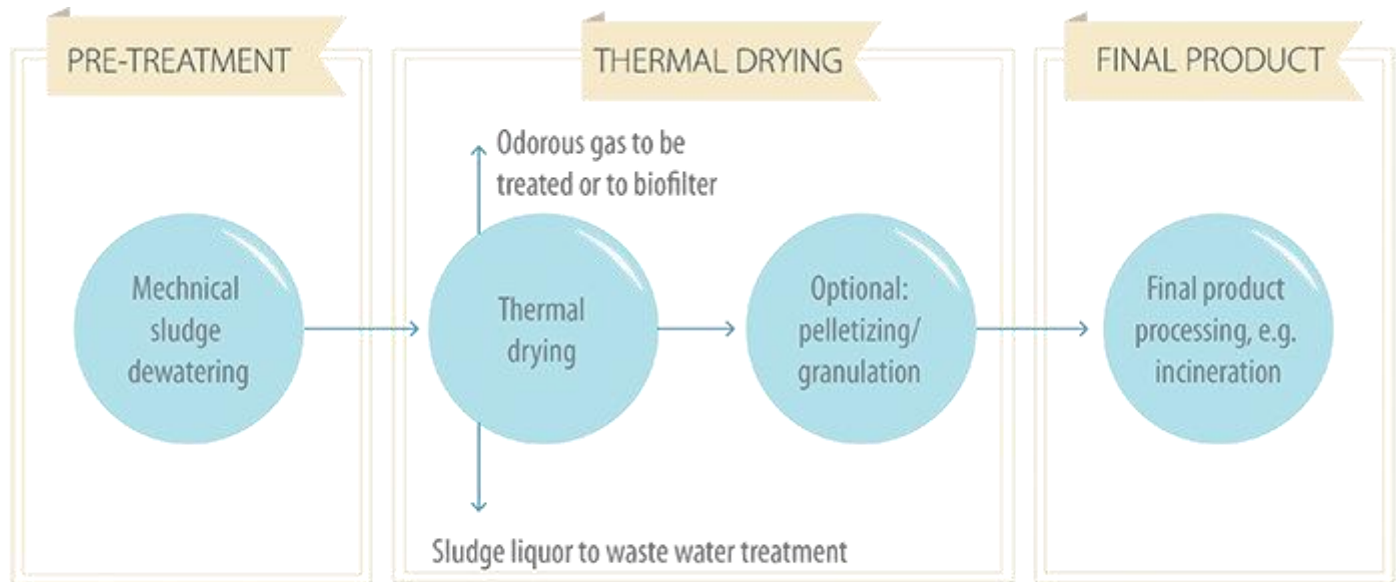
The biological technologies for reject water treatment are the same as for nitrogen removal in general. The most common is the traditional *denitrification-nitrification process (DN process)*, which is boosted with an external carbon source for better denitrification. The carbon source is needed to reach a favourable ratio of nitrogen and carbon. In practice, this method has not been functioning satisfactorily and therefore alternative methods have been developed. The methods are not yet widely proven.

A development of the denitrification and nitrification process is the *nitritation and denitritation* process. The *deammonification* process was developed in the 1990s, and

many plants utilising it are in operation in the Netherlands. The most challenging point of all these processes is the process control, which has to be stable, for example:

- the temperature requirement when the operating temperatures are under 30 °C; and
- the suspended solids requirement when the solids content is high.

Another biological reject water treatment method is the *enhanced nitrification-denitrifying process* in a sequential batch reactor (SBR), the commercial application being the *BABE® process*.



Reject water treatment with the nitrification-deammonification process.

In the Baltic Sea region, the nitrogen reduction requirements in waste water treatment plants have become stricter. The internal reject water load can be even 20 % of the whole ammonium nitrogen load. The capacity of the activated sludge treatment process is often not sufficient for such a high load and therefore the reject waters are preferably treated separately.

There has been full-scale operation experience of the biological process worldwide since 2005. One example is at Lakeuden Etappi, in Seinäjoki, Finland, which is handling waste water sludge and municipal biowaste from households. There is a new plant starting up in Kokkola, Finland, using only waste water sludge as the feedstock. The municipal waste water treatment plant Himmerfjärdsverket in Sweden has a carrier-based nitrification-deammonification process and the waste water treatment plants in Linköping (since 2009) and Helsinki have tested SHARON. The waste water treatment plant in Helsinki took the nitrification-deammonification process in use for a part of their reject waters during spring 2012. In the Netherlands, the SHARON process is in operation in Rotterdam, Utrecht and Zwolle, for example.

Summary of main reject water treatment methods

Technology	Features	Applicability	Remarks
DN process	A traditional DN process. External carbon source needed to achieve good nitrogen removal.	Earlier used for reject waters from the digestion of primary and excess sludges. Not used anymore because new processes are more efficient and reliable.	Investment costs from EUR 1.5 million to EUR 3 million. High operational cost because of an external carbon source (e.g. methanol).
Nitrification-denitrification process	A process without nitrification. Less energy consumption and less carbon source needed.	Sometimes used for reject water treatment as pre-stage to the deammonification process.	Investment costs from EUR 1.5 million to EUR 3 million. Operational costs are much lower compared with a DN process.
Nitrification-deammonification process	An activated sludge treatment process, producing molecular nitrogen from nitrite and ammonia. Optimal operation at 30–40 °C and minimum temperature of 25 °C.	Used for reject waters for the digestion of primary and excess sludge and applicable in medium-size and large waste water treatment plants.	Investment costs EUR 1 million to EUR 2 million. Low operational cost makes this process attractive. Installed power 20–40 kW.
Ammonia stripping	A chemical process producing a nitrogen rich fertiliser (ammonia salt).	Used for reject waters for the digestion of primary and excess sludge and applicable in medium-size and large waste water treatment plants.	Investment cost EUR 2 million to EUR 4 million. Operational cost is very high and may be a reason not to choose the alternative.

Comparison of different reject water treatment methods. DN process = denitrification-nitrification process.

Recovery of phosphorus from sludge handling

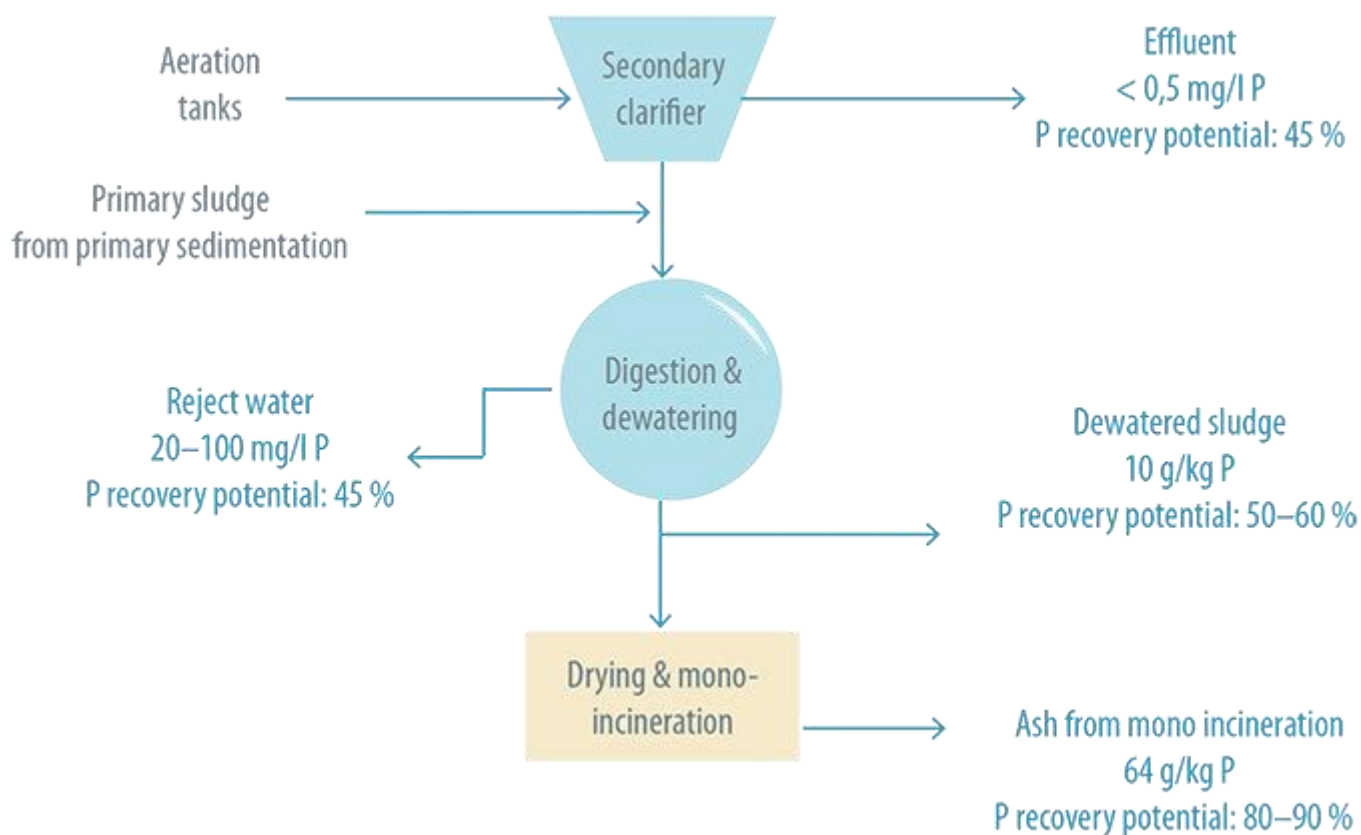
*Phosphorus is an essential plant nutrient that is used for the fertilization of field crops and also in consumer products such as detergents. Phosphorus is often the limiting factor for plant growth, and discharges of phosphorus in rivers, lakes and seas cause and excessive growth of plants and algae, i.e. a process called **eutrophication** with many negative consequences in the water ecosystems. Phosphorus, on the other hand, is a limited resource, which is mined only in some parts of the world, e.g. in Western Sahara (Morocco), China and the United States. Worldwide consumption of phosphorus (as P_2O_5 contained in fertilisers) has been projected to grow at a rate of 2.5% per year over the next 5 years, with the fastest increases in Asia and South Africa (USGS, 2012)*

Avoiding the use of phosphorus is the best possibility of saving this resource, for example

in detergents like it is done in some countries (PHöchstMengV in Germany 1980, or the amendment of EU Directive EC 648/2004 on detergents). With the help of phosphorus recovery, it is possible to partly replace the production from apatite and the import of phosphorus. Recoverable phosphorus sources are:

- waste water, sewage sludge and ash from mono-incineration;
- ground animal bones and similar products;
- animal manure; and
- food waste.

Different research initiatives have been launched during recent years, for example in Scandinavia and in Germany, to recover phosphorus from sewage sludge. Individual countries have taken phosphorus recycling as an objective to their long-term strategic plans or new technology programs.



Different possibilities of phosphorus (P) recovery, typical concentrations of phosphorus and the recovery potential. Numbers: Jardin, 2010 and Adam, 2009.

The nutrient recycling methods are still emerging technologies primarily developed in Europe and in North America, but the number of pilot and demonstration plants is growing rapidly. These technologies cannot yet be considered to be fully proven since the several demonstration applications have faced serious start-up problems – some have even been shut down. The technologies presented below here cannot be recommended for a wider use. Overall, they are all expensive and not yet economical.

Recovery from waste water or sewage sludge

The potential of recovery from waste water and sewage sludge is much lower than from the ashes of mono-incinerated sludge. Phosphorus can be recovered from the excess sludge, reject water, dewatered sludge and also from the effluent. The effluent of the waste water treatment plant is not recommended due to too high volume and too low concentrations of phosphorus.

Additional processes to conventional waste water treatment have been recently summarised by Adam (2009), and can be based on:

- *Precipitation* such as PRISA process or AirPrex process; and
- *Crystallisation* such as Ostara PEARL, Unitika PHOSNIX, CSH process Darmstadt or DHV Crystalactor.

There are plants from pilot-scale to demonstration scale with Ostara PEARL, Unitika PHOSNIX, AirPrex and DHV Crystalactor with capacities ranging from 20 to 250 m³/h. Although the results are more or less encouraging, more development work needs to be carried out to increase the cost-efficiency and the end-use of the recovered phosphorus. With many of the above-mentioned methods, scaling of precipitated chemicals in pipes, pumps and the surfaces of the tanks has been a problem, that needs to be solved before the technology can be considered proven (Adam, 2009).

There are several **wet chemical processes** applied to sludge in different DS contents and with using acid, pressure, heat and oxidizing agents. The most common are the following processes (Adam, 2009): KREPRO, LOPROX, Aqua Reci and Seaborne (or Gifhorn).

The Mephrec process is a **thermal method** to recover phosphorus (Adam, 2009, Scheidig, 2009 and Petzet and Cornel, 2011). Mephrec is able to use dewatered sludge as well as also ashes out of mono-incineration. The process utilises smelting-gasification technology using metallurgical coke in temperatures of about 2000 °C, and produces slag containing most of the phosphorus.

Recovery from ashes

In the ashes from mono-incinerated sludge, phosphorus is available in a high concentration, but it is chemically bound. Organic matter is burned and all harmful organic substances are destroyed. Mercury is cleaned in the flue gas treatment after incineration. All the other heavy metals, however, are present in higher concentrations than in dewatered or dried sludge. Disposing the ashes to landfill means a loss of resources and therefore cannot be recommended. Ashes from co-incineration often have too low phosphorus concentrations for phosphorus recovery caused by mixing with waste or coal.

There are different possibilities to reuse the phosphorus from mono-incinerated sludge:

- use of the ash after a treatment to increase the bioavailability (e.g. RecoPhos); or

- separation of heavy metals and treatment to increase the bioavailability (with acids and base by PASH and BioCon; thermal chemical by AshDec and Mephrec (Petzet and Cornel, 2010)).

Summary of main phosphorus recovery methods

In 2012, many different methods and technologies are partly being employed – sometimes on a full-scale basis. Nearly all techniques have some problems, including high costs and less efficiency than planned. Many studies are being carried out in several countries, and thus a feasible technical solution is expected in the near future. Marketing these products could begin in some years, although this development also depends on the global price of the phosphate rock.

Relevant legislation in the EU and Baltic Sea Region countries

In this section, the relevant legislation of the European Union concerning sludge handling is presented and briefly described, with most attention paid to the EU Sewage Sludge Directive. Further, the chapter concentrates on the national legislation of the states in Baltic Sea Region, both EU and non-EU members. Many legal restrictions concerning different sludge handling possibilities are identified.

EU level legislation on sewage sludge handling

EU regulations concern the other states around the Baltic Sea except Russia and Belarus. The legal framework established by the European Union and regulating the ways of sludge treatment and disposal mostly consists of directives, which should be incorporated into the national legislation systems of the member states. In their final provisions, each directive gives national legislators a timetable for the implementation of the expected outcome (in case the directive sets out precise objectives, e.g. the Landfill Directive), and also reporting and communication rules.

The directives have been adopted during past two decades, which has resulted in the varying levels of strictness of their requirements. Several member states have already managed to substitute two or more laws designed to implement one directive. As a consequence, there are currently more stringent rules on sludge handling in some of the EU countries than in others, and thus there is an urgent need for revision, particularly of out-of-date directives.

The EU legislative acts affecting the treatment and disposal of waste water sludge as per 1 September 2011 are the following (in chronological order, according to the day of adoption):

1. *COUNCIL DIRECTIVE of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC) – **The Sewage Sludge Directive***
2. *COUNCIL DIRECTIVE of 21 May 1991 concerning urban waste water treatment (91/271/EEC) – **The Urban Waste Water Treatment Directive***

3. *COUNCIL DIRECTIVE of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC) – **The Nitrates Directive***
4. *COUNCIL DIRECTIVE of 26 April 1999 on the landfill of waste (1999/31/EC) – **The Landfill Directive***
5. *DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 December 2000 on the incineration of waste (2000/76/EC) – **The Incineration Directive***
6. *COMMISSION DECISION of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EU establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC in hazardous waste (2000/532/EC)*
7. *DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market (2001/77/EC) – **The Renewable Energy Directive***
8. *REGULATION (EC) OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 October 2003 relating to fertilisers (Nr 2003/2003) – **The Fertilisers Regulation***
9. *DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives (2008/98/EC) – **The Waste Framework Directive***
10. *DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council (2008/105/EC) – **The Priority Substances Directive***

National legislation on sewage sludge handling in the countries of the Baltic Sea Region

This section includes examination of country-specific legislation in the Baltic Sea region, compared to the EU regulations. Taking into account similarities of their legislation, countries have been grouped as follows: 1) the three Scandinavian countries of Denmark, Finland and Sweden plus Germany, which has established the strictest requirements on sludge handling; 2) Poland and the three Baltic States of Estonia, Latvia and Lithuania; and 3) the two non-EU members in the region – Russia and Belarus.

The structure of the analysis of each country's sludge-related legislation is built on the following points:

- Regulations on the agricultural use of sludge:
 - types of sludge covered
 - mandatory or preferred treatment methods
 - limit values for heavy metal concentrations, pathogens and organic compounds
 - maximum allowed quantities of sludge or specific element (e.g. total phosphorus) to be applied annually
 - surfaces on which the use of sludge is prohibited
 - sludge and soil analyses and their frequency

- Regulations on other uses of sludge, e.g. in forestry, landscaping, re-cultivation, green areas.
- Specific rules concerning incineration and landfilling of sludge.

Information on each group of countries has been collected in two comparative tables – one of heavy metals concentrations limit values, and one summarising the key points in the legislation – in order to better illustrate the similarities, differences and stringency level of the legal measures chosen by each country to regulate sewage sludge handling.

- [Scandinavian countries and Germany](#)
- [Baltic States and Poland](#)
- [Russia and Belarus](#)

Scandinavian countries and Germany

Country (substance analysed)	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
	in mg/kg of dry matter							
FINLAND (in sludge)	3	300	600	2	100	150	1 500	-
SWEDEN (in sludge)	2	100	600	2.5	50	100	800	-
DENMARK (in sludge)	0.8	100	1 000	0.8	30	120	4 000	25 gar- dening
GERMANY (in sludge)	10 (5)*	900	800	8	200	900	2500 (2000)*	-
EU directive 86/278 (in sludge)	20–40	-	1 000 – 1 750	16–25	300– 400	750– 1 200	2 500 – 4 000	-
FINLAND (in soil, pH>5.8 (lime- stabilised 5.5))	0.5	200	100	0.2	60	60	150	-
SWEDEN (in soil)	0.4	60	40	0.3	30	40	100–150	-
DENMARK (in soil)	0.5	30	40	0.5	15	40	100	-
GERMANY (in soil)	1.5 (1)*	100	60	1	50	100	200 (150)*	-
EU directive 86/278 (in soil, pH 6-7)	1–3	-	50–140	1–1.5	30–75	50–300	150– 300	-
in g/ha/year								
FINLAND (annual average loads to land)	1.5	300	600	1	100	100	1 500	-
SWEDEN (annual average loads to land)	1.75	100	600	2.5	50	100	800	-
DENMARK (annual average loads to land)	Limit values are not provided by Danish legislation							
GERMANY (annual average loads to land)	Limit values are not provided by German legislation							
EU directive 86/278 (annual loads)	150	-	12 000	100	3 000	15 000	30 000	-

Comparative heavy metal limits values when sewage sludge is used for agricultural purposes, established by the current legislation of Finland, Sweden, Denmark and Germany. In case a country has more than one legal act and they provide different requirements for heavy metal concentrations, the one that implements the Sewage sludge Directive was selected as the source for this table.

- For soils classified as light soils, a clay content of <5%, and with a pH 5–6.

Aspect Country	Treatment techniques (agricultural use)	Use of untreated sludge (agricultural use)	Pathogen limit values (agricultural use)	Organic compounds limit values (agricultural use)	Max. quantities applied to the soil (agricultural use)	Frequency of analysis (agricultural use)	Use in forestry, silviculture, land reclamation, green areas	Incineration/landfilling
FINLAND	Digestion, lime stabilisation, or other method significantly reducing pathogen content	Forbidden	---	---	To be determined on the basis of soil quality and the nutrient needs of the cultivated crops	Sludge: 12 per year first year, then 4 per year. Soil: before first application	Ministry of Agriculture and Forestry Decision – same limit values as in agriculture + Arsenic	Collection, treatment and use of landfill gas. Incineration: preferable energy recovery.
SWEDEN	Biological, chemical, heat, long term storage or other process significantly reducing health hazards	Allowed, if worked into the soil within 24 hours after being spread	---	---	Max. amount of total P: depending on the P-class of soil, and of total NH ₄ -N: 150 kg/ha/year	Sludge: 1, 4 or 12 per year. Soil: before first application	SEPA recommendations	Landfill: prohibited since 2005. Incineration: regional authorities' permits.
DENMARK	Stabilisation, composting, pasteurisation	Forbidden	No occurrence of <i>Salmonella</i> , fecal streptococci below 100 per gram	DEHP, PAHs (9), NPE, LAS	7 tonnes of dry matter /ha/year	Sludge: for heavy metals – every 3 months, org. compounds – annually. Soil: before first application	In forestry – if local councils allow; in green areas – pasteurised	---
GERMANY	---	Forbidden	---	AOX, PCB (6), PCDD/PCDF	5 tonnes of dry matter /ha/3 years	Sludge: for heavy metals, org. compounds – 2 per year. Soil: before first application, every 10 years	Prohibition of use on forest, silviculture and green areas	Only waste with less than 5 % of organic matter is accepted in landfill from 2005 onwards
EU	Biological, chemical, heat, long term storage or other process significantly reducing health hazards	MS are allowed to lay down conditions of the use of unthreaded sludge (if it is injected or worked into the soil)	---	---	MS shall lay down max. quantities of sludge which may be applied to the soil	Sludge: 1-2 per year. Soil: before first application (MS may decide on further frequency)	Not regulated by Sewage Sludge Directive (86/278/EEC)	Landfill Directive (1999/31/EC). Incineration Directive (2000/76/EC)

Summary analysis of the current Finnish, Swedish, Danish and German legislation on sludge handling and vs. EU regulation. MS = member state(s) of EU; --- = 'not specified'.

Baltic States and Poland

Country (substance analysed)	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
	in mg/kg of dry matter							
ESTONIA (in sludge)	20	1 000	1 000	16	300	750	2 500	-
LATVIA (in sludge)	10	600	800	10	200	500	2 500	-
LITHUANIA (in sludge: I category / II category)	1.5/20	140/400	75/1000	1/8	50/300	140/750	300/2 500	-
POLAND (in sludge)	20	1 000	500	16	300	750	2 500	-
EU directive 86/278 (in sludge)	20–40	-	1 000–1750	16–25	300–400	750–1200	2 500–4000	-
ESTONIA (in soil)	3	100	50	1.5	50	100	300	-
LATVIA (in soil)*	0.5–0.9	40–90	15–70	0.1–0.5	15–70	20–40	50–100	-
LITHUANIA (in soil: sand, sandy loam / loam, clay)	1/1.5	50/80	50/80	0.6/1.0	50/60	50/80	160/260	-
POLAND (in soil: light / medium / heavy)	1/2/3	50/75/100	25/50/75	0.8/1.2/1.5	20/35/50	40/60/80	80/120/180	-
EU directive 86/278 (in soil, pH 6–7)	1–3	-	50–140	1–1.5	30–75	50–300	150–300	-
in g/ha/year								
ESTONIA (annual average loads to land)	150	4 500	12 000	100	3 000	15 000	30 000	-
LATVIA (annual average loads to land: sand, sandy loam / loam, clay)	30/35	600/700	1 000/1200	8/10	250/300	300/350	5 000/6000	-
LITHUANIA (annual average loads to land: sand, sandy loam / loam, clay)	100/150	7 000/ 10 000	8 000/ 12 000	50/100	2 000/ 3 000	10 000/ 15 000	20 000/ 30 000	-
POLAND (annual average loads to land)	Limit values are not provided by the Polish legislation							
EU directive 86/278 (annual loads)	150	-	12 000	100	3 000	15 000	30 000	-

Comparative heavy metal limits values when sewage sludge is used for agricultural purposes, established by the current legislation of Finland, Sweden, Denmark and Germany. In case a country has more than one legal act and they provide different

requirements for heavy metal concentrations, the one that implements the Sewage sludge Directive was selected as the source for this table.

- Latvian limit values for heavy metal concentrations in soil vary depending on the types of soil (sand/sandy loam, loam/clay) and its pH (5–6; 6,1–7 and >7), thus altogether there are six limit values for each heavy metal. In this table, they are presented as a range, from the lowest (which is for sand/sandy loam soils with pH 5-6) to the highest (for loam/clay soils with pH >7).

	Treatment techniques (agricultural use)	Use of untreated sludge (agricultural use)	Pathogen limit values (agricultural use)	Organic	Max. quantities applied to the soil (agricultural use)	Frequency of analysis (agricultural use)	Use in forestry, silviculture, land reclamation, green areas	Incineration/landfilling
ESTONIA	Aerobic/anaerobic digestion, incl. composting; chemical or thermal treatment	Allowed only for landscaping and re-cultivation, if worked into the soil within 2 days after being spread	Fecal coliforms <1000 CFU, and no occurrence of helminth eggs in 1 litre	---	---	Sludge: 2,4,6 or 12 times/year first year, then 4,3,2,1 per year next years. Soil: before the first application, + every 5 years	Landscaping and recultivation is governed by the same regulation as agricultural use, all rules apply.	---
LATVIA	Storage, anaerobic digestion, aerobic and lime stabilisation, composting, pasteurisation, drying at 100 °C	Defined by the regulation, but no usage specified	---	---	Max. amount of total P: 40 kg/ha/year, and of total NH ₄ -N: 30 kg/ha/year	Sludge: 1,2,3,4, or 12 times per year. Soil: before the first application	In forestry and land reclamation special provisions in same regulation + max. amounts; in green areas add. heavy metals limits.	Landfill: special provisions in same regulation as agriculture; Incineration: ---
LITHUANIA	Biological, chemical or thermal, long-term storage or other process significantly reducing health hazards	Forbidden, as well as sludge of III category or C class	<i>Escherichia coli</i> , <i>Clostridium perfringens</i> , helminth eggs and larvae, and pathogenic enterobacteria ⁶	---	Max. amount of total P: 40kg/ha/year, and of total N: 170 kg/ha/year	Sludge: 1,4, or 12 times per year. Soil: before the first application, further – depends on results	Recultivation and fertilization of energy crops special provisions in the same regulation + max. amounts 100 t/ha/year	Landfill: (National Strategic Waste Management Plan) targets for reducing biowaste on landfills; Incineration: ---
POLAND	Stabilisation +biological, chemical, heat or other process significantly reducing health hazards	Forbidden	No occurrence of <i>Salmonella</i> in 100 g, as well as eggs of ascaris, trichuris, or toxocara	---	3 t/ha/year	Sludge: 2,5 or 6 times per year. Soil: before the first application	Any other use than in agriculture, green areas, recultivation, compost forbidden, + max. amounts 15 t/ha/year	Landfill: (Law on Waste) targets for reducing bio-waste on landfills; Incineration: ---
EU	Biological, chemical, heat, long term storage or other process significantly reducing health hazards	MS are allowed to lay down conditions of the use of unthreaded sludge (if it is injected or worked into soil)	---	---	MS shall lay down max. quantities of sludge which may be applied to the soil	Sludge: 1-2 per year. Soil: before the first application (MS may decide on further frequency)	Not regulated by Sewage Sludge Directive (86/278/EEC)	Landfill Directive (1999/31/EC). Incineration Directive (2000/76/EC)

Summary analysis of the current Estonian, Latvian, Lithuanian and Polish legislation on sludge handling and vs. EU regulation. MS = member state(s) of EU; --- = 'not specified'.

- These parasitological parameters should be analyzed, albeit different limit values are provided for all of them, taking into account differentiation of sludge into 3 classes.

Russia and Belarus

Country (substance analysed)	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
	in mg/kg of dry matter							
RUSSIA (in sludge: group I / group II)	15/30	500/1 000	750/ 15 000	7.5/15	200/ 400	250/500	1 750/ 3 500	42/131
EU directive 86/278 (in sludge)	20–40	-	1000–1750	16–25	300–400	750–1 200	2 500– 4 000	-
RUSSIA (in soil, pH>5,5)								
Maximum permissible concentrations	-	6**	3*	2.1	4*	32/6*	23*	2
Tentatively permissible concentrations (sandy loam / clay)	0.5/2	-	33/132	-	20/80	32/130	55/220	55/10
EU directive 86/278 (in soil, pH 6-7)	1–3	-	50–140	1–1.5	30–75	50–300	150–300	-
in g/ha/year								
RUSSIA (annual average loads to land)	Limit values are not provided by the Russian legislation							
EU directive 86/278 (annual loads)	150	-	12 000	100	3 000	15 000	30 000	-

Comparative heavy metal limits values when sewage sludge is used for agricultural purposes, established by the current legislation of Russia and Belarus vs. EU regulations. Russia and Belarus use the same standards and are thus compared to the requirements established by the EU Sewage Sludge Directive.

- values for mobile forms of elements
- *value for mobile form Cr (III)

	Treatment techniques (agricultural use)	Use of untreated sludge (agricultural use)	Pathogen limit values (agricultural use)	Organic compounds limit values (agricultural use)	Max. quantities applied to the soil (agricultural use)	Frequency of analysis (agricultural use)	Use in forestry, silviculture, land reclamation, green areas	Incineration/landfilling
RUSSIA	Biological, heat treatment, aerobic stabilisation, long term storage, pasteurisation, composting	No specific provisions are mentioned	<i>Escherichia coli</i> >100/1000*, <i>Salmonella</i> , Helminth eggs and cysts of intestinal pathogenic protozoa	Organic matter >20%, total N >0.6% of DM, P ₂ O ₅ >1,5% of DM	Max. amount of total N- 300 kg /ha/year; max amount of dry matter: heavy soils- 10 t/ha/5 years, light sandy soils-7 t/ha/3years	Sludge: undefined. Soil: before the first application of sludge	Allowed in industrial horticulture, green areas, in forests, for reclamation of land and landfills	Landfill: sludge is accepted to municipal solid waste landfills, no treatment required; Incineration: ---
EU	Biological, chemical, heat, long term storage or other process significantly reducing health hazards	MS are allowed to lay down conditions of the use of untreated sludge (if it is injected or worked into soil)	---	---	MS shall lay down max. quantities of sludge which may be applied to the soil	Sludge: 1-2 per year. Soil: before the first application (MS may decide on further frequency)	Not regulated by Sewage Sludge Directive (86/278/EEC)	Landfill Directive (1999/31/EC) Incineration Directive (2000/76/EC)

Summary analysis of the current Russian and Belarusian legislation on sludge handling vs. EU regulations. MS = member state(s) of EU; N = nitrogen; --- = 'not specified'.

- for group I / group II of sludge

Conclusions

Three kinds of the sludge handling legislation exist in the countries of the Baltic Sea Region: EU-level directives and other legal acts; EU member states' laws created to implement the abovementioned directives; and standards and norms of non-EU countries. All of them can be studied depending on two aspects: the form in which the legal acts were adopted and the content of the requirement they carry. Whereas the significance of the requirements' content seems to be obvious, it is also important to take into account the form, or the type, of the legislative documents when assessing the legal restrictions.

The content of the restrictions posed by the legislation of the Baltic Sea Region countries on sludge handling can be divided into requirements common to all regulations, and to more specific requirements in the legislation of some or in only one country. The common restrictions usually concern:

- pre-treatment methods;
- limit values of heavy metals contained in sludge and in soil;
- the restriction on the choice of crops and surfaces where sludge is to be applied; and
- the control of legislative compliance.

For more details on the national sludge handling legislation in the countries of the Baltic Sea region see [appendix](#) to the book.

Drivers and obstacles for different sludge management practices

The everyday choices and future challenges in sludge handling are not related to water management issues alone but are dependent on restrictions, incentives and policies in agriculture and energy, for example. The problems thus relate to wider policy guidance and governance. Waste water treatment plants in the Baltic Sea region, however, already have the possibilities to develop towards a modern biorefinery concept, producing renewable energy and recycling nutrients.

The costs of sludge management may be up to 50 % of the total running costs of a waste water treatment plant, and optimizing the sludge treatment and disposal may significantly contribute in the cost effectiveness of the water management as a whole (Starberg et al., 2005). The increasing costs of external energy sources together with feed-in tariffs and other support schemes for renewable energy are drivers for increasing anaerobic digestion and biogas production in waste water treatment plants. It may also be possible to outsource sludge disposal from water companies to external actors in soil improvement or fertiliser production, or to energy companies in case of biogas.

Sewage sludge has to be stabilised and possibly hygienised to remove pathogens. In addition to pathogens, sludge contains many chemicals in small amounts. Heavy metals have been regulated for a long time in EU and national legislations, which has significantly decreased their amount in urban waste water sludge. Recently, there has been intensive discussion on organic substances that are present in urban waste waters and sludge which are classified as hazardous.

For decades the crucially important phosphorus was discarded to waterways with inadequately treated sewage. Since the 1970-80s, the municipal waste waters have been treated more and more efficiently in the Baltic Sea region. However, the nutrients separated from the waste water flow have not been reused efficiently. To increase the efficiency of phosphorus recycling it needs to be perceived not only as a polluting substance but as a recoverable resource in different policies. More efficient recycling of phosphorus would also help to reduce the phosphorus loading to the environment.

The current common restrictions on the possible ways of sludge handling and disposal usually concern pre-treatment methods, the limit values of heavy metals contained in sludge and in soil, the restriction on the choice of crops and surfaces where sludge is to be applied, and control of legislative compliance. A wide collection of EU level decrees regulate the sludge management and disposal in eight of the nine countries around the Baltic Sea.

Besides directives, the European Union has also other governance instruments. Another international actor is the intergovernmental Baltic Marine Environment Protection Commission (HELCOM) that implements wide-scale policies and recommendations based on an ecosystem approach to improve the state of the vulnerable marine environment and to reduce pollution. As Russia is also a contracting party of HELCOM, all the nine coastal countries are committed to implementing HELCOM policies.

Language versions and appendix

For descriptions of national legislation on sludge handling in the Baltic Sea Countries see [appendix](#) to the book.

Other available language versions of the PURE 'Good practices in sludge management': [German](#), [Latvian](#), [Polish](#), [Russian](#).

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