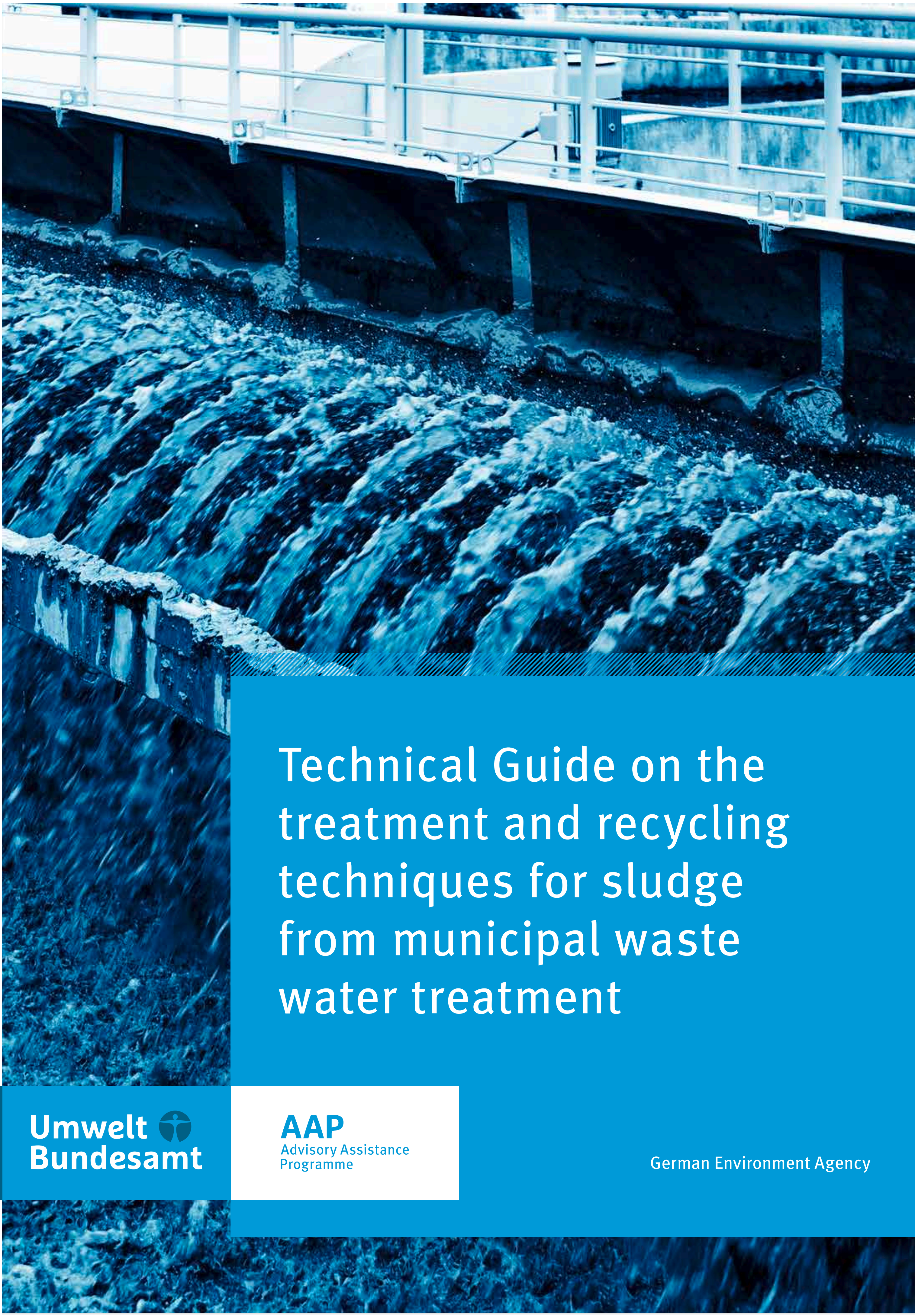

Technical Guide on the treatment and recycling techniques for sludge from municipal waste water treatment

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Federal Ministry for the
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LIST OF ABBREVIATIONS

a	annum
BAT	Best Available Technique
BOD	biochemical oxygen demand
BREF	Best Available Techniques Reference Documents
BREF TCI	Reference Document on Best Available Techniques in Common Waste Water and Waste Gas Treatment / Management Systems in the Chemical Sector
BREF WI	Reference Document on the Best Available Techniques for Waste Incineration
BREF WT	Reference Document on Best Available Techniques for the Waste Treatment Industries
°C	degree centigrade
COD	chemical oxygen demand
d	day
DAS	diammonium sulphate
DS	dry solids
DWA	German Association for Water, Wastewater and Waste
EC	European Commission
EU	European Union
EUR	Euro (European Currency)
g	gram
h	hour
H_2O	dihydrogenmonoxide or water (molecular formula)
JRC	Joint Research Centre (the in-house science service of the EC)
kg	kilogram
kJ	kilojoule
kWh_{therm}	kilowatt hours thermal energy
l	litre
m	meter
m^2	square meter
m^3	cubic meter
MAP	magnesium ammonium phosphate
mg	milligram
MJ	mega joule
MSW	municipal solid waste
µg	microgram

N	nitrogen
n/a	not applicable, not available
NH_4OH	ammonium hydroxide
NO_X	generic term for mono-nitrogen oxides
O_2	oxygen (molecular formula)
oDS	dry organic substance
ORC	organic rankine cycle
P	phosphorus
p.e.	population equivalent
PFOS	perfluorooctane sulfonate tensides
pH	chemical term, the negative log of the activity of the hydrogen ion in an aqueous solution
ppm	parts per million
SNCR	selective non-catalytic reduction
t	tons
TOC	total organic carbon
TTC	triphenyl-tetrazoliumchloride
TWG	Technical Work Group Best Available Technology
W	watt
Wh	watt hour
WWTP	waste water treatment plant

INTRODUCTION

Foreword

Nearly all waste water treatment techniques have one thing in common: the formation of solids or residue from filtration or sedimentation. With that the separation of the pollutant from the aqueous medium is possible, resulting in pollutant-enriched sludge. In as much as this sludge is not returned into the process of direct waste water treatment, it becomes necessary to have it safely treated on site or forwarded to disposal with different options of secondary use.

The application of appropriate thickening, stabilisation and dewatering processes is crucial in order to get sewage sludge utilized or disposed of correctly and efficiently. Thickening and dewatering must be well adapted to the further processes of sewage sludge utilization. Only input material suiting the subsequent treatment processes will allow the optimum treatment results to be attained. Before material utilization, recovery of energy from the organic components or final depositing of the sludge takes place, various stages of pre- and post-treatment must be passed. Within the individual steps and procedures leading to the ultimate use of sludge a variety of process configurations can be applied.

An overview and detailed information on state-of-the-art technologies in this field can meanwhile be obtained from compendia and technical fact sheets, including the Best Available Techniques Reference Documents (BREF). Of particular relevance in the area of sewage sludge treatment are the following BREF documents:

- Reference Document on Best Available Techniques for the Waste Treatment Industries (BREF WT)
- Reference Document on the Best Available Techniques for Waste Incineration (BREF WI), and
- Reference Document on Best Available Techniques in Common Waste Water and Waste Gas Treatment / Management Systems in the Chemical Sector (BREF TCI).

These and further information sources on sewage sludge treatment methods were analysed to create the present guide on sewage sludge treatment and recycling techniques.

The purpose of the present guide is to orient stakeholders on the process flow which follows sludge generation in waste water treatment plants (WWTPs) beginning from the stabilisation of the sludge up to the wider spectrum of options for its utilization. The document structure follows this chain of possible process options (**Figure 1**) and wants to give orientation for decisions that have to be made on the appropriate techniques and the equipment needed. In this sense, the present guide has an informative, not an obligatory character.

It should be noted that every application has its advantages and disadvantages, therefore no single sludge treatment process can claim to provide the “ideal” solution. It is important that local conditions and needs as well as long-term environmental and economic effects are adequately taken into consideration while selecting the appropriate sludge treatment paths and technologies.

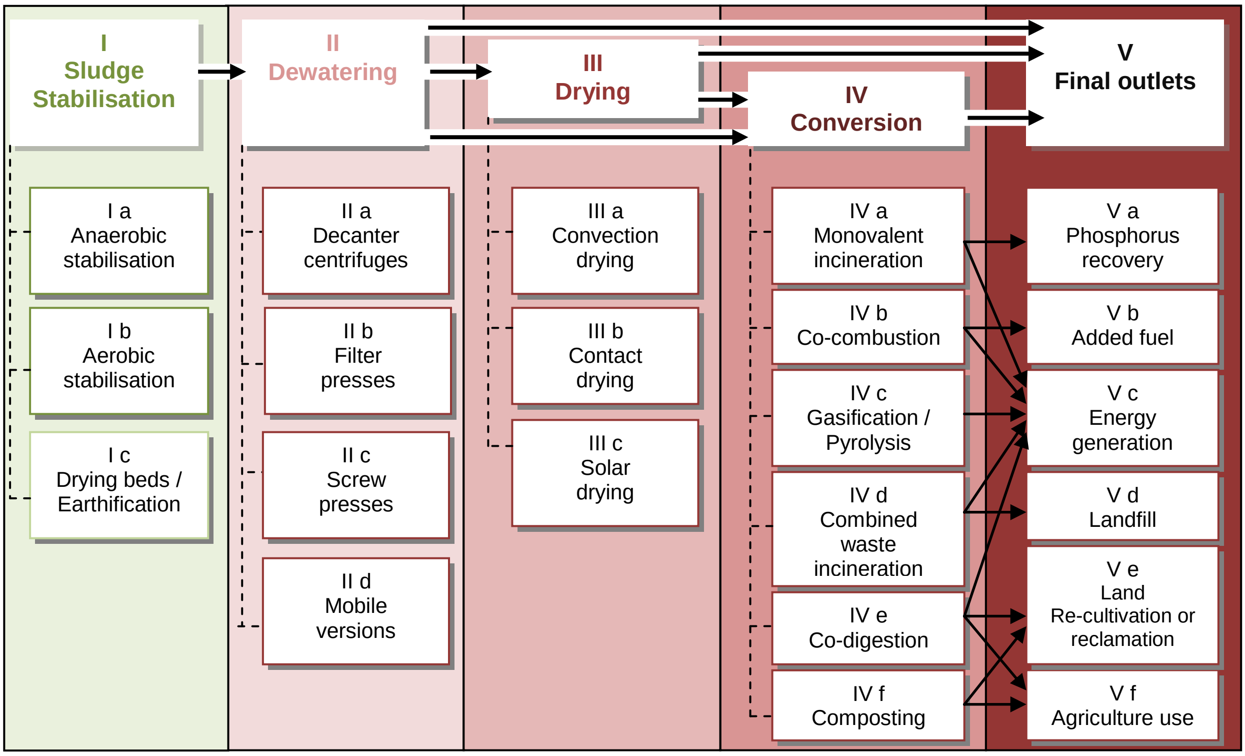
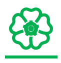


Figure 1: Overview on the possible options for a sludge management process (as covered from this document)

Usage of this guide

When using this technical guide, the following should be duly considered. The document has been developed to present proven techniques available at the moment of its creation and does not enumerate all possible approaches, techniques and technologies for treating sludge from WWTPs. Following the general introduction of each process step including a brief explanation about its purposes and objectives, a tabular format has been created to supply more specific details about the different technologies and equipment applicable to it.

Information describing basic characteristics and procedures of the respective technology can be found in the second column of this table. For orientation purposes some characteristic cost figures and price ranges are also included here. These were highlighted by applying a light blue writing colour. The third column contains some essential aspects and information on the beneficial and restrictive circumstances associated with each particular technique and/or application. A special scheme of symbols shall help the readers to get note of the various impacts and the affected areas quickly. The order of their arrangement does not imply any ranking of importance. The symbols used and their individual meaning are as follows:

	*indicates an environmentally positive aspect*
	*indicates an energetically positive effect*
	*indicates a cost advantage*
	*indicates a positive operational impact or general efficiency advantage*
	*indicates an adverse operational impact or general negative effect*

Measures which can contribute to achieve a further enhancement of the process or improve the process efficiency and/or effectiveness of subsequent applications are described under

‘*Potentials for optimization’*. A grey background colour makes these information easily recognizable from the surrounding text.

Reference locations are to be understood as an incomplete listing of examples where the specified technologies are in practical use. They have been chosen as places from which further details regarding the application of each method may be individually obtained or where technical visits could be useful to learn about best practice solutions in sludge treatment.

The ↗*-symbol* indicates points of reference in this guide or where is recommended to the users to look for further information in this document or in other sources.

To get a good understanding of the different types of techniques and utilization possibilities for sludge does require the reader to be aware of the existence of various kinds of sludge generated by waste water treatment installations. For that an introduction shall be given on the following basic terms:

Table 1: Explanation of sludge terms used in this document

Primary sludge This type of sludge is generated in the mechanical cleaning stage as a result of physical processes, i.e. sedimentation. It represents the vast majority of the total sludge volume produced by WWTPs. Primary sludge contains approximately 2.5–3.0 % solids, the rest is water. *Return sludge* This is sludge from the biological treatment which comes along with the excess sludge. It is the proportion of biomass that settles in the sedimentation stage (intermediate and secondary clarifiers), from where it is subtracted and returned to the activation basin in order to maintain the biological process there. It contains about 0.5–1.0 % solids and is eventually consumed completely at the end of that stage. *Excess sludge (secondary sludge)* This sludge originates from the biological treatment and comes along with the return sludge. It is the proportion of the biomass that settles in the sedimentation stage (intermediate and secondary clarifiers) but for which there is no need of returning it to the activation basin to maintain the biological process. The excess sludge from the biological stage contains only about 0.5–1.0 % solids, thus requiring an up-concentration with the help of primary sludge for further processing. The generation of excess sludge can and should be minimized through appropriate measures in order to reduce the sludge treatment costs.

SLUDGE STABILISATION

Raw sludge from the thickener can be left untreated only for further processing in a fresh sludge incineration. All other methods require a stabilisation of the sludge. The objectives of the sludge stabilisation process are:

- stabilisation of the substrate;
- reduction of sludge and solid component quantities;
- improvement of the dewatering characteristics of the sludge;
- creation of a possibility to recover biogas, however, at significant reduction of the calorific value of the stabilised sludge;
- utilization of the recovered gas for power generation (gas engines or gas turbines) or heat generation; and
- creation of a buffer and storage capacity for sludge treatment.

Different levels of sludge stabilisation are required to make use of certain utilization outlets. In principle, the following is recommended:

- Stabilisation is ***not mandatory*** for sludge that will be used ***in thermal processes or*** that will undergo ***biological conversion*** (unless this is required due to transport, safety or odour development concerns on the part of the operators of the respective facilities).
- Utilization ***in agriculture*** (in a liquid or drained state) requires sludge which is ***fully stabilised***.
- Utilization ***in a quasi-liquid state on land***, especially for landscaping purposes also requires ***fully stabilised*** sludge.
- Utilization ***after dewatering on land*** which can be for re-cultivation and landscaping requires the sludge to be at least ***semi stabilised***.
- Disposal ***on landfills*** does require dewatering or drying, as well as ***partially to fully stabilised*** sludge (depending on the method applied).

For biological sewage sludge stabilisation a distinction is to be made between aerobic and anaerobic processes. Digested sludge can generally be dewatered more easily than non-digested sludge, thus allowing a slightly higher DS content after mechanical dewatering (↗ BREF WI; 2.2.3.2.3 Sludge digestion, p.31). Chemical stabilisation, for example with lime, does give rather short-term but not sustainable results unlike biological processes.

It is recommended that each operator, depending on the chosen procedure for sludge stabilisation, should periodically analyse the following parameters in order to determine the sludge stabilisation degree achieved and to detect changes in the effectiveness of the method applied.

- Ignition loss; where the value <50 % indicates the sludge is well stabilised / 50–65 % - partially stabilised / >65 % – not-yet stabilised.
- Oxygen depletion: where 0.06 kg O_2/(kg oDS•d) indicate a sludge that is well stabilised.

Additionally should be performed a test on the toxic effects of water constituents with Triphenyl-tetrazoliumchloride (TTC) and formazan as indicator dye.

	DESCRIPTION OF THE BASIC PROCEDURE	ASPECTS TO CONSIDER	REFERENCE LOCATION
I a ANAEROBIC STABILISATION	**DIGESTION** - This is a stabilisation method for primary and secondary sludge usually executed in digesters (e.g. towers) and open lagoons. The active organic load and the quantity of the sludge are reduced through the biodegradation of organic material content in the absence of oxygen (anaerobic digestion). In digesters this process takes place in a mesophilic (30–38 °C) or thermophilic (49–57 °C) temperature range and usually requires a period of 20–30 days. Methane gas (biogas) is generated as a by-product and can be used to produce energy, which in turn may be used for a subsequent drying of the remaining sludge. - Digested sludge residue smells no longer since the organic substances it initially contained are mostly metabolized. The material instead has an earthy appearance and is therefore referred to as stabilised. The specific investment costs for classic egg-shaped digesters come to 600–1,000 EUR/m³ digester capacity; additional staffing requirement is 8–10 hours/month. The coupling of the energy flows obtainable from digestion with heat generated during sewage sludge or biogas combustion is an efficient way to realize sludge drying. Anaerobic digestion of sewage sludge before combustion can be counterproductive because of the reduced calorific value of the digested sludge, only dewatering is necessary here. The combination of digestion with a mobile sludge dewatering is to be avoided due to the high nitrogen burden of the filtrate.	Capture of the fermentation gases resulting from organic decomposition prevents their free escape into the atmosphere and thus climate damage. Digested sludge can generally be dewatered more easily than non-digested sludge, thus allowing a slightly higher DS content after mechanical dewatering. By breaking down organic substances very efficiently, the amount of residual sludge remaining after the process is about 20 % lower than what is achieved with aerobic sludge stabilisation. This process is disadvantageous for subsequent thermal utilization in that it decreases the calorific value of sludge.	

I a **Potentials for optimization**	Various measures can help to improve material decomposition and thus to reduce sludge volume, increase gas yield and to reduce foaming. They also have a particularly positive effect on further sludge utilization. Principally the following actions are recommendable : - *Sludge homogenization* can be achieved by introducing ordinary stirring elements (such as screw shovels), air pressure injection or circulators, two-nozzle low pressure systems (up to 15 bar) are even better for the generation of hydrodynamic turbulence and shear forces. The results are the dissolution of sludge flocs, mixing in of treated parts and an improved flowability. Ideally, this is done between the drain line for activated sludge and the supply line to the septic tank. - *Steady feeding of the digestion tanks* ensuring 24 h round-the-clock feeding of the digester - *Avoiding temperature fluctuations* Setting the temperature in the digester not below 38 °C and making sure it remains in a stable range	Homogenization leads to an up to 40 % higher viscosity, increases the available COD by 130 % and thus allows 10–30 % greater gas production. In turn a reduction of unwanted GG emissions can be observed. € Cost savings from reduced need for cleaning the installation from flocculation and residues. Heating the digester for a better process consumes more energy.	
	<u>DISINTEGRATION</u> In this procedure, the sewage sludge structure is changed by mechanical, chemical and/or thermal processes and better biodegradation is thus facilitated.	Higher gas yield while significantly reducing the residual sludge.	

	- *Chemical disintegration*
	Includes mainly
	  - to induce precipitation reactions by use of iron salts which lead to the reduction of phosphorus and thereby improve dewaterability,
	  - the use of polymer based flocculants
	  - the addition of lime suspension/hydrated lime (about 20–35 % CaO in the solid fraction) for the liberation of sludge from parasites and for acid-base stabilisation.
		10–50 % higher biogas yield due to better decomposition of the hydrolysate.
		Chemical disintegration artificially inflates the original dry mass of the waste which may result in additional costs.	

I a *continued* Potentials for optimization	- *Thermal disintegration* Practical applications are the process of thermal hydrolysis or thermal-pressure-mediated hydrolysis. With these techniques, the organic content of digested sludge is split through temperature and pressure increase in a continuous reactor system into short-chain, biologically available fragments. The resulting hydrolysate is degraded faster in the digester and leads to a significantly increased formation of gas. From the formation of the hydrolysate remains only a small proportion of solids which can be returned for digestion. This can be achieved by retrofitting the existing digesters or bioreactors at the WWTP. The application is possible either before or after the digester.	Better utilization of load volume and increased turnover free additional treatment capacity. Improved drainage characteristics (up to 33 % dry residues). The digestion process becomes more stable (reduced formation of foam/scum).	<u>Germany:</u> WWTPs in Blümeltal/ City of Pirmasens, Oppenheim and Untere Selz/ Ingelheim, Rhineland-Palatinate
	- *before the digester* Primary and excess sludge is thickened to 6–10 % DS and fed to a pressure reactor under the inclusion of a heat exchanger. - *after the digester* Sludge is thickened to around 10 % DS and fed via high-pressure pumps to the pressure reactor, primary and excess sludge of 6–10 % DS is introduced together with the hydrolysate in the digester.	Better hygienisation of the digested sludge. A return of the investment is already possible as disposal costs are avoided and additional gas is produced. Nitrogen and phosphorus chargeback does increase unless a Magnesium ammonium phosphate (MAP) precipitation process is additionally applied. *(see ↗ Recovery of phosphorus)*	

I b AEROBIC STABILISATION	**<u>AEROBIC SLUDGE STABILISATION</u>** The microorganisms contained in the sludge are stimulated through the supply of oxygen to convert almost all available organic matter into humus-like substances and mineral end products. The stimulation of the micro-organic activity and subsequent stabilisation is achieved in activation basins, which are ventilated in various ways, e.g. centrifugal aeration, rotary brushes, fans or other ventilation devices such as membrane diffusers.	An energy-consuming procedure for which additional reaction volume is also required.	
I b Potentials for optimization	**<u>NITRIFICATION USING A CASCADE SYSTEM</u>** Waste water and activated sludge must pass through several successive basins. Ammonium is oxidized by bacteria under the consumption of oxygen first to nitrite and further to nitrate and thus detoxified (nitrification). A combination with pre-denitrification is useful. - In the first denitrification basin organic nitrogen is turned into molecular nitrogen, which escapes into the atmosphere (denitrification). Return sludge is the main target medium. The stabilisation process benefits from the overall depletion in nitrate concentrations. - In subsequent denitrification stages (cascade of basins) the amount of nitrate formed in the preceding nitrification basins is reduced in the same manner. In practice, arrangements of 2–4 cascades were found to be most useful. The technical advantage of the solution does not arise directly from the cascade, but from the way the waste water inflow is distributed in it.	Allows energy savings compared with plants of the same initial capacity. Helps expanding the capacity of the existing systems with simultaneous aerobic stabilisation, peaks and fluctuations in the influx are better compensated by a cascade system. Slightly higher costs for the distribution of flows and the regulation of different stress situations in each basin of the cascade.	<u>Germany:</u> WWTP Silstedt, Saxony-Anhalt; WWTP Lennestadt-Greven-brück, North Rhine-Westphalia

I c EARTHIFICATION (DRYING BEDS)	Represents a close-to-natural method for slow dewatering and stabilisation of sewage sludge up to its mineralization. The sludge is converted into an earth-like substrate by bringing it in and letting it settle in bed or lagoon-like basins. A reduction of the initial sludge volume of about 90–95 % can be achieved in the long run. Dehydration occurs through evaporation and due to the gravitational effect. Basins with concrete walls or earth basins with liner and drainage layer are used. Beds which are alternatively in use for simple stabilisation and drying and only filled up to 0.5 m in height are usually cleared 1–3 times a year. Filling heights for earthification as an extended process are higher (>1 m). Processes in which mixtures of different input materials including sludge are piled up in simple windrows and let for outdoor composting belong in the same category. Depending on the actual procedure employed, structure material, mineral substances and aggregates might be added step by step. As an input for joint biological treatment of sewage sludge with mineral and organic materials can be used excavated material, other biogenic wastes, contaminated soil and fibre sludge. The space requirement for sewage sludge earthification at a medium usable basin depth of 1.5–1.7 m (without drainage construction) is approximately 0.25 m²/p.e. for aerobically stabilised sludge and 0.5 m²/p.e. for anaerobically stabilised sludge. The total occupation time till the first complete clearance of a basin of the given size is in the range of 5–10 years.	Very low energy consumption (only about 10 % of the energy demand for mechanical drainage). € Low operating costs, e.g. no expenses for stirring and conditioners. Highly space and time demanding.	
I c Potentials for optimization	<u>**Reed planted basins**</u> Instead of unplanted drying beds, the design of a constructed wetland, consisting of a sand-gravel mixture as a base layer, can be used for earthification processes. The drainage in the basin is supported by the plants' need of water. The pores of the filter material also serve as a development medium for waste water purifying microorganisms. Advantageous are basins planted with reeds (for example *Phragmites australis*) as they were found to facilitate an increased degradation of pollutants in addition to a higher water withdrawal (volume reduction). All organic components present in the sludge are broken down by more than 50 %. Reed should be planted at a density of 4–5 stems/m². Reed beds can be used for about 20–25 years without being cleared. The excess filtrate should be returned via a drainage system into the inflow of the WWTP, however. The indicative investment for a sludge earthification facility in Germany is 60 EUR/m² treatment area (all installations included). Setting up and using <u>*extra storage basins*</u> for separate storage of sludge in the period from November to April to prevent problems resulting from feeding operations in the winter season (freezing of basins does not allow the introduced sludge to dewater sufficiently so that in spring there is a risk of digestion processes within the trapped liquid layer leading to intense smell).	Higher degree of sludge stabilisation in the long-term than the one ordinary aerobic treatment provides as well as production of usable biomass. High flexibility as regards - feeding (particularly good for areas with strongly fluctuating volumes of sludge); - actual outlets for the residue of the process (utilization on land according to demand).	<u>Germany:</u> Sludge earthification plants Norderney, Schleswig-Holstein; Simmern/ Hunsrück, Rhineland-Palatinate; WWTP Eibelshausen, Hesse

DEWATERING

For the further utilization of sludge and in particular for its efficient transportation, it is essential to reduce the water content in the sludge significantly. The first technical step which goes far beyond the simple thickening of the sludge at the WWTP is dewatering. This process increases the DS content of sludge and produces a solid filter cake by filtration through fabric filter cloths/centrifuges or filter presses. By way of mechanical pressure and physical processes an aqueous waste stream is separated from the sludge mixture and thus its initial volume is reduced. An increase of the heat value is associated with this process. This allows independent and economical incineration. Overall disposal costs would be expected to be reduced in cases where the aqueous waste stream requires no, or minimal, additional processing to remove contaminants.
Dewatering at ratios typically higher than 10 % will first require some form of chemical conditioning to assist in the separation of the bound and entrained water from within the sludge. This is achieved with the help of flock building additives, so called flocculants (*see under ↗ 'Potentials for optimization'*).

Dewatering produces a sludge cake, which may have between 20–50 % DS. The success of mechanical drainage depends on the selected techniques, the conditioning carried out, and the type and composition of the sludge. A number of sludge dewatering processes exist and the choice depends upon the nature and amount of the solids produced, as well as upon the sludge cake required. Most common for mechanical drainage of sewage sludge is the use of machines such as decanters, centrifuges, belt filter presses and chamber filter presses. Filter presses and belt filter presses produce good dewatering rates but require a large amount of space, as some of them operate discontinuously and have throughput rates lower than those of other technologies.
The following rough differentiation between the main types of dewatering techniques/machines used can be done:

- Filter (or plate) presses are employed in batch or manual processes that can be quite intense. With filter presses a cake of up to 40 % DS content can be produced.
- Belt press are used in a continuous process with the filter cloth continually running through rollers that forcefully dewater the sludge. A belt press can produce cakes of up to 35 % DS content.
- Centrifuges are also suitable for continuous processes and can produce a cake of up to 40 % DS content for certain sludge. Because of the shear forces, they can break up the solid particulates very effectively.

The majority of sites up to now use filter presses and then send the aqueous fraction through clarification or dissolved air flotation units prior to its discharge. Excess solids are returned for treatment (↗ BREF WT; 2.3.3.6 Dewatering, p.68ff.).

The energy required to raise the DS content of the sludge from 5 % to 35 % is approximately 3–5 $kWh_{electr.}$ per kg H_2O for the drainage installation.

	DESCRIPTION OF THE BASIC PROCEDURE	ASPECTS TO CONSIDER	REFERENCE LOCATION
II a DECANTER CENTRIFUGES	Decanter centrifuges are machines that separate solids and liquid phases in a single dynamic process by rapidly rotating the mixture in a vessel. The centrifugal force separates the different phases and drives away the excess liquid. Decanter centrifuges are used when solids have a much higher specific gravity than water. Baffles inside the centrifuge determine the correct flow path of the separated phases and prevent any risk of cross contamination. The sediment, which is formed by the solid particles is continuously removed, for example by a screw conveyor, which rotates at a speed different from that of the bowl of the centrifuge. The centrifuge technique allows sewage sludge to be dewatered from about 3 % to at least 25 % DS. The power consumption for using this technique is quoted at the order of 50 W/kg DS, the operating costs per operating hour of a centrifuge are rated to start at 20 EUR. Per each ton of dry residue of the sludge fed into the centrifuge, up to 12 kg of organic flocculants are used. In Germany the annual net operating costs incl. constructive expenses/maintenance amount to 180 EUR/t DS.	Higher throughput rates compared to other techniques. Shear forces effectively break up the solid particulates. Centrifuges are prone to wear from sand and other mineral solids and have a particularly high power demand for start-up.	
II a Potentials for optimization	The *rotational filtering technique* is similar to the technique of centrifuges but it also has a brush unit inside the drum. The method is commonly used for sand-water separation and has been further developed for sludge dewatering. There is the need for more frequent emptying of the rotating drum, however. Drainage results comparable to those of other conventional techniques (up to 28 % DS) can be achieved even without conditioning with flocculants.	No conditioning with flocculants necessary. Reduced contaminant separation in the sludge water which thus carries higher pollutant loads.	

II b FILTER PRESSES	In a filter press, the sludge suspension is pressed against a filter medium that will hold back the solids and is permeable for the liquid portion only. The liquid portion of the suspension passes through the filter and is collected as a solid-free filtrate whereas a filter cake forms on the filter medium. In some types of presses the filter medium are textile fabrics, known as filter cloths. Others use semi-permeable membranes or plates. In discontinuous processes (plate press) this cake is eventually taken out from the machine when the press opens. To use textile filter presses requires a press-stable suspension which does not stick to the filter medium or cause clogging. The annual net operating costs incl. constructive expenses/maintenance in Germany range from 200–240 EUR/t DS.	The technique is not vulnerable to wear by sand and other mineral solids.	
	<u>PLATE (OR CHAMBER) FILTER PRESS AND FRAME (OR MEMBRANE) FILTER PRESSES</u> These are dewatering machines which utilize pressure (60–80 psi, typically) to remove the liquid from a liquid-solid slurry. They are particularly suited to low solids content suspensions (‹2 % solids) or solids composed of fines (mesh number -200). However, they will essentially dewater many combinations of particle size distribution and percent solid slurries. Based on the principle of the chamber filter press (rigid chamber wall plates are pressed one to another after the intermediate chamber is filled with sludge suspension), membrane filter presses operate in two phases using a chamber and membrane sheets. In the first phase the chambers are filled up to a level where physical power already leads to drainage. During the second phase the already formed cake is pressed against elastic membranes.	Higher solids content in the filter cake and better separation from the filter walls, improved consistency of the drainage results. More cost-intensive as a result of the higher initial investment (equipment costs) and maintenance need.	
	<u>BELT FILTER PRESS</u> This is a sludge dewatering device that applies mechanical pressure to a chemically conditioned slurry, which is sandwiched between two tensioned belts passing through a serpentine of decreasing diameter rolls. The machine's operations can actually be divided into three general stages: initial de-watering, which makes pulp from the sludge; pressing or medium pressure filtration, which conditions the sludge for high pressure filtration quality; and high pressure filtration, which raises the DS content in the sludge cake to the optimum. There are belt filter presses with three belts and an extended gravity two-belt design. The three-belt press has an independent gravity zone with a more open belt for more rapid drainage of the volume of water. The extended gravity design has a longer gravity drainage zone. The choice of the basic machine depends upon the type of sludge and solids fed. The advantage of the belt filter is its continuous operation. Typically, a belt filter press receives slurry with a solids content ranging from 1–4 % and produces a cake of 12–35 % solids content.	Shorter loading times, higher throughput than with discontinuous techniques.	

II c SCREW PRESSES	This technique consists of a screw conveyor which rotates at variable speeds in a cylindrical basket. The free water is filtered through the screen openings, while the solid is moved through the auger inside of the basket slowly against gravity to the exit. The basket is cleaned regularly with an automatic flushing device. Screw presses are quite insensitive to coarse material because of the wider space for passage between the screw conveyor and the sieve. There is no filter cake structure and thus high filter resistance is avoided. The consumption of conditioners is said to be low. The total investment for setting up a dewatering process with a screw press (incl. construction and piping) is quoted to reach 0.11 million EUR for a WWTP of 30,000 p.e.. The energy consumption is approx. 10 W per kg DS.	Comparatively low noise generation, low washing water consumption. Low energy demand. Low wear and high operational stability. € Quoted as the least costly way of mechanical dewatering.	
II d MOBILE VERSIONS	Mobile versions for sewage sludge dewatering mostly use the centrifuge, screw and plate press technique. The use of mobile dewatering equipment is usually preferred at decentralised WWTPs with lower sewage sludge generation as is often the case in rural areas. The discontinuously available amounts of dewatered sludge render co-incineration as the only practical option for subsequent thermal utilization which ceases the opportunity for phosphorus recovery. The direct costs for mobile dewatering under the conditions in Western Europe are in the range of 7–12 EUR per m³ wet sludge input.  Picture source: Huber SE in wwt 5/2011 Photo image of a mobile screw press	Associated with relatively high costs; interim storage capacity, additional space for manoeuvring and high electrical connection values are needed at the WWTP. Discontinuous output of dewatered sludge at the respective plants limits the use of different utilization options and negotiability of disposal prices.	

II d **Potentials for optimization**	**SLUDGE CONDITIONING** The consistency of the thickened sludge is vitally important for the success and effectiveness of dewatering. Those methods which provide well-structured and ideally crumbly thickened sludge with a high particle surface are preferable. Redilution of the filtrate or concentrate (sludge water) should be kept as low as possible. To improve drainage results and achieve levels above ›10 % DS content, organic coagulating or other precipitating agents are usually added in the pre-treatment of the sludge. It is necessary to differentiate between inorganic flocking substances (iron and aluminium salts, lime, coal, etc.) and organic flocking substances (organic polymers). Inorganic substances not only act as flocking substances but are also builders, i.e. they increase the inorganic content substantially, and hence the unburned proportion of the drained sludge (ash). For this reason, mostly organic conditioning substances are used in the treatment of sewage sludge (↗ BREF WI; 2.2.3.2.1 Physical dewatering, p.29). There is a wide range of high molecular weight polymeric flocculants that are particularly effective at improving dewatering performance.	Reduces energy demand. More effective dewatering and operations. Salts used as flocculants increase the ash content in sludge. Organic flocculants in the form of polymers are hardly biodegradable and may cause hazards to water which is why their use should be restricted. *(Remark: Germany for example began to ban the commercial deployment of fertilizer substrates obtained with the said kind of additives from 2014).*	
	PHOSPHATE ELIMINATION Decreasing phosphate levels in the sludge have a generally positive impact on the dewatering. The DS content after drainage can be increased by up to 5 % and more through phosphate reducing measures. For phosphate elimination biological and chemical processes (e.g. by means of iron precipitation) can be applied. Most often used are biological processes which are less expensive and technically easier to implement. However, in these processes phosphorus is not finally fixed but eventually migrates into interchangeable biologically structured compounds from where it can be dissolved and remobilised by various environmental changes. In addition to biological phosphorus removal a specific phosphate precipitation by increasing the pH can help to solve this problem. One possible approach is offered by the **AIRPREX**®-process which can be applied after the anaerobic stabilisation prior to dewatering. The pH is raised by means of air stripping and adding magnesium chloride.	Saving on polymeric flocculants. MAP (Struvit) which precipitates during this process is a product with proven potential as a fertilizer. (*see* ↗ *Recovery of phosphorus*) Increases the effectiveness of dewatering.	Germany: WWTP Berlin-Waßmanns-dorf, Brandenburg

Table 2: Specific parameters of different dewatering technologies

Applied technology	Available throughput rate	Handling capacity	Energy demand	Consumption of the conditioning agent			achievable DS-content
	m^3 sludge/h	*kg DS/h*	*kWh/m^3 sludge*	$Ca(OH)_2$ *kg/m^3*	$FeCl_3$ *kg/m^3*	Polymer *kg/t DS*	%
Decanter / centrifuges	1 - 200	20 - 6,000	1 - 1.6			8 - 12	~20 - 32
Chamber filter press			0.8 - 1	~15	~5 - 7.5	6 - 12	~22 - 40
Membrane filter press				~3 - 4	~1 -1.5	~5	~30 - 45
Belt filter press	2 - 30	100 - 1,500	0.5 - 0.8			~6	~20 - 30
Screw press	1 - 30	5 - 1,000	0.2 – 0.3			0.01	~20 - 35

DRYING

There exist a number of reasons that require a further drying of the sludge following its mechanical dewatering. Principal arguments for using this technical option are:

- a further reduction of the sludge amount to be handled;
- a further increase of its calorific value;
- further stabilisation and increased hygienic safety;
- easier storage and transportation;
- elimination of the problems of handling paste-like substances resp. the possibility of a better dosing in their further utilization.

A critical economic evaluation should always precede the decision for drying sludge. An economical drying process can be realized where there is enough excess heat available from other processes or where solar energy can be used for drying and the dry product can be marketed as a secondary fuel. For auto-thermal incineration in monovalent sewage sludge incineration plants, the drainage of raw sludge up to a DS content of 35 % is generally sufficient. This can be achieved by mechanical dewatering and may not require thermal drying. Often sludge that has been dried by mechanical drainage is still insufficiently dry for auto-thermal incineration, however. The required DS content for auto-thermal incineration in a given installation will depend on the composition of the sludge (energy content of the dry solids, largely related to the content of organic material). This is influenced not only by the nature of the sludge as such, but also by the applied pre-treatment, e.g. by sludge digestion, or by the use of organic or inorganic sludge conditioners. Dried sewage sludge represents free-flowing granulate with low to medium calorific value which can be used as added fuel especially in power plants and cement kilns. Waste heat or solar power should preferably supply the energy required for the drying process.

The drying/further dewatering of sewage sludge is carried out in separate or connected installations. Generally, the following drying methods for sewage sludge are known:

- contact drying (for example with the help of a thin film dryer, disk dryer, centrifugal dryer);
- convection drying (for example with the help of a belt dryer, drum dryer, fluidized bed dryer, cold air dryer);
- solar drying,

and combinations of the different types. The drying methods applied can be divided into two groups:

- ***partial drying***, up to ***approximately 60-80 % DS;***
- ***complete drying***, up to ***approximately 80-90 % DS***.

Drying thickened sludge from 25 % to 90 % DS requires approx. 70–80 kWh_{therm} per kg of evaporated H_2O using contact and convection drying techniques.

Partial drying is an option where drying in subsequent energetic utilization process reactors (e.g. fluidized bed incinerator) can be achieved at higher efficiency than with any other drying technique. Pre-drying should only be carried out up to the point at which the sludge contributes positively to the energy balance of the following incineration process.

Additional sludge drying may be required for simultaneous incineration of sewage sludge with other waste streams in municipal waste incineration plants (typically with a mixture ratio of drained sewage sludge to municipal waste of max. 10 % weight of drained sewage sludge). The heat required for the drying process is usually extracted from the incineration process. In some drying processes, the sewage sludge to be dried comes into direct contact with the thermal carrier, e.g. in convection dryers or direct dryers (e.g. belt, double-deck, fluidized bed dryers).

During *convection drying*, vapour is produced that is a mixture of steam, air, and released gases from the sludge; and hot gases are produced in the direct drying process. The vapour and gas mixture must be cleaned.

Contact dryers generally achieve a dry solids level of 35–40 %. The evaporated water produced during the drying process is only contaminated with leaking air and small amounts of volatile gases. The steam can be condensed almost totally from the vapour and the remaining inert gases can be deodorised in the boiler furnace. The treatment of the condensate may be complicated due to the presence of ammonium hydroxide (NH_4OH) or high total organic carbon (TOC).

Direct dryers can also be used in an indirect system by the recirculation of evaporation vapours. In indirect drying systems (e.g. disk, thin film dryers), the heat circulates in the system with the help of steam generators or thermal oil and there is no contact of the heating fluid with the sludge. Heat transfer occurs between the wall of the system and the sludge itself (↗ BREF WI; 2.2.3.2.2 Drying, p.30ff. ; ↗ BREF WT; 2.3.3.7 High temperature drying, p.69ff.).

An alternative to external drying is the *in-situ drying of sludge* where it is incinerated together with high calorific waste. In such cases, the water from the dewatered sludge helps to prevent the otherwise possible high temperature peaks that can be seen if only high calorific waste were incinerated.

Drying installations for sludge without an appropriate exhaust gas cleaning device should accept sludge with a content of perfluorooctane sulfonate tensides (PFOS) up to a maximum of 125 µg/kg DS only. Sludge with higher loads should be directly incinerated after drainage.

	DESCRIPTION OF THE BASIC PROCEDURE	ASPECTS TO CONSIDER	REFERENCE LOCATION
III a CONVECTION DRYING	**DRUM (OR CONTAINER) DRYER** The suspension of drained sludge with a DS content in the range of 20–35 % is introduced via appropriate feeding devices into a revolving drying drum. Transport buckets take the material away from the entry point and carry it to the drum internals whose volume can vary depending on the desired product properties. Most of the drying takes place in the direct current. Here the suspension comes in contact with hot drying gas (up to 1,000 °C). The residence time in the dryer depends on the drum speed, drum inclination, flow rate of the drying gas and the storage device at the drum end. The working capacity usually ranges from 1,000 kg/h to 10,000 kg/h of evaporated water.	Thermal efficiency is comparatively low but can be improved through the combination with heat exchanger systems.	
III a Potentials for optimization (Drum dryer)	Various modifications have been developed to optimize the application efficiency. The *Combi-Dry technique* uses a combination of a drying drum, drying and technical support containers. From the drying drum which is heated by a hot air stream, the semi-dried product falls down into an underneath drying container where final drying up to a DS content of 90 % takes place with the help of hot air. The equipment gives a very compact solution that can be set up in the open air and does not require special building construction.	The technique is particularly suitable for smaller WWTPs with a total annual volume of around 1,000 tons of drained sludge.	
III a *continued* CONVECTION DRYING	**BELT DRYER** The drained sludge, coming from an intermediate storage buffer, is evenly distributed (a 4–15 cm thick layer) over the complete width on a perforated belt. The belt, predominantly in a horizontal position, carries the product through the drying area which is divided into several sections. In these sections the drying gas flows through or over the sludge. Evaporation takes place when the biosolids come in contact with the heated air. Each cell can be equipped with a ventilating fan and a heat exchanger. This modular design allows the drying temperatures to be controlled separately in the different sections. Thus, each dryer cell can be individually controlled and the drying air flow can be varied in each cell. In addition, the speed of the conveyor belt can be varied giving an additional parameter for setting the drying time. The cells can be heated directly or indirectly, and all heating media, such as oil, steam, hot water or hot gas can be used. The process temperature is in the range of 120–150 °C. The condensate which incurs during cooling is taken out.	Comparatively low emissions and low dust developments. Lower thermal requirements (around 800 kcal/kg of evaporated water). Flexible and able to handle great changes in the input stream, especially a wide range of moisture contents which in most cases exceeds the range of other dryer types.	Germany: WWTP Straubing, Bavaria Switzerland: BDS Plant Wohlen

III a *continued* **CONVECTION DRYING**	Where a heated air stream is used for drying, blowers are used which create a negative pressure that helps to avoid odour emissions and dust development. This type of dryers is operated with a high recirculation rate, meaning that a large amount of the drying air is sent back for secondary heat generating. An after-treatment of the exhaust air must be undertaken to remove fine dust, odours and other undesired components. The technical capacity usually ranges from 300 kg/h to 10,000 kg/h of evaporated water. There exist also mobile versions of the belt dryer system.		
	FLUIDIZED-BED DRYERS Are suitable for a wide range of processes for treating solids and liquids. They operate on the basis of an upwardly directed air flow which is heated for drying and causes the solids that are being treated to be fluidized. A fluid-like condition is achieved in the fluidized solid, thereby creating optimum drying conditions. The liquid distributed through nozzles is dried on the fluidized inert bodies. This reliably deagglomerates the solid and turns it into fine powder.		
III a **Potentials for optimization**	**HEAT EXCHANGER** This can be employed by WWTPs as a plant-integrated solution for the generation of the thermal energy needed for sludge drying. Heat exchangers are technical devices built for efficient heat transfer from one medium to another. One possible option is available for WWTPs in the form of the cross-flow heat exchanger technology. In this device the fluids travel roughly perpendicular to one another through the exchanger. The thermal energy for drying is obtained from the heat of the primary air flow which is developed from the blowers supplying the activation basins (**CAKIR**-process). Blowers that bring in the oxygen into the activation basins are often the biggest energy consuming installations of the WWTPs (contributing between 50–80 % to a plant's total energy consumption). Drained sludge with a DS content of 23 % can be dried up to a level of 90 % DS by supplying the heat generated by the blowers discontinuously to the drying drums.	Cost saving effect, up to 50 % of the energy costs otherwise needed to achieve the same drying results using other methods.	Germany: WWTP Weissach, Baden-Wuerttemberg

III b CONTACT DRYING	**DISK DRYER** This type of dryer provides continuous dehydration by an indirect contact between the material to be dried and the heat medium. The rotor consists of a stack of discs on a heated horizontal tube. The discs are heated by steam or a thermal fluid is injected into the rotor axis and distributed across the discs. The combined action of the disc, arms-scrapers and stirring paddles ensures an excellent heat transfer and a slow progression of the product to be dried. The RotaDisc-technique uses steam-heated discs fixed on a horizontal axis whose rotation ensures permanent mixing and movement of the sludge through the cylindrical body. Wipers and paddles clean the disc surface and thus keep it free for the wet particles. The permanent contact of the sludge with the heated discs ensures high thermal efficiency. The steam consumption ranges from 1.3 to 1.4 kg of steam per kg of water evaporated.		Denmark: RotaDisc: WWTP Lynetten
	THIN FILM DRYER Thin-film dryers use a horizontal cylindrical stator with a rapidly spinning rotor (peripheral speed of approx. 30 m/s) inside. The rotor is equipped with a variety of blades of adjustable pitch. These take the sludge suspension to the heated wall, where it forms a thin, turbulent film of 3-5 mm thickness. Due to the excellent heat transfer in this film, the liquid evaporates quickly, resulting in a powdery, partially finely ground solid. The discharge of the dried product occurs due to the position of the blades and the carrier gas flowing through the dryer. The technical capacity usually ranges from 750 kg/h to 3,000 kg/h of evaporated water.	A heat requirement of less than 800 kcal/kg of evaporated water is possible. Single passage, continuous process.	

III c SOLAR DRYING	This technique uses the solar energy for the drying of the sludge. The drying, depending on the employed mode of operation, is executed in a continuous or batch process in walled halls with transparent roofing (usually a type of glass house). The solar radiation warms the surface of the sludge and the air around it. The rise in the temperature forces the water molecules out into the surrounding air. The moist air transports the water and has to be evacuated. However, while the surface dries, the lower parts remain moist and have to be turned. Frequent turning of the bed and the intermixture of the already dried and still wet portions is the best way to achieve good drying efficiency. The drying bed is fed and emptied with appropriate equipment such as conveyor belts or shovel loaders. The optimum drying level is reached with a 70 % DS content, but up to 85 % DS is also possible. Solar drying leaves only 20–30 % of the original mass. It is perfect before sludge is going to be used for energy recovery. The sludge is transformed into a granular, free-flowing bio-solid which is easy to handle. The granule is odourless and if its utilization in agricultural is permitted, it can be spread with conventional machinery. It can also be stored in heaps, containers or bags and transported on trucks or by train in silo containers. With an energy input corresponding to the annual solar radiation in Central Europe of 1,000–1,100 kWh/m² an annual evaporation of about 850 litres of water can be achieved on each m² of hall space under the terms of the solar sludge drying. The total energy required for the operation of the equipment is about 25 kWh per ton of evaporated water. The specific investment for a solar drying installation is in the range of 280–400 EUR per m² of drying area whereby on 1 m² can be dried 2–6 m³ of wet sludge in a year.	Low energy demand (10-30 kWh per ton of water removed from the input). The concept is also perfectly suitable as a complementary solution in areas with high seasonal fluctuations in sludge generation due to summertourism (e.g. sea resorts). Highly space demanding and rather time-consuming (i.e. comparably low drying efficiency). Sufficient buffer space is needed for the critical period (December to February).	Luxembourg: STEP Bettembourg Germany: Weil am Rhein, Baden-Wuerttemberg; Penzing Weil, Bavaria

Table 3: Technical characteristics of different drying systems for sewage sludge

Applied technology	Heating medium	DS sludge input	DS sludge output	Process temperature	Energy electr.	Energy therm.	Heat recovery system
		%	%	°C	Wh/kg H_2O	kJ/kg H_2O	
Rotary kiln - direct drying *system Maurer*	combustion gas	22.5	90	100-130	63	4,250	water and process air heating
Rotary kiln - indirect drying *system Elino*	saturated steam	30	95	95-130	50	3,060	water heating and sludge pre-heating
Direct/indirect belt drying *system Sevar*	combustion gas thermo oil	25	95	100-140	70	3,300	water heating
Fluidized bed dryer (direct) *system Sulzer*	thermo oil	20	95	85-115	110	2,500	water heating and sludge pre-heating
Linear thin film drying (indirect) *system Limus*	thermo oil	25	90	115	70	3,000	water heating
Thin film drying (indirect) *system Buss*	saturated steam thermo oil	25	50	100-110	75	2,600	water heating and sludge pre-heating
Rotadisc dryer (indirect) *Stord type*	saturated steam	27.5	95	115-120	125	2,900	water heating and sludge pre-heating
Mobile disc dryer (indirect) *system Babcock*	thermo oil saturated steam	25	90	110-120	87	2,900	water heating and sludge pre-heating
Mobile drum drying (direct) *system Amann*	combustion gas	25	92,5	120	112	3,000	water heating
Mobile dryer (direct) *system PKA*	combustion gas hot air	20	95	110-130	31	3,560	n/a
Mean value					***79***	***3,107***	

Based on data compiled by Kraus, J. Diss. Herstellung von Leichtzuschlagstoffen aus Klärschlamm. ISWW Technical series – Vol. 112 - Karlsruhe 2003

CONVERSION

Conversion stands for a wider range of processes in which material transformation of sewage sludge takes place for the purpose of using its ingredients and substantially neutralizing the potentially hazardous components it contains. Sludge conversion processes may require dewatering and/or drying as a pre-treatment stage, although under certain conditions a direct application next to stabilisation can be possible (see figure below).

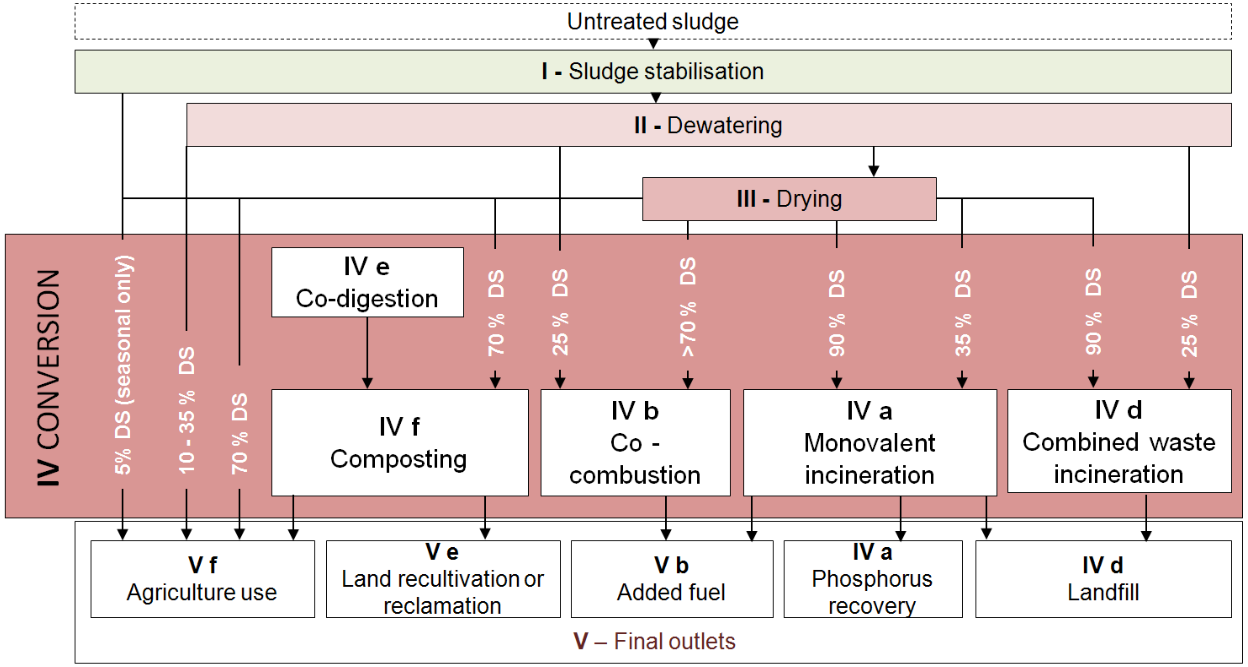


Figure 2: Position of conversion processes in sludge processing and their basic requirements

With conversion sewage sludge loses its original properties and then comes to use in the form of other products. That is why this document ends with the presentation of the treatment technologies after this chapter and continues to explain the different forms of utilization. This means that the focus then changes to the main outlets currently available for treated sludge, showing that the value chain is not finished with conversion. These outlets characterize the main options to utilize sludge as a resource although partly a utilization can be an inherent part of conversion. No detailed considerations will be given on further by-products or secondary uses which may arise from the conversion, however.

To make effective use of the available conversion capacities and pathways for sludge utilization, WWTPs are advised to secure access to or maintain separate ***storage space***. A storage capacity equivalent to one year is considered to be optimal, in the minimum it should be for 3-6 months. With this buffer the WWTP operators can respond to the vast majority of uncertainties regarding sludge disposal. Sludge failing to conform to specifications or the drop-out of a sludge user may require new ways of disposal or at least some time to negotiate and conclude new utilization contracts. Also in these cases, storage capacities are needed (*see storage recommendations under ↗ 'Potentials for optimization' in the respective technology descriptions*).

THERMAL UTILIZATION

Thermal utilization is the method which guarantees at best the destruction of potentially hazardous components and is supposed to become the most widely available disposal alternative as other options are ruled out for diverse reasons. Incineration of sewage sludge is, compared with other disposal options, one of the most costly ways of sludge utilization, though. Typical process conditions apply to sewage sludge incineration.

The heat values of the sludge for auto-thermal incineration lie between 4.8 MJ/kg and 6.5 MJ/kg. Approximately 3.5 MJ/kg of sludge is considered the limit for auto-thermal incineration. Values between 2.2 MJ/kg and 4.8 MJ/kg of sludge are seen where raw sewage is thermally utilized in municipal solid waste (MSW) incinerators and co-combustion processes (rotary furnace). The need for additional fuel can be reduced by the use of efficient internal energy recovery systems, e.g. recovery of heat from flue-gases to heat incineration air and/or use of heat for sludge drying. The composition of sewage sludge varies greatly. Particularly important factors to take into account when incinerating sewage sludge are:

- the DS content (typically this varies but has a major impact on the incineration process),
- whether the sludge is digested or not,
- lime, limestone and other conditioning contents of the sludge,
- the composition of the sludge as primary, secondary, bio-sludge, etc.,
- odour development, especially during sludge feeding in the storage (↗ 64, TWG Comments, 2003; ↗ 74, TWG Comments, 2004).

(TWG = Technical Work Group Best Available Technology)

Incinerators dedicated to sewage sludge combustion (***monovalent incinerators***) are designed to effectively destroy harmful organic compounds in the sludge and to generate energy. Such installations are usually erected at WWTP sites and have the advantage for the plant operator that waste water treatment and sludge disposal can take place independently at the site. Generally these incinerators are operated at temperatures between 850 and 950 °C. Temperatures below 850 °C can result in odour emissions, while temperatures above 950 °C may result in ash fusion. Gas residence time exceeding 2 seconds is commonly employed. The temperature level achieved during incineration depends mainly on the energy content and the amount of sewage sludge to be incinerated and on the atmospheric oxygen level. There are some examples of sewage sludge incinerators (often fluidized bed processes) that operate at temperatures closer to 820 °C without deterioration of the incineration performance or increased emissions. Used oil is the most used additional fuel in monovalent sewage sludge incinerators. Heating oils, natural gas, coal, solvents, liquid and solid waste and contaminated air are also used. Contaminated gas is preferred for the incineration of digested sludge. The primary influences on the requirement for additional energy are the air preheating and degree of drainage needed. The influence of conditioning agents is relatively low. Monovalent sludge incineration opens up the possibility of phosphorus recovery from the ash. The furnace systems used function according to different process technologies. The furnace structure, design, and the operational technology of the incineration, the resulting post-connected cleaning equipment, as well as the transport of different material flows, all have a significant influence on the resulting emissions. In recent years, the stationary fluidized bed has become a preferred technology for monovalent incineration. There are different other incineration technologies used in this area some of which are also employed for ***co-combustion*** and ***combined incineration in municipal waste incinerators*** (↗ BREF WI; 2.3.5.11 Various techniques for sewage sludge incineration, p.79). The following table displays the main spectrum of thermal treatment techniques and fields of their deployment. Interesting alternatives can be found on the market for biomass furnaces. These furnaces are produced in larger quantities and can, following some minor adjustments, also be used for dried granulated sewage sludge.

Table 4: Application of different process techniques for the incineration of sludge and other types of waste

Technique	Sewage sludge	Untreated municipal waste	Pretreated MSW and RDF	Hazardous waste	Clinical waste
Grate-reciprocating	Not normally applied	Widely applied	Widely applied	Not normally applied	Applied
Grate-travelling	Not normally applied	Applied	Applied	Rarely applied	Applied
Grate-rocking	Not normally applied	Applied	Applied	Rarely applied	Applied
Grate-roller	Not normally applied	Applied	Widely applied	Rarely applied	Applied
Grate-water cooled	Not normally applied	Applied	Applied	Rarely applied	Applied
Grate plus rotary kiln	Not normally applied	Applied	Not normally applied	Rarely applied	Applied
Rotary kiln	Applied	Not normally applied	Applied	Widely applied	Widely applied
Rotary kiln-water cooled	Applied	Not normally applied	Applied	Applied	Applied
Static hearth	Applied	Not normally applied	Not normally applied	Applied	Widely applied
Stationary fluid bed	Widely applied	Applied	Applied	Not normally applied	Not normally applied
Fluid bed-circulating	Widely applied	Rarely applied	Applied	Not normally applied	Not normally applied
Fluid bed-bubbling	Applied	Rarely applied	Applied	Not normally applied	Not normally applied
Fluid bed-rotating	Applied	Applied	Applied	Not normally applied	Applied
Pyrolysis	Rarely applied	Rarely applied	Rarely applied	Rarely applied	Rarely applied
Gasification	Rarely applied	Rarely applied	Rarely applied	Rarely applied	Rarely applied

Note: This table only considers the application of the technologies at dedicated installations. It does not therefore include detailed consideration of the situations where more than one type of waste is processed.

Principal characteristics of the main furnace systems used for monovalent sewage sludge incineration can be seen in the following overview.

Table 5: Characterisation of furnace systems predominantly employed for monovalent incineration of sewage sludge

	Fluidized bed furnace	Multiple hearth furnace	Multiple hearth fluidized bed furnace	Cycloid furnace
Main features of the technique	• no mechanically moveable parts • low wear	• no separate pre-drying is necessary • extensive furnace structure with moveable parts • cooled hollow shaft	• no separate pre-drying is necessary • moveable hollow shaft • low fluidized bed volume	• no mechanically moveable parts and low wear • no fluidized bed material
Operational aspects	• fast start-up and shut-down through short heating- and cooling times, intermittent operation possible	• long heating time, continuous operation necessary	• medium heating- and cooling time	• comparable to the fluidized bed • deployable for a wide range of wastes
Possible operational problems	• agglomeration • de-fluidization		• possible emissions of organics movable parts in the furnace	• maintaining desirable temperature
Incineration stag main features	• low air surplus required • complete incineration only above the fluidized bed	• incineration difficult to control • immune to fluctuations in loads and coarse material	• low air surplus required • good incineration control • incineration completed within the fluidized bed • greater immunity to quality fluctuations in the sludge than fluidized bed furnaces	• solid material shares • long and gaseous shares • short residence times • variable primary and secondary air supply on several levels.
Ash content in flue gas	• high	• low	• high	• high
Ash removal	• via flue gas flow and sand removal	• directly from the lowest level	• via flue gas flow and sand removal	• via flue gas flow • crude ash at the bottom
Residues	• ash • fluidized bed material	• ash	• ash • fluidized bed material	• ash • possibly coarse ash

In recent years, the ***co-combustion of sewage sludge*** in power plants and industrial furnaces has taken an increasing share of the sewage sludge disposal. Sewage sludge can be co-incinerated in the kilns of cement plants, lime works as well as in coal-fired power plants. In most incinerating facilities there is no substantial problem with sludge in feeding, conveying and combustion itself, but all industrial processes burning sludge within the EU must fulfil Directive 2010/75/EU, and with effect from January 2016 the Directive 2001/80/EC which both aim to ensure that co-combusting does not cause higher specific emissions than a specialised single combustion. Regulations of the given kind are needed to prevent that industrial undertakings which miss to get their installations equipped with adequate purification units for the flue gas are excluded from the spectrum of service providers for thermal sludge disposal.

Dried sewage sludge used for cement production can replace fossil fuels and at the same time substitute part of the raw materials such as sand or iron ore through its mineral components. Cement plants and lime works hence use sewage sludge to the extent of about 15 % of their thermal power requirement as an added fuel. These plants prefer dried sludge material with 90–95 % DS content, since this degree of drying is useful for introducing into the rotary kiln. In addition to sewage sludge, other wastes from the waste water treatment process are often incinerated, e.g. swim scum, screenings, and extracted fats. Considering that the combustion of sewage sludge is CO_2-neutral, the use of sewage sludge as substitute fuel means for the operator a reduction of his CO_2-emission quota. The advantages of co-combustion lie in the substitution effect that can be obtained from the utilization of sludge as regards conventional fuel and raw materials, reduced disposal costs for WWTP operators and the safe destruction of potentially harmful organics that can be achieved with it. Rather critical points are the additional drying efforts and transports that most often become necessary and the fact that the nutrients contained in the sludge get lost in this way since also the recovery of phosphorous from the ashes is impossible here, either.

For most power stations a share of sludge of up to 5 % of the total fuel mass was found to be the optimum. Pulverized coal injection or fluidized bed firing systems are mainly used for co-combustion in power stations. In power plants with pulverized coal firing sewage sludge is usually introduced into the process via the coal mill where it is dried and crushed together with the coal. Power stations in general accept only stabilised sewage sludge for incineration. The use of raw sludge is associated with great difficulties in handling and storage, mainly due to problems with the formation of gas and odours and with dewatering. Technically possible is the combustion of just drained as well as dried sewage sludge. Most power plants to date use drained sewage sludge with a DS content in the range of 25 to 35 % DS.

Table 6: Usual arrangements for the co-combustion of sludge in coal-fired power stations

	Original fuel material	Added fuel	Combustion technology used
Hard coal-fired power station	Hard coal Water content 7-11 % Calorific value 27-30 MJ/kg	Stabilised and drained sludge (proportion is limited by the drying capacity of the coal mill)	Pulverized coal firing Slag tap and cyclone boiler Circulating fluidized bed
Lignite-fired power station	Lignite Water content 45-60 % Calorific value 8.5-12.5 MJ/kg	Stabilised and drained sludge (proportion is limited especially by the heavy metal content)	Pulverized coal firing Circulating fluidized bed

Municipal waste incineration plants are left as the ultimate option to have sewage ***sludge incinerated together with other waste (combined incineration)***. Where added to MSW incinerators, the feeding techniques often make the major difference to other incinerators and represent a significant proportion of the additional investment costs. At a high level of sewage sludge and a limited piling capacity, the ideal solution is to spread well-structured, pre-dewatered sewage sludge continuously on the refuse in the bunker with a spreading machine. This spreading process can be carried out either in the refuse bunkers and the product then displaced and mixed with commercial and domestic refuse with the aid of a grab, or by spreading onto the continuous-operation hoppers feeding the incinerators. The effectiveness of mixing in the waste bunker can be optimised by a skilful crane operator.

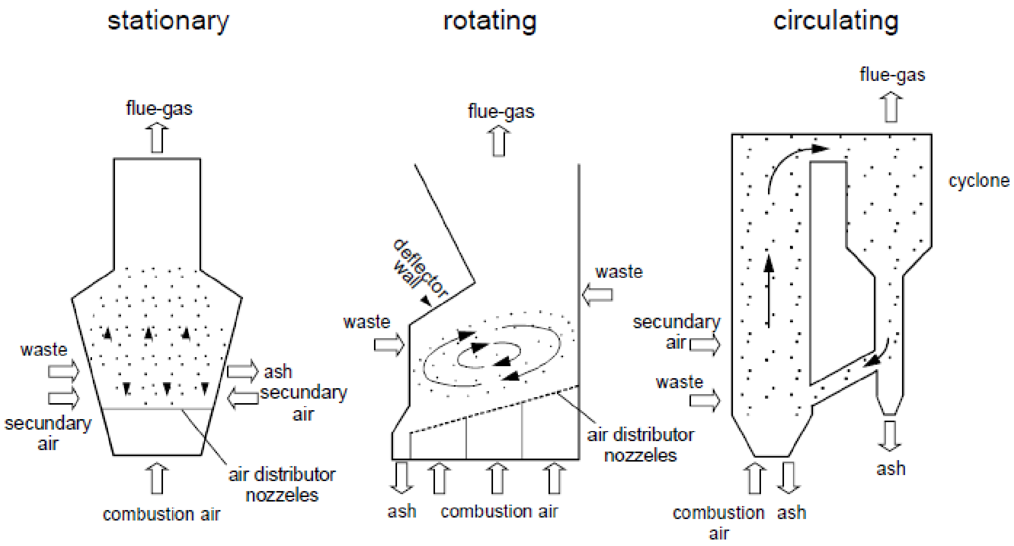
Also ***other methods for thermal utilization***, such as *pyrolysis* and *gasification* have already more advanced in the area of sludge treatment than in other waste areas. This mainly has to do with the sludge's homogenous nature whilst for other wastes, where this is more seldom the case, the success both processes have on the market is rather limited until to date. Both pyrolysis and gasification are processes in which the chemical decomposition of thermally unstable organic substances takes place at temperatures below those for incineration (400–800 °C) and under the absence or a strongly limited supply of oxygen. Gasification depicts an incomplete combustion of the organic matter under the formation of a syngas and is theoretically the stage next to pyrolysis. The great difference between pyrolysis and gasification is that it is a highly endothermic process requiring an outer energy source so as to take place. The further treatment of pyrolysis products (further treatment to a fertilizer or recovery of nutrients from the products) are not sophisticated yet. Both processes are also associated with high investment and operating costs.

	DESCRIPTION OF THE BASIC PROCEDURE	ASPECTS TO CONSIDER	REFERENCE LOCATION
IV a MONOVALENT INCINERATION	Dedicated sewage sludge incinerators are generally designed and operated at temperatures between 850 and 950 °C. Temperatures below 850 °C can result in odour emissions, while temperatures above 950 °C may result in ash fusion. Gas residence times in excess of 2 seconds are commonly employed.	Inorganic pollutants (different heavy metals) remain after combustion in the combustion residues.	<u>Germany:</u> WWTP in Altenstadt, Bavaria
	<u>FLUIDIZED BED INCINERATION</u> *(↗ BREF WI, p.47)* The fluidized bed incinerator is a lined combustion chamber in the form of a vertical cylinder. In the lower section, a bed of inert material (e.g., sand or ash) is fluidized on a grate or distribution plate with air. Waste material combustion using a fluidized bed is an advanced, obviously cleaner technology adopted for modern incinerators and power plants.	Allowing a very effective burnout of the input at a rather low rate of emission generation.	<u>Germany:</u> Power station* Werdohl-Elverlingsen, North Rhine-Westphalia **doing co-combustion*

IV a *continued*

MONOVALENT INCINERATION

Fluidized beds suspend solid fuels on upward-blowing jets of air during the combustion process. The result is a turbulent mixing of gas and solids. The tumbling of the waste material provides more effective chemical reactions and heat transfer. In the fluidized bed, drying, volatilisation, ignition, and combustion take place. The process requires an input material of rather small and consistent particle size and is therefore particularly suited for sewage sludge. Fluidized bed incineration is less sensitive to changes in the calorific value of the waste. Circulating and stationary fluidized bed systems are preferred as solutions for sewage sludge incineration.



Graphic source: INTECUS

The **STATIONARY FLUIDIZED BED** *(↗BREF WI, p.49)* is especially useful for burning wastes with a low calorific value (6.5 to13 MJ/kg).

Heavy metals are bound to a low extent only into the ashes. The ashes can therefore well be utilized as a filling material for bound applications in civil construction or as a filling material for mines without demanding much further preparation.

With less mechanical upkeep, equipment, staffing, and repair costs, fluidized beds tend to be less expensive to operate and maintain than other incinerator technologies.

Reduced need for flue gas denoxification.

Higher flexibility as regards the effective incineration of sludges of different quality (DS content and calorific value).

In the **CIRCULATING FLUIDIZED BED** *(↗BREF WI, p.51)* the bed sand and ashes constantly leave the furnace due to a particularly high air velocity and must be separated in a cyclone. High air velocities allow the use of high calorific waste (7 up to 22 MJ/kg).

Sewage sludge of unsuitable quality may cause a blockage of the fluidized bed and increase the risk of operational problems then.

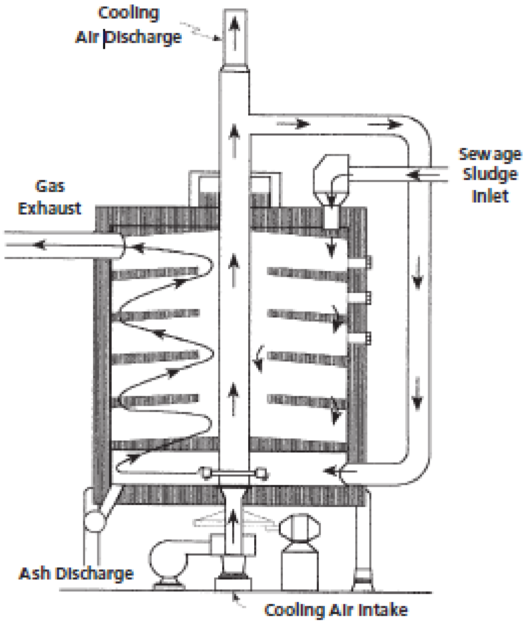
Germany:

WWTPs Munich - Gut Großlappen and Steinhäule, Bavaria

IV a *continued*
MONOVALENT INCINERATION

MULTIPLE-HEARTH FURNACE *(↗ BREF WI, p.67)*

The multiple hearth furnace is mainly employed for sludge where the ash forms such eutectics with the bed material that it would cause operational problems in the fluidized bed. The different combustion stages take place at different trays in the combustion chamber. The installation consists of a cylindrical lined steel jacket, horizontal layers, and a rotating sleeve shaft with attached agitating arms. Sludge and combustion residues are led from the top against an ascending current of hot air and flue gases and fall through holes from one level to another.



Graphic source: www.neiwpcc.org

The number of trays for drying, incineration, and cooling is determined based on the residual material characteristics. Usually the combustion chamber is made of six trays allowing three zones to be created, the upper for drying, the real combustion taking place in the middle and the lower part as a cooling zone. The conversion of organic sludge particles into CO_2 and H_2O occurs at temperatures between 850 and 950 °C. The furnace can be operated with or without an afterburner chamber, whereas in the type without afterburning the combustion gases are recirculated.

Higher temperatures (temperature differences between furnace head and foot) can be avoided leading to a lower formation of NO_x.

Flexible to accept sludge of quite varying type and quality.

Multiple hearth furnaces can be operated by removing the flue gases at the highest drying level and then feeding them to post-combustion. This is advantageous in such locations where boiler plants are already available, facilitating the feeding of flue-gases into those plants.

With a bit more of mechanical upkeep, equipment, staffing, and repair costs, multiple hearth furnaces tend to be more expensive to operate and maintain than fluidized bed incinerators.

Germany:

WWTP Sindlingen, Hesse

IV a *continued* MONOVALENT INCINERATION			
	MULTIPLE-HEARTH FLUIDIZED BED FURNACE *(↗ BREF WI, p.70)* This is a combination of multiple-hearth incinerator and a fluidized bed. The technology works with a pre-drying and dispenser zone that may stretch over six layers in the upper part of the furnace. Located underneath is the chamber with the fluidized bed. 40–60 % of the contained water is evaporated in the pre-drying zone. The concentrated vapours flow through the pre-combustion zone where all volatiles are burned. Due to the high degree of pre-drying and pre-combustion, the subsequent fluidized bed chamber can be kept relatively small in comparison to the previous zones. Uniform incineration is promoted by optimising air supply, sand addition, and evaporation in the layers and in the fluidized bed.		
	CYCLOID INCINERATION *(↗ BREF WI, p.72)* The cycloid incineration chamber was originally developed for incinerating old coke derived from flue gas cleaning at waste incineration plants but is now also used for the thermal disposal of sewage sludge. The optimal particle size for fuel ignition lies between 1 and 5 mm. Therefore, only dried sewage sludge granules can be used. The fuel granules are supplied gravimetrically via a radial chute into the lower part of the incineration chamber, which is designed as a metallic air-cooled hopper. Atmospheric oxygen is blown into the incineration chamber at various air levels: The primary air enters the furnace at an angle through the lower part of the hopper, and the secondary air is injected on different levels through tangentially placed jets above the fuel feed. The distribution of primary and secondary air varies according to the specific fuel characteristics. The incineration of sewage sludge requires even temperature distribution between 900 and 1,000 °C throughout the entire incineration chamber. Using this method, the temperature of the ash is maintained under its softening point. Flying dust is removed along with flue-gas from the incineration chamber. The coarse kernels circulate in the tangential flow field until they are incinerated to the point when they can be removed as fine kernels. Crude ash, remaining coke, or metallic parts are removed in a downward direction via a lock system.		

IV a Potentials for optimization	*Recycling of recovered ammonia-solution into the furnace* Condensed waste water from the partial pre-drying of sewage sludge is specific to sewage sludge incineration, although it does not arise in all cases as the steam generated during drying is sometimes evaporated with the incinerator flue gas instead of being condensed. It generally has a high Chemical Oxygen Demand (COD) and contains substantial concentrations of N (mainly NH_3), as well as other pollutants that were originally present in the treated sludge. The high nitrogen content can form a bottleneck for treatment; in this case stripping of nitrogen may be used, although there may be a risk of fouling and additional energy requirements for its operation. A solution in this case may be recycling in the furnace, where the recovered ammonia-solution (concentration approx. 10 %) can be used for SNCR de-NO_x feed.	The establishment of a closed process helps to reduce treatment needs for generated effluents.	
IV b CO-COMBUSTION	Most furnace technologies and firing techniques applied for monovalent incineration are in principle also good and practically used for co-combustion. Co-combustion is especially suitable for selected industrial processes where it can render the *Rotary kiln* (↗ *BREF WI, p.44*) a good solution in this area. Rotary kilns are robust furnaces that can be used to incinerate almost any waste, regardless of its type and composition. Operating temperatures of rotary kilns burning wastes range from around 500 °C (as a gasifier) to 1,450 °C. The rotary kiln consists of a slightly inclined cylindrical vessel that is refractory lined and internally fired. The vessel rotates or oscillates around its horizontal axis (reciprocating motion). The waste is conveyed through the kiln by the gravity as it rotates. Cement or lime producing plants usually work with rotary kilns to convert the raw materials into clinker. Within the kiln system, different chemical reactions and phase formations occur that are defined by specific temperature ranges of the feed material. The evaporation of water, dehydration of clay minerals and calcination are sequential processes in the kiln body. Calcining takes place in an oxidizing atmosphere and completely decomposes the carbonates in the feed materials. The burning of the calcined kiln feed actually occurs in the kiln's hot end.	Hazardous substances are effectively destroyed by the high temperatures in the kiln. Ash residues including heavy metals are incorporated into the clinker, so there are no residues that require further management. Allows for a partial substitution of conventional fuel and certain raw materials. Opens up the way for reducing disposal costs as compared to incineration in municipal waste incinerator.	Luxembourg: Cement plant Rumelange *(using the solar dried sludge from Bettembourg)* Germany: Cement plants Cemex Rüdersdorf, Brandenburg; Schwenk Cement Karlsfeld, Bavaria; and Mergelstetten, Baden-Wuerttemberg; Holcim Lägerdorf, Schleswig-Holstein

IV b Potentials for optimization	**INTERMEDIATE STORAGE** The consumption of sludge by incinerators and co-combustion facilities cannot be regarded as being continuous and stable as these plants must undergo revisions and are not saved from changes in the supply and prices of their other fuel products requiring them to adapt their operations. WWTPs that make use of these outlets should maintain storage capacities equivalent to 3–6 months of their sludge volume in the minimum so as to bridge times where these plants cannot operate in the usual manner.	Sludge storage is highly space demanding and requires additional structural, organisational and logistic efforts as well as appropriate safety measures.	
IV c PYROLYSIS	Pyrolysis is the degassing of wastes in the absence of oxygen, during which a pyrogas and a solid coke are formed. Sewage sludge (drained or dried) may be co-treated with municipal waste fractions. In general, the temperature of the pyrolysis stage is between 400 °C and 700 °C. At lower temperatures (approx. 250 °C) other reactions occur to some extent. This process is sometimes referred to as thermal conversion of sludge.	The process input is almost completely converted into usable products, very little waste material remains.	Germany: Pyrolysis units temporarily operated for technical trials in Emmerich, North Rhine-Westphalia; and Neustadt a.d. Weinstraße, Rhine-land-Palatinate *Note:* *The commercial success of the above pilots remained limited with the consequence that no extension has so far been initiated here*
	HIGH TEMPERATURE PYROLYSIS *(↗ BREF WI, p.56)* An example of high-temperature degassing is provided with the so-called **PYROMEX**®-process. In this process the sludge gets pre-dried before degassing to a DS content of 80 % with the help of the generated pyrogas at temperatures between 280–300 °C. The resulting vapours are cleaned by means of biofilter and two wet scrubbers to minimize odour emissions. The degassing takes place in an oven heated by induction at 1,200–1,700 °C in the absence of oxygen. The organic material is hereby quantitatively transferred into CO and hydrogen-rich gas (fuel gas). A predominantly mineral residue remains from this process.	Until to date most of these techniques proved to be investment and cost intensive, sophisticated cleaning technologies are often required to make use of the products and for some by-products.	
	Alternatively the **PYREG**®-process is now more intensively tested for larger-scale applications. Dewatered sludge (>50 % DS) is fed into a reactor that is heated up to 650 °C. Syngas forming as a result of the carbonation reaction in this slow pyrolysis process is subsequently burned in a chamber equipped with an efficient FLOX®-burner at 1,250 °C. Biochar generation and phosphorus recovery shall be facilitated.	The process is marked by low exhaust emission values and the need to deal with substances of concern said to be insignificant.	Germany: Pilot installation at WWTP Linz-Unkel, Rhineland-Palatinate

IV c *continued* **PYROLYSIS**	**ULTRA-HIGH TEMPERATURE PYROLYSIS** This process uses a special high temperature-resistant reactor for degassing. It is already in use for a daily sludge volume of 10 tons dry solid matter. The high calorific pyrogas obtained from the above two technical schemes must be cleaned from pollutants prior to its use in energy generating processes (e.g. combined heat and power generation by combustion in an engine). Critically important here as a pollutant is mercury. The pyrogas must therefore go to a scrubber in order to be cleaned.	The technology has not found a wider application yet as long-term experience has proven the existence of certain setbacks and higher overall costs than predicted. The process output has also not proven to meet safely and consistently the expected quality. Technical development and upgrading is continued but until now has not allowed large-scale installations to operate stable and in the long run.	
	LOW TEMPERATURE CONVERSION TECHNIQUE In the low-temperature conversion a thermocatalytic conversion process takes place in the absence of oxygen at atmospheric pressure and a temperature between 380–450 °C. Gaseous substances (up to 35 %) which evolve in that process condense upon cooling to reaction water, salt and a kind of crude oil (about 10 % liquid hydrocarbons). The partition of this mixture occurs in a condenser. A small amount of non-condensable gases ecapes. The remaining substance (approx. 55 %) is a coal-like material in which all non-volatile substances are incorporated. The gas can be used within the process for heating of the converter. The resulting oil-like substance can be utilized by WWTPs or other users as a substitute fuel. Also the coal can be used as an added fuel for sludge drying or as an auxiliary filter substance replacing activated coal in the waste water treatment process. The conversion technique can be applied to sewage sludge and other organic substances, e.g. organic household waste, oil seeds or animal by-products.		Germany: LOTECOTEC project and process demonstration plant at WWTP Mintraching, Bavaria; KDV test installation in Eppendorf, Saxony; and Ennigerlohe, North Rhine-Westphalia

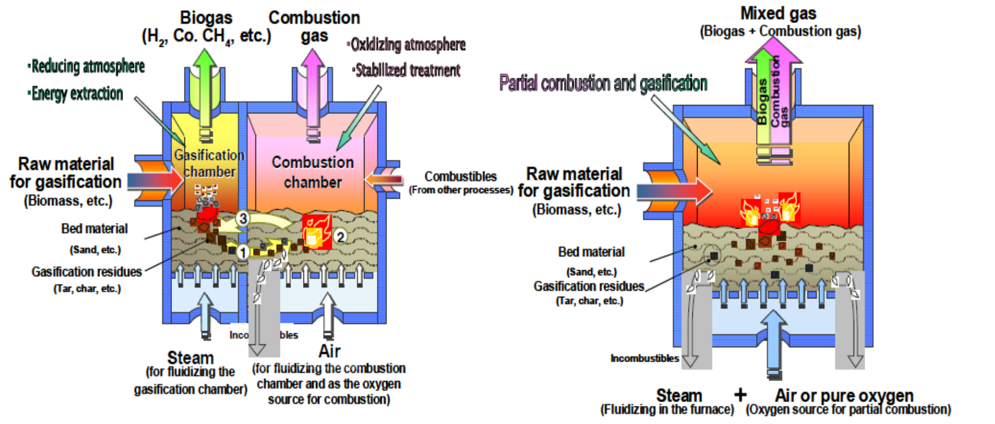
MOBILE INCINERATION / IV c PYROLYSIS	A mobile incinerator is an incineration system mounted on a trailer. These systems are usually designed to treat various types of waste including sludge. The furnace of recent models consists of a main combustion chamber (primary chamber) and a post combustion chamber (secondary chamber). An automated burner serves for the heating of the combustion chamber and depends on the calorific value of the input. Circulating bed or rotary-kiln (pyrolysis) are the two principal process technologies used for this type of incinerators. Combustion temperatures between 850 °C and 1,200 °C in the post combustion chamber ensure an environmentally safe destruction and emission within prescribed limits. There are devices in the market operating without flue gas treatment but there are also others that have a dry flue gas cleaning system complying with European standards.  Picture source: Wikipedia Photo image of a mobile incineration unit	Can flexibly be used for different types of waste and at places with lower sludge accumulation where no economical disposal alternatives are available. A very costly solution in terms of price per unit treated. Keeping emissions limits with devices operating without a flue gas treatment can be difficult.	

IV c GASIFICATION

In this process sludge is first heated to approximately 500 °C in the absence of oxygen whereas the resulting energy-rich gases are used in a secondary combustion chamber to produce steam. By adding controlled amounts of oxygen the material is subsequently calcined. Harmful components that stand the calcining process are incorporated into the matrix of the mineral granule. The granule has a sand-like structure and can be stored at mineral deposits but also utilized by the construction industry. The gasification of sludge is performed using as standard technologies the

- fixed bed
- (circulating) fluidised bed (in the below picture shown on the left)
- spouted bed.

The common gasifier (in the below picture shown on the right) is supplied with the input materials (in which sludge is contained to 100 % or in a lower proportion, e.g. as low as 50 %), steam, and the oxygen source such as air in a single space for pyrolytic gasification and partial combustion.



Graphic: adapted by INTECUS using elements from various sources

Very efficient in terms of energy recovery. Energy inherent in sewage sludge but remaining largely unused in incineration processes becomes accessible for use.

The biogas obtained from pyrolytic gasification of sewage sludge contains, at a concentration of a few thousand ppm, highly toxic substances, such as hydrogen cyanide, stemming from the nitrogen components in the sewage sludge.

The technology has not found a wider application yet as long-term experience has proven the existence of certain setbacks and high overall costs.

Germany:

Sludge gasification units at WWTPs Balingen and Mannheim, Baden-Wuerttemberg

Japan:

Kiyose plant

Packed bed gasifier technology *(↗ BREF WI, p.55)*
is used for gasification of coal waste mixtures. The feed rate proportion for waste is up to 85 %. The waste enters into the reactor through the entry lock and is transformed into synthesis gas at approx. 800–1,300 °C and 25 bar with the help of steam and oxygen.

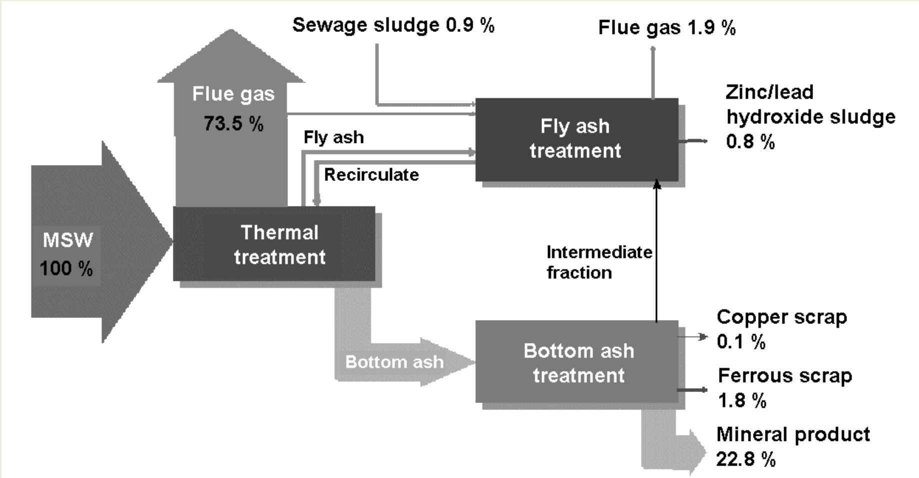
IV c Potentials for optimization	**COMBINATIONS OF PYROLYSIS AND POST-GASIFICATION** are also used to combine the advantages of both processes in terms of energy efficiency and usability of the generated products. One such model is to use dried sludge (85–90 % DS) at 600–700 °C in a rotary kiln and avail of the generated pyrogas directly for heating purposes.		
IV d COMBINED WASTE INCINERATION	Ordinary facilities for municipal waste incineration can be used for the thermal treatment of sludge, provided that certain procedural changes are observed. The following three supply technologies are used: - dried sewage sludge (~90 % DS) is blown as dust into the furnace, - drained sewage sludge (~20–30 % DS) is supplied separately through sprinklers into the incineration chamber and distributed on a grate. The sludge is integrated into the bed material by overturning the waste on the grates. Operational experience shows that up to 20 % of the mass should be sludge (at 25 % DS). Other tests have shown that if the percentage of the sludge is too high (e.g. >10 %.), high fly ash content or unburnt material may occur on the bottom. drained, dried or semi-dried (~50–60 % DS) sludge is mixed with the remaining waste or fed together into the incineration chamber. This can occur in the waste bunker through targeted doses by the crane operator, or controlled in a feeding hopper by pumping dewatered sludge into the hopper or by spreading systems into the bunker (↗ 74, TWG Comments, 2004). It should be noted that fluidized bed combustion is very different from grate combustion, and that the nitrous oxide emissions from MSW grate incineration with a secondary combustion temperature over 900 °C are generally negligible (↗ *64, TWG Comments, 2003*).	Provides a safe way for the destruction for most of the potentially harmful components of sludge and usually concerns installations that have the most effective and best emission control techniques and regimes. Leads to complete destruction/loss of the nutrients in the sludge and does generate energy only at low efficiency.	France: Waste incineration plants in La Tronche, Dinan, and Annecy Germany: Municipal waste incinerators in Munich and Wuerzburg, Bavaria
IV d Potentials for optimization	**SPRAYING THE SLUDGE** through special nozzles in selected locations above the waste bed (often in the gas burnout zone) may provide benefits for some MSW incinerators in that the water content of sludge provides an additional means of controlling temperature and may assist with the primary NO_x control.	Reduced emissions of NO_x.	

IV d *continued*
Potentials for optimization

HOT GASES are detracted from the boiler at a temperature of 900 °C and passed through a rotary kiln. Drying and combustion of just drained sludge (‹25 % DS) takes place in the kiln following the counter flow principle. A ventilator blows the combustion gases generated in the rotary kiln back into the boiler room for post- combustion.

The use of additional fuel for the drying and burning of just drained sludge can be avoided using waste heat.

COMBINED INCINERATION - PECK COMBINATION PROCESS *(↗ BREF WI, p.459)*
In this combined process, dewatered sewage sludge is used as a kind of additive to the fly ash collected from the boiler and electrostatic precipitators of a MSW grate incinerator. The mixture is fed to a pelletiser and the resulting dry pellets are treated in a fluidized bed reactor, where chlorination and evaporation of metals take place at 900 °C. The evaporated metals leave the fluidized bed reactor together with the flue gas. By a partial quench the heavy metals are condensed and filtered afterwards. The filtered heavy metal concentrate is then transported to the zinc and lead refining industry. The process is preferably equipped with a conventional wet flue gas purification unit.



Graphic: adapted from materials of IWB, ETH and Doka Ökobilanze, CH

Lowers the fly ash volume and leads to reduced content of heavy metals in the mineral residues as compared to conventional MSW incinerator operations,
these heavy metals are concentrated into potentially recyclable metal concentrates.

Costs for the disposal of MSW incineration residues are significantly reduced.

Requires a higher investment and operating expenses at the MSW incinerator.

Switzerland:

KVA Basle

IV d FLUE GAS CLEANING	Flue gas cleaning must be an integrated part of any waste incineration to secure the abatement of the hazard potential of emissions resulting from the incineration process. Particular attention in the exhaust gas treatment after sewage sludge combustion must be devoted to nitrogen oxides and mercury. For reducing nitrogen oxides measures of proven furnace management such as staged combustion and flue gas recirculation *(↗BREF WI, p.111)* are required. Additionally, the selective non-catalytic reduction (SNCR) by injecting urea into the flue gas *(↗BREF WI, p.113)* is very common. Mercury in sewage sludge combustion occurs in the flue gas in a metallic form and is thus more difficult to remove than metal chloride, which forms during the combustion of residual waste. Metallic mercury is converted by the addition of oxidizing agents into the ionic state and can thus be separated in the wet scrubber *(↗BREF WI, p.105)*. For the removal of acid gases such as SO_2 and HCl dry-sorptive processes and flue gas scrubbers *(↗BREF WI, p.107)* are available. Using the dry-chemical method, chemical reactive, disperse material that contains a basic component ($Ca(OH)_2$) is applied to the exhaust stream. The elimination of unburned hydrocarbons, dioxins and furans is achieved via absorption with activated coal. The adsorbent needs to be provided in excess so that the desired pure gas values can be obtained safely. Afterburners are used to burn organics in exhaust gases more completely. In order to separate the fly ash, cyclone *(↗BREF WI, p.106)* and bag filters *(↗BREF WI, p.105)* have proven to be effective. The water consumption for flue gas cleaning in the context of sewage sludge incineration is 15.5 m³ per ton of input *(↗ BREF WI, p.202)*.	Reduced emissions of potentially toxic and noxious pollutants. By injection of ammonia, nitrogen oxide reduction from 100-200 mg/Nm³ to 70 mg/Nm³ can be achieved. High investment and cost intensive, very energy consuming.	
IV d Potentials for optimization	Sulphur dioxide neutralization using lime during combustion can reduce the proportion of metallic mercury in the exhaust air in relation to the total amount of mercury. Thus mercury separation is improved *(↗ BREF WI, p.116)*.	Reduced mercury emissions	

BIOLOGICAL CONVERSION

Sludge contains nutrients and organic carbon from which plants and the soil can benefit. Sludge also contains inorganic and organic contaminants as residue substances from waste water treatment. Thus, it is necessary to analyze the sludge before it can be classified for further utilization. Before suitable sludge can be applied to land it must be stabilised to convert it into an environmentally safer product. An option before the material utilization of sludge is therefore the supply of sludge to ***composting***. Sludge or residues from sludge digestion are usually added to other composting input only at proportions, which permit allowable pollutant levels to be kept. During composting microorganisms break down organic matter in the presence of oxygen and produce carbon dioxide, water, heat, and humus, the relatively stable organic end product. Sludge compost is a stabilised organic fertilizer with moderate nutrient content, which releases the nutrients slowly and evenly to the plant and affects positively the balance of the soil humus. The material quality, environmental quality and hygienic safety of the finished compost are to be secured by external and internal supervision, such may include quality control measures, participation in a quality assurance scheme and/or certification mechanism. Regular lab analyses are important elements of a compost quality assurance and certification system.

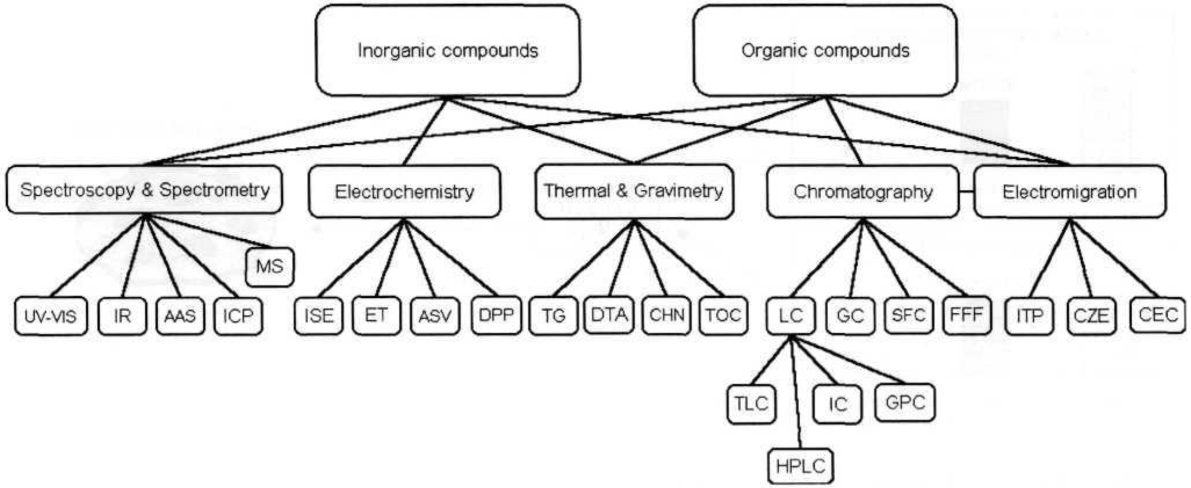


Figure 3: Overview of analytical methods used in compost analysis

with the following meaning of the abbreviations shown: AAS - Atomic Absorption Spectrometry, ICP - Induced Coupled Plasma, MS - Mass Spectrometry, ISE - Ion Selective Electrode, ET - Electrotitration, ASV - Anodic Stripping Voltamperometry, DPP - Derivative Pulse Polarography, TG - Thermogravimetry, DTA - Differential Thermal Analysis, CHN - Elemental Analysis, TOC - Total Organic Carbon, LC - Liquid Chromatography, TLC - Thin Layer Chromatography, HPLC - High Performance Liquid Chromatography, GPC - Gel Permeation Chromatography, GC - Gas Chromatography, SFC - Supercritical Fluid Chromatography, FFF - Field Flow Fractionation, ITP - Isotachophoresis, CZE - Capillary Zone Electrophoresis, CEC - Capillary Electrochromatography

Graphic source: Kosobucki, A. Chmarzyński, B. Buszewski: Sewage Sludge Composting. in Polish Journal of Environmental Studies Vol. 9, No. 4 (2000)

Mixed with other biodegradable waste, sludge can also be a suitable input material in ***digestion processes***. The production of biogas from sewage sludge is well-known from the technologies used at the beginning of the process chain for sludge stabilisation. Brought in a mix with other biogenic substances such as kitchen and food waste and introduced into modern bio-digester installations, it has been found that an optimal biogas yield can be obtained, significantly higher than that with digestion from each fraction individually. The output, processed to gas of natural gas quality, can be used for many purposes: to fuel vehicles, to generate electric power and heat buildings or to support sludge drying processes.

	DESCRIPTION OF THE BASIC PROCEDURE	**ASPECTS TO CONSIDER**	**REFERENCE LOCATION**
IV e CO-DIGESTION	Additionally to the use of the technique for the stabilisation of raw sludge **ANAEROBIC DIGESTION** can also be used for the further utilization of sewage sludge together with other organic wastes as co-substrate. The use of co-substrates should be preceded by a preliminary energy analysis. Through this analysis technical and implementation-related parameters (e.g. digestion time required) can be estimated as well as the compensation of deficiencies in the material composition through changes or addition of substrates can be assessed in advance. Energy-rich substances such as the contents of grease traps, swim scrums or waste from the food and beverage production are especially suitable as co-substrates. For a stable and economical operation of the co-digestion co-substrates should be contractually secured over a longer period, at least for about 5 years. Digester installations set up directly or close by the site of the WWTP should be exclusively considered for the implementation of co-digestion for reasons of transport efficiency. This can be facilitated for example by addition or modification of digestion units and the relevant accompanying infrastructure (reception bays, pre-treatment and supply facilities). The mixing with the co-substrate is preferably to be done in the primary clarifier, thickener or directly at the feeding entrance of the digester (*see for more process details the earlier chapter on ↗ sludge stabilisation*).	Capture of the fermentation gases prevents their free escape into the atmosphere and thus climate damage. € Increased biogas yield in comparison to the pure sludge digestion, possibility for WWTPs to tap another income source. A positive overall energy balance is rather difficult to achieve (especially in smaller WWTPs) without modern technical systems in place (*see ↗ Potentials for optimization*).	Germany: WWTP Radeberg, Saxony
IV e Potentials for optimization	With a retrofit under integration of advanced heat exchanger an almost complete recovery of energy from the exhaust air streams and power units installed in the WWTP can be achieved so that even for small WWTPs an almost complete self-supply of the energy and heat needed for the operation should become possible.	Reduced or no need of an external energy supply.	

IV f COMPOSTING

Composting

is a bio-thermal aerobic process that decomposes the bio-organic portion of the input materials. In this process the content of organic matter is reduced by approximately 25 %. Aerobic microorganisms and fungi are mainly responsible for the decomposition of the biologically digestible parts in that they use them as a nutrient and energy source. A portion of the carbon is hereby bound in the microorganisms' cell substance while another part is released as carbon dioxide to the atmosphere. Within a period of 10–30 weeks (depending on the input and composting technique applied) a total mass reduction of 50–65 % can be achieved.

To kill pathogens in the compost material safely, minimum process temperatures of 55 °C must be ensured for at least two weeks or 65 °C (60 °C in encapsulated systems) for at least one week. The heat is produced by the decomposition of the organic portion, it lowers the moisture content and further stabilises the input and renders the material harmless by transforming it into a usable bio-solid. In general, the higher the bio-organic content of the input, the greater the quantity of heat released during composting.

Sewage sludge from municipal WWTPs without unacceptable loads of heavy metal concentrations and pharmaceutical residues are generally suitable as composting feedstock. Sludge composting then is a particularly suitable method to achieve sufficient hygienisation/stabilisation. Since raw sludge (from primary and secondary clarifiers) contains more organic material than digested residual, it is reasonable to prepare compost in particular from dewatered raw sludge. Before composting, it is necessary to dewater the sludge. Dewatering, among other things, decreases the amount of moisture to be evaporated by the composting process.

For proper composting to take place a C/N-ratio of the input in the range from 20:1 to 40:1 plus adequate moisture content is required. The range 25:1–30:1 describes the optimum for a fast composting process. Overloads of nitrogen in the input material must be avoided since almost the entire nitrogen fixed in the organic material is going to be released as ammonium through micro-biological activities. High concentrations of ammonium at a pH ›7 can cause unwanted emission of ammonia. Through the addition of structural materials containing cellulose (i.e. wooden shavings, sawdust, bark, straw, leaf litter) the proper C/N-ration can be created. Mechanical pre-treatment is normally used to attain the optimum structure and C/N ratio in the composting input by combining various organic wastes. Bulking agents can be added to the input if it lacks the structure to maintain adequate porosity for air access.

Nutrients in the sludge are saved and made available in a safe way for agriculture and land reclamation purposes.
A humus-like material for use as soil conditioner is produced, pathogens and germs are usually inactivated and destroyed.

€

Reduced moisture content and reduced bulk volume provide favourable transportation costs.

Composted, biologically dried sludge is a homogenous, storable product.

Sludge composting produces significant GHG emissions and causes odour nuisances,
concentrations of heavy metals and pharmaceutical residues remain largely unchanged.

Germany:

Sludge composting facility of the Entsorgungs-Gesellschaft Westmünster-land in Vreden-Ellewick, North Rhine-Westphalia

Poland:

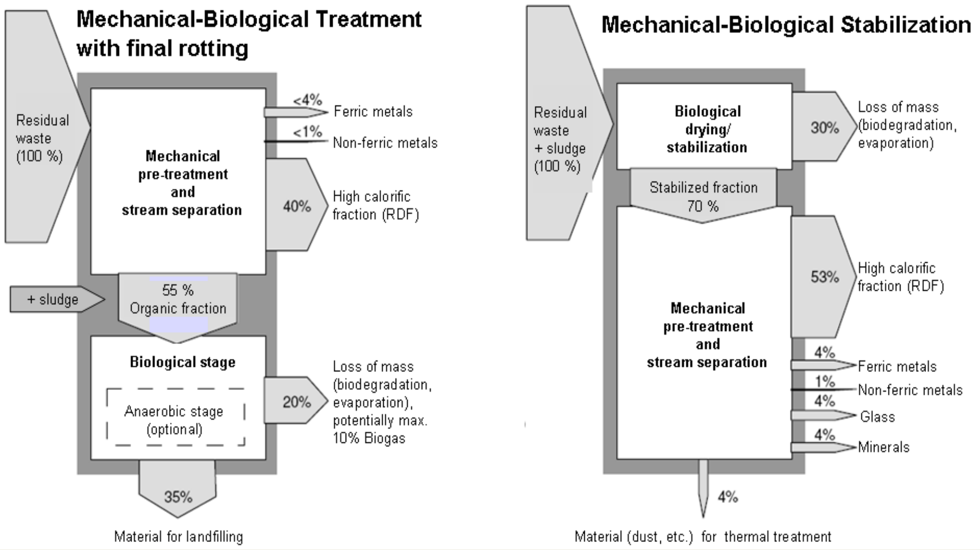
WWTP Torun

IV f *continued* COMPOSTING	Basically two different composting arrangements can be distinguished: open air (windrow or heap) composting and encapsulated composting systems. *Windrows* are typically used for larger quantities which can require a lot of space. In addition, windrows can have odour problems and leachate concerns. While various methods can be used to control the odour, a favorite method is the addition of quick lime (CaO) to change the pH of the sludge. Experience shows that organic material loses its odour when the pH is raised from the typical 5.5 to 6.5 to a pH of 10.0 to 10.5. In addition to changing the pH, the hydration of the quick lime (absorbing moisture from the sludge) causes the quick lime to release heat to the material. Composting in *encapsulated systems* means composting in a closed environment with minimised thermal exchange with the atmosphere and various methods of aeration and mechanical turning to control the process. These systems are designed to minimize odours and process time by controlling airflow, temperature and oxygen concentration. Encapsulated systems make possible to collect gaseous emissions, odours and particulates. Most common techniques used here are tunnel reactors, rotting boxes and drum or vessel composting. Mechanical processing is the most energy intensive stage of composting. Encapsulated systems with intensive rotting have an energy demand in the range of 15–65 kWh/t, whereby mechanical pre-treatment usually takes about 10 kWh/t. The space demand for installations with intensive rotting is in the range of 0.2–0.3 m²/t*a. Open systems do have a considerably higher space demand. The demand on labour force depends largely on the capacity of the installation. The mature compost should meet the following parameters to ensure that it is stable and safe: - a C/N ratio of less than 22 to be safe for agricultural use, - not re-heat over 20 °C upon standing, - low heavy metal concentrations as prescribed by international standards. The liquor collected from composting has to be adequately treated.		
IV f Potentials for optimization	**CO-COMPOSTING** of sludge is a process which is often connected with other treatment activities, as can be co-digestion or sludge earthification, where it is employed as a secondary treatment stage.	Easy integration of sludge treatment into existing facilities.	

IV f *continued*

Potentials for optimization - Integration into MECHANICAL BIOLOGICAL TREATMENT

MECHANICAL BIOLOGICAL TREATMENT (MBT) has a similar base scheme like composting in that it comprises a combination of mechanical and biological processes. The possible process configurations are numerous although consisting always of mechanical processes and a core biological treatment. The biological treatment stage serves the reduction and stabilisation of organic matter by anaerobic-aerobic or aerobic processes. The main distinction between the different concepts is made on the basis of the order of the technical processes and the aim of the biological treatment. The differences lie either in “splitting” of the waste prior to the biological treatment or in its “stabilisation” and subsequent processing.



Graphic: adapted by INTECUS using elements from various sources

The inclusion of sewage sludge in MBT processes makes sense only where combinations of mechanical treatment with digestion processes are used (for energy generation; *see ↗ co-digestion*) or where the output is a stabilised material which may be used as waste-derived fuel. MBT can be viewed as an optimized technique for sludge disposal where the respective facilities have been set up for the treatment of household and commercial waste streams and sludge can be added in the process. MBT exclusively for sludge is an uneconomical solution.

Easy integration of sludge treatment into existing facilities.

Only selected installations (preferably such operating with digestion processes) can be used.
The technology is unsuitable for the exclusive treatment of sludge as sludge is likely to increase the load of the waste stream with harmful substances while its potentials get used to a limited extent only.

Germany:

MBA plant in Raabrede/City of Lübeck, Schleswig-Holstein

Austria:

MBT plants in Frohnleiten and Halbenrein, Steiermark

FINAL OUTLETS

(Main utilizations of the sludge within the process of conversion or after pre-processing)

Pre-processing and conversion of the sludge aim at one principal purpose: to minimize the volume and risks of the sludge to be disposed of and to make beneficial use of it whenever possible and economically feasible. Part of the conversion process or ultimate step in the processing chain is the final utilization of the sludge as an added fuel in thermal processes or in digesters for biogas production. Principally, the electrical energy can be used to operate the WWTP or it can be fed into the grid. Waste heat contained in the exhaust gases of the turbine or gas engine, from heating the pyrolysis kiln or the support combustion can be used for the thermal drying of sewage sludge. Excess steam or waste heat from cooling water (from the gas engines) is generally suitable for heating where appropriate users are available at a closer distance (e.g. greenhouses).

From the ash which remains after monovalent sludge incineration, phosphorous can be directly recovered as a precious resource. Ashes from sludge incineration and the mineral granule respectively vitrified residue left after pyrolysis/gasification may also get used as aggregates or additives in the construction sector.

In the case of compost or completely stabilised sludge as result of stabilisation and earthification procedures, the final outlets are found in agriculture, wood plantations, landscaping and land reclamation/re-cultivation activities. In case the respective analyses reveal that the limit values for contaminants are met this resource can serve as a soil conditioner, fertilizer or growth medium. Where landfills are closed down and remediation is undertaken, sludge compost can also be a useful substrate for the covering layers. Also applications on barren land left behind from mining activities or forest fires can be useful and have been successfully practiced in a number of cases, already.

The final section of this guide is dedicated to explain the most frequently applied ways to utilize pre-treated sludge or the products won during sludge conversion processes. Certain processes shall be particularly highlighted as will be major requirements and pre-cautions for a safe application and sludge use.

	DESCRIPTION OF THE BASIC PROCEDURE	ASPECTS TO CONSIDER	REFERENCE LOCATION
V a RECOVERY OF PHOSPHORUS	Processes for the recovery of phosphorus can be integrated at different stages of municipal waste water and sludge treatment. A portion of the dissolved phosphorus in the waste water and the colloidal, fine particulate fraction are incorporated into the activated sludge or precipitated and removed with the excess sludge from the cleaning system. The phosphate released during the decomposition of organic substances in the digester for the most part is also bound by flocculating agents. The concentration of phosphorous in the medium to which the technical measures for its recovery will be applied is critically important to achieve a high recovery rate. Now here shall be explained processes which are applied on the drained digested sludge and on the ashes from sludge incineration. In Europe only a few process operators today can assert the economic viability of the applied phosphorus recovery processes, there are many more processes however that are just at the pilot stage and have not yet achieved market maturity.	Phosphorus as a scare resource is recovered for direct use as a fertilizer, thus substituting certain amounts of fertilizers from primary raw materials. Elimination of phosphorus has positive impacts on the further processing of the sludge, e.g. the efficiency of dewatering. Processes are generally cost intensive.	
	Recovery from drained digested sludge The precipitation of phosphorus with magnesium compounds and recovery in the form of MAP (Struvit) is implemented internationally in a number of ways. Two processes which have meanwhile been transferred from the pilot stage into stable operations shall be mentioned hereunder.	Processes can be well integrated in conventional WWTP operations.	
	AIRPREX®-PROCESS This process is applied after the anaerobic stabilisation prior to dewatering. Sludge from the digester is fed directly into a multi-stage reactor system and subjected to air stripping. While carbon dioxide escapes the pH is raised and magnesium chloride is added. MAP which precipitates during this process is a product with proven potential as a fertilizer. For a successful process, the pH, phosphorus content and the quantity and type of the precipitating agent must be precisely synchronized.		Germany: WWTP Berlin-Waßmannsdorf, Brandenburg

V a continued **RECOVERY OF PHOSPHORUS**	**<u>Seaborne-process</u>** Right after the digestion, a separation of heavy metals and nutrient recovery is performed in two cycles. The extraction from the solid matter is achieved with the help of acidification and addition of reactive oxygen. Kept in a liquid phase, biogas is passed through the reactor. Hydrogen sulphide in the biogas reacts with the heavy metal ions in the liquid to heavy metal sulphides. These fall out from the liquid and are removed. The next step is a nitrogen recycling system. In the first stage ammonium, phosphate and a divalent metal such as magnesium are brought in a specific molar proportion. MAP precipitates as a consequence of raising the pH. The precipitate is separated from the liquid by a centrifuge. The products obtained are MAP and diammonium sulphate (DAS). The installation costs for the referenced Seaborne plant with a maximum daily MAP output of about 1.3 tons or 1.8 tons/day of liquid nitrogen fertilizer amounted to 4 million EUR, the implementation of the whole project (incl. demonstration and optimization) came to 7.6 million EUR. For the referenced plant in Baden-Wuerttemberg with 50 kg MAP output per day (reactor volume of 12 m³) the quoted total investment was 0.8 million EUR. Generally, process costs for the precipitation of MAP are quoted in the range of 3–4 EUR per kg of phosphorus. Possible proceeds are 0.5–1 EUR per kg.		<u>Germany:</u> WWTP Griesheim b. Offenburg, Baden-Wuerttemberg; WWTP Gifhorn, Lower Saxony
	<u>Recovery from the ashes of sewage sludge</u> This type of recovery process can be done with ashes from the monovalent incineration of sewage sludge only. In selected applications a recovery rate of up to 90 % can be achieved. The content of phosphorus in the ash from sludge is in the range of 5–10 % (in average 64 g P per kg ash). The phosphorus in the ash is however chemically bonded in the form of iron-, aluminium and mainly calcium phosphates. Basically, two methods for its recovery have emerged: the wet-chemical and thermal approach. In the *wet-chemical approach*, phosphorus is dissolved from the ashes with an acid suspension, for example with sulphuric acid. Parts of the heavy metals are brought into solution with this. They can subsequently be precipitated, for example as sulphides and separated from the dissolved phosphate. Depending on the pH the phosphates then fall out during the neutralization as aluminium phosphate, iron phosphate and calcium phosphates. Calcium phosphates will be mainly won if the pH is raised with lime. The wet-chemical extraction of phosphorus due to its comparatively high costs has been so far a limited application on an industrial scale. Indicative calculations for 15,000 t of ash treatment per annum (WWTP >500,000 p.e.) put the investment at	Phosphorus can be recycled at the highest concentrations.	

	11 million EUR and annual costs at 5.80 EUR per kg of $P_{eliminated}$..		
V a *continued* RECOVERY OF PHOSPHORUS	**THERMAL EXTRACTION** A proven technique that is meanwhile industrially applied is the ASH DEC (OUTODEC)-process. The advantage lies in the separation of a small stream in the form of a heavy metal concentrate from the main mass flow, while the phosphorus-rich stream is converted into a useful product. The ash is homogenized with alkaline chloride in an intensive mixer and then pelletized. Composition and dosage of the additives are essential parameters, which help the calcium and aluminium phosphates to be turned into soluble phosphate compounds and toxic substances to be removed via the gas phase. The pellets are placed in a thermal reactor and exposed to temperatures around 1,000 °C for 30 minutes. 99 % of the heavy metals, especially mercury, cadmium and lead, react at this temperature with the additives and evaporate. The concentration of other heavy metals which are permitted as trace elements for agricultural use are also lowered this way. 97 % of the ash input is converted into a directly usable P-rich granulate. 3 % of the ashes are kept back as a metal concentrate from a multiple stage flue gas cleaning system.	Additional high energy demand.	Germany: WWTP Altenstadt, Bavaria Austria: Pilot installation Leoben, Steiermark
	The **MEPHREC®-PROCESS** enables the recovery of phosphorus in a metallurgical process which is not only suitable for sewage sludge but also for other input material containing phosphorus (e.g. bone meal). It can be adopted in various types of installations, e.g. in a combination with monovalent sludge incineration and even in cement kilns. The technology is based on the high-temperature oxygen driven melt-gassing process of dried sludge (briquettes) or sludge ash. The resulting phosphate slag is granulated in a water bath and gives a ready-to-use fertilizer.	Energy content of the sludge gets likewise used.	Germany: Pilots in Nurnberg, Bavaria; and Lünen, North Rhine-Westphalia; Test installation in Freiberg, Saxony

V b ADDED FUEL	The importance of using sludge as added fuel derives from the substitution effect that can be obtained. From the point that sludge allows for auto-thermal incineration (which usually corresponds to a dried sludge of >35 % DS content), it would meet the characteristics of a true fuel product as which it is used in incineration processes for energy and heat generation (*see ↗ Use for energy generation*) or as added fuel, for example in cement kilns (*see ↗ Co-combustion*). Still, the industry accepts sludge as added fuel against the payment of a disposal fee only. The price is mainly determined by the calorific value and content of harmful matter, the disturbing components in the sludge and its matching properties with the combustion process. Comparatively low payments are due for dried sludge used in appropriate cement kilns and coal-fired power stations. Disposal prices here may go below 50 EUR/t DS and reach a zero payment in some occasions whereas a profitable sale like with conventional fuels is highly unlikely.	Provides a CO_2-neutral fuel and allowing substitution effects (by replacing conventional fuel and raw materials). Depending on the quality and type of the process employed it might be difficult to recover valuable components, e.g. nutrients.	Germany: Numerous cement plants, e.g. Dyckerhoff Lengerich, North Rhine-Westphalia

V c **USE FOR ENERGY GENERATION**	The following is a selection of common processes for the generation and use of energy from sludge. **STEAM TURBINE** An example of an optimized approach is the **ORGANIC RANKINE CYCLE** (ORC)-process. It works on the same principle as the water-steam process with the difference that instead of water an organic working fluid (hydrocarbons such as iso-pentane, iso-octane, toluene or silicone oil) is used. These working fluids have favourable properties at lower evaporation temperatures and pressures. The heat produced during sludge incineration is transferred via a thermal oil boiler to the ORC process. Thermal oil is used as a heat transfer medium, as with this the required ORC-process temperatures of 300 °C can be achieved and a virtually non-pressurized boiler operation is possible. With the heat transferred from the hot oil to the ORC-process the used organic working fluid is vaporized. The steam is passed to a low-speed axial turbine in which under expansion into vacuum mechanical work is produced and transformed into electrical energy by a generator coupled directly to this turbine. Also the heat generated from the fluidized bed in fluidized bed incinerators is sent to a steam turbine. Fluidized bed incinerators working with pressurized systems operate at elevated pressures and produce a high-pressure gas stream at temperatures that can drive a gas turbine. Together with the steam turbine a highly efficient combined cycle system can be created.	Ensures a safe destruction of the organic contaminants and pathogens in the sludge. Energy potential of the sludge is exploited for power generation or to fed heat-requiring processes for sludge pre-treatment. Enables self-supply of WWTPs with energy and heat. Thermal utilization is usually an expensive option for WWTPs (either due to the investment required or the higher disposal fees that must be paid to operators of incineration facilities).	Germany: Power plants Boxberg and Lippendorf, Saxony Austria: Power plant Mellach, Steiermark
	GAS ENGINE Pyrogas obtained from sludge gasification processes can be used to power a gas engine which is coupled with an electric power generator. The high calorific gas obtained during pyrolysis must be cleaned from its pollutants prior to energy production with a combustion engine. For this the pyrogas flows via a scrubber into the power unit for combined heat and power generation.	Depending on the quality and type of process employed there might be no chance for a recovery of valuable components other than the energy content the consequence of which is, e.g. the loss of nutrients.	

V c continued	**<u>PEBBLE-HEATER</u>** This technology is especially suitable for small-scale incineration in combination with a micro gas turbine for producing electrical energy from the hot flue gases, without requiring the installation of a water-steam cycle. Upon passing through the pebble-heater, compressed air is heated to about 900 °C and then applied to the turbine. Without adding more fuel the air relaxes in the turbine and cools down to about 600 °C. The turbine drives both the compressor and the generator to produce electricity (up to 98 % heat recovery, an electrical efficiency of 30 % can be possible with small installations whose capacity does not exceed 1 MW).		
V e **USE IN RE-CULTIVATION**	The chemical and physical characteristics, like a high content of organic matter and plant available nutrients as well as a high water storage capacity, make sewage sludge compost a suitable material to give depleted raw soils the "normal" soil function and to establish so-called re-cultivation layers to cover closed landfills and mining dumps. Using material derived after sludge earthification or sludge compost in a mixture with sandy soil gives an effective covering substrate for the re-cultivation of lignite and potassium mining waste dumps. A higher amount of precipitation can be stored, plant rooting can take place in this layer and after about one year, a significant reduction of the NO_3-N and NH_4-N concentrations in the seepage water becomes visible. Other places of application are brownfields, accident and leakage sites after their decontamination, mining fields and abandoned depositing areas. Mixtures of soil and sludge material are usually derived with anaerobically digested, lime-stabilised sludge or composted sludge. The presence of sludge components at values of 50 % and above in the soil-sludge mix increases the water holding capacity and activates soil biology significantly. Mixtures from stabilized sludge and soil also have value for landfill rehabilitation purposes.	Can work as a soil conditioner and growth media on depleted soils. Risks from contaminants and pathogens are not finally evaluated and cannot totally be eliminated, thorough analyses and permits are required.	<u>Germany:</u> Former uranium mining area Aue, Saxony; Exploited lignite strip mines in Lusatia area, Brandenburg

V f **USE IN AGRICULTURE**	The *agricultural utilization* of sludge must be limited to the sludges with no or an acceptable low content of contaminants (↗ *pls. check for any national regulations in this field*) and in parallel a high content of available phosphate. Where the soil quality has been tested as being appropriate but still in a rather degraded stage, the use of pure sludge has to be forbidden because it is connected with environmental disadvantages in any cases. Here the use of compost products which have been derived under the inclusion of sludge and licensed for their quality shall be considered only. An example for permissible practices and procedures for the application of sludge on agricultural land provides the EU Directive 86/278/EEC and corresponding national legislation in the EU member states. Monitoring of the sludge use and place of application should be a legal requirement for its agricultural use and should be strictly implemented.	Soil and plants benefit from nutrients and other positive properties, substitutes fertilizers. € Offers a reasonable sludge utilization pathway for WWTPs. Risks from contaminants and pathogens are not finally evaluated and cannot totally be eliminated, thorough analyses and permits are required.	
V d **DISPOSAL ON LANDFILLS**	The *disposal of sludge on landfills* should remain as the last and ultimate solution for sludge amounts and residues from sludge treatment processes for which no other uses or disposal options can be found. Sludge can be mono-landfilled or co-disposed with solid household waste at sanitary landfills of appropriate standard. There are two basic types of co-disposal methods: sludge/solid waste mixture and sludge/clay mixtures. Mixtures of the latter kind can in particular be used at operating landfills for daily coverage.	€ A comparatively low cost method at existing landfills of appropriate standard. Loss of all benefits from sludge utilization, loss of the nutrients in the sludge and creation of an environmental burden; an expiring disposal method.	

MAIN INFORMATION SOURCES

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DOCUMENTS OF FURTHER INTEREST

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II Dewatering

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V Final Outlets

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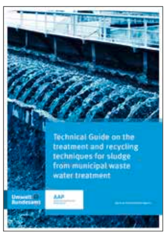

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