SLUDGE FROM MUNICIPAL WASTE WATER TREATMENT

RELEVANCE OF WASTE STREAM:

- Solid remains from municipal waste water treatment contain organic carbon and nutrients from which plants and the soil can benefit as well as other substances worth to recover. Other inorganic and organic components are potential contaminants to soil and ground water or have pathogenic effect on human health which is why particular precaution or treatment must be adopted when the material is further utilized. Forms of combined treatment with municipal solid waste can be used to realize protection goals and benefits in an efficient and optimized manner.
- This waste stream is governed by specific requirements during its disposal within the EU.

COMPOSITION/ MAIN MATERIAL COMPONENTS

Sludge generated in the course of the treatment of municipal waste water is differentiated as follows:

- *Primary sludge* – is the sludge 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 waste water treatment plants (WWTPs). Primary sludge contains approximately 2.5–3.0 % solids, the rest is water.
- *Return sludge* – is sludge that results from biological treatment. It comes along with the excess sludge but depicts 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 where it is eventually consumed completely.
- *Excess sludge (secondary sludge)* – is the portion of sludge from biological treatment for which there is no need of returning it to 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.

Primary and excess sludge together make up the sludge volume for which subsequent treatment is needed. Also known as tertiary sludge this is the sludge amount municipal sewage treatment plants release once phosphate precipitation (removing phosphorous with the help of iron or aluminium salt, or lime) is completed and/or need to take care of. The sludge still contains a whole series of harmful substances that complicate proper management, such as heavy metals, pathogens and endocrine disrupters. But it also contains a number of nutrients such as phosphorus, nitrogen and potassium.

Sewage sludge can be regarded as a multi-substance mixture. Because of the inhomogeneity and tremendous differences in the concentrations of its components, it is difficult to determine or define a standard composition for sewage sludge (Table 1a+b+c)

Table 1a: Orientation values on the selected properties of municipal sewage sludge

Main properties	Unit of measure	Orientation value range (based on reference values from various sources)
pH-value		7.7
Loss on ignition	%	45–80
Net calorific value	MJ/kg dry solids (DS)	10–12

Table 1b: Orientation values on material properties of municipal sewage sludge

Substances in sewage sludge of particular interest for the nutritional value	Orientation value range in g/kg dry solids (based on reference values from various sources)
Phosphorus (P)	2–55
Magnesium (Mg)	9–9.5
Calcium (Ca)	70
Potassium (K)	2–3
Cobalt (Co)	6–7
Molybdenum (Mo)	3.5–4

Most of the organic substances in sewage sludge comprise a bacterial mass that is mainly composed of carbon, hydrogen, oxygen, nitrogen and sulphur. There are also organic pollutants, the most harmful being polychlorinated dibenzodioxins/furans (PCDD/F), halogen compounds and organic tin compounds.

Tensides and polycyclic aromatic hydrocarbons (PAHs) are also found in sewage sludge. All of these various organic substances often stem from numerous household products while wood preservatives or pharmaceutical products can make up sources as well. Heavy metal concentrations in sludge from municipal waste water treatment are for the most part attributable to inputs from the surfaces of roads and other man-made urban elements.

Table 1c: Orientation values on further material properties of municipal sewage sludge

	usually present in sludge in following ranges of concentration per kg dry solids content (based on reference values from various sources)						
Substance in sewage sludge	› 300 mg	›100–300 mg	› 50–100 mg	5–50 mg	1– ‹ 5 mg	0.1– ‹ 1 mg	‹ 0.1 mg
Antimony (Sb)				x			
Arsenic (As)				x			
Lead (Pb)			x				
Cadmium (Cd)					x		
Chrome (Cr)			x				
Copper (Cu)	x						
Manganese (Mn)	x						
Nickel (Ni)				x			
Selenium (Se)					x		
Thallium (Th)						x	
Vanadium (V)				x			
Mercury					x		
Zinc (Zn)		x					
Tin (Sn)			x				
AOX	x						
PCDD/F							x
PAC						x	
DEHP				x			
Polybrominated diphenyl ethers							x
Polychlorinated biphenyls (PCB)							x
Linear alkyl benzene sulfonate (LAS)					x		

Last but not least of importance are pathogens such as bacteria, viruses, parasites and worm eggs that can be found in sewage sludge. These can endanger the health of humans and animals when entering their bodies via direct contact or food chains. The goal of sewage sludge treatment and management is to minimize harmful sludge content and its potential threats for environment and society while retaining sludge nutrients.

EUROPEAN LEGISLATION AND REFERENCE DOCUMENTS

The legal framework for the utilization of sewage sludge from municipal waste water treatment for agricultural purposes or in other ways on soil in the countries of the EU is provided in the form of the Council Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. This piece of legislation currently undergoes a process of review and debate in order to get new findings made on the harmful substances content and their impacts, as well as progress occurring on technology and in analytical fields properly considered in the future. Selected countries already adjusted their national regulations in accordance to these new insights and in some cases imposed a halt on the use of sewage sludge in agriculture and/or ordered a recovery of phosphorus to be applied on one or various process stages, i.e. from waste water, the sludge or on the treatment residues such as the ashes from mono incineration.

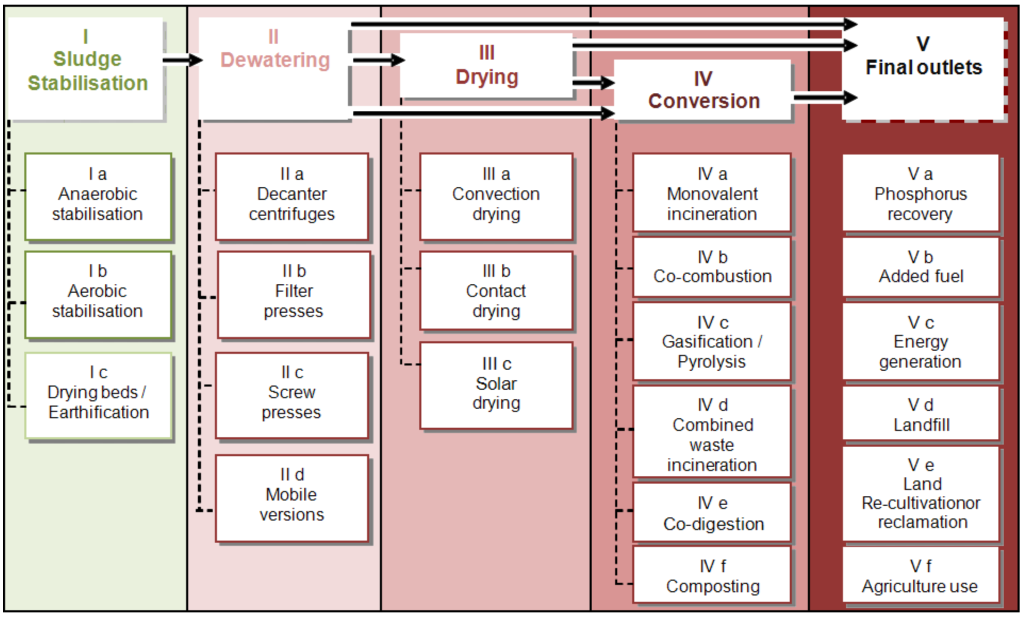
NEEDS AND PRINCIPAL REQUIREMENTS FOR HANDLING THE WASTE STREAM

With the treatment of the sludge it has to be ensured that potentially dangerous substances are reduced to uncritical levels or diverted to routes of safe disposal while best possible utilization of its valuable content shall also become possible. 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 that has been suitably pre-treated with view to subsequent processes will allow the optimum treatment and utilization results to be attained.

Various stages of pre- and post-treatment must be passed before a material utilization, recovery of energy from the organic components or final depositing of the sludge can take place. In any case can and should be minimized through appropriate measures the generation of excess sludge in order to reduce the overall need and costs for sludge treatment.

The individual steps and procedures that eventually facilitate the ultimate use or disposal of sludge can be varied, generally there exist several process options and techniques which, depending on the final objectives and next process step can be used in combination but partly also replace one another. Figure 1 gives kind of an overview on that.

Figure 1: Overview on the principal options for a sludge management process



All treatment steps have to be accompanied from specific pollution control measures, management practices and careful monitoring, including analytical measurements, so as to mitigate the risks associated with harmful constituents of the sludge and residues from its processing. Critical process control parameters and baseline data on sludge properties should be established and recorded to facilitate and support subsequent management operations and for optimizing treatment processes.

Table 2: Overview on main operations parameter's relevance for sludge disposal and use options(ISWA/EEA, 1997)

		Stabilisation											
	Sedimentation	aerobic	anaerobic	chemical	thermal	Thickening	Dewatering	Drying	Transportation	Landfilling	Composting	Agriculture	Incineration
Temperature		x	x				x	x			x		x
Density						x		x	x				
Rheological prop.							x	x	x	x		x	x
Settleability	x					x	x						
Solids concentration	x	x	x	x	x	x	x	x	x	x	x	x	x
Volatile solids		x	x	x	x				x	x	x	x	x
Digestability			x										
pH		x	x	x			x				x	x	
Volatile acids			x										
Fats and oils		x	x									x	
Heavy metals			x							x	x	x	x
Nutrients		x	x								x	x	
Particle size	x					x	x						
CST						x	x						
Spec. resistance						x	x						
Compressibility							x						
Centrifugability							x						
Calorific value													x
Leachability										x			
Microbial. Prop.		x	x								x	x	

APPROPRIATE COLLECTION STRATEGIES AND SCHEMES	Sludge from municipal waste water is generated during processes at specialized waste water treatment facilities and does accumulate there. No specific mechanisms or forms of collection must therefore be established. However, amounts of faecal matter and/or sludge from waste water tanks also accumulate under certain conditions or circumstances at private properties and need to be collected from them. These quantities must be forwarded then to aforementioned specialized waste water treatment facilities for further treatment in their processes. For collection and transport specialized tank vehicles capable to undertake the suction dredging of the liquid slurry are being used.
APPROPRIATE TREATMENT AND RECOVERY SCHEMES	Sludge treatment methods include thickening, biological stabilisation, dewatering, drying and conversion techniques that lead to hygienization and/or inertisation (through incineration) of the sludge. It should be noted that every application has its specific advantages and disadvantages (including for downstream processes and further disposal), 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 when selecting appropriate sludge treatment paths and technologies. **Thickening:** The purpose of sludge thickening is to reduce sludge volume by removing as much water as possible from the sludge. Thickeners similar to sedimentation tanks in terms of their design and processes allow sludge particles to naturally sink to and deposit on the bottom. Other thickening techniques (disc or snail-wheel design) split off water by simple sludge densification. Reducing sludge volume is critical to let storage, transportation and treatment become more efficient. Raw sludge from the thickener can be left untreated only for further processing in a fresh sludge incineration. **I. Stabilisation:** Sludge stabilisation can involve chemical, physical and thermal methods. Stabilised sludge with reduced concentrations of harmful components offers higher security as far as different disposal options and access to them are concerned. Objectives of the sludge stabilisation process are: - lowering reaction potential of the substrate; - reduction of sludge and solid component quantities; - improvement of the dewatering characteristics of the sludge; - creating a possibility to recover biogas, at the cost of lowering the calorific value of the stabilised sludge; - creation of a buffer and storage capacity for sludge treatment Different levels of sludge stabilisation are required to make use of utilization options for sludge. 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 fully stabilised sludge. - 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. - Dewatering or drying and a partial to full stabilisation of the sludge (depending on the applied method) comprise the minimum treatment needed where a landfill disposal is necessary and allowed. Chemical stabilisation, for example with quicklime, leads to a rather fast but short-term result but not the sustainable effect that biological processes provide. For biological sewage sludge stabilisation a distinction is to be made between aerobic and anaerobic processes.

Table 3: Key specifics of anaerobic and aerobic sludge stabilisation methods

	Anaerobic processes	Aerobic processes
Main process features	- 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). - Stabilisation method is usually executed in digesters (e.g. towers) in a mesophilic (30–38°C) or thermophilic (49–57°C) temperature range and usually takes 20-30 days. - Methane gas (biogas) is generated as a by-product and can be used to produce energy. - The coupling of the energy flows obtainable from digestion with heat generated from biogas combustion is an efficient way to realize an economical drying of sludge. It is also essential that digestion improves sewage sludge de-watering capacity. - The specific investment costs for classic egg-shaped digesters come to 600–1000 EUR/m³ digester capacity; additional staffing requirement is 8–10 hours/month.	- 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. - Activation basins which are ventilated in various ways (e.g. centrifugal aeration, rotary brushes, fans or other ventilation devices such as membrane diffusers) are used to stimulate the micro-organic activity. - Alternative applications of aerobic stabilisation processes are composting (see factsheet on "**Composting**") and soilification of sludge (using for example reed planted basins). - The indicative investment for a sludge earthification facility in Germany is 60 EUR/m² of treatment area (all installations included).

Chemical or thermal disintegration as integrated or preceding steps to anaerobic digestion help optimizing the gas yield and stabilisation result. However, anaerobic digestion of sewage sludge before sludge combustion can be counterproductive because of the reduced calorific value of the digested sludge.
Nitrification using cascade design processes is also a recommendable practice to support stabilisation and detoxification especially in conjunction with an aerobic treatment process.
A possibility that must be considered as well is that of a recovery of phosphorus from the sludge (see fact sheet on "Phosphorus recovery").

II. Dewatering (Drainage):

Lowering the sludge's water content significantly is essential for further efficient utilization and in particular for an economical transportation of sludge. Dewatering is the first technical step which reduces the water load far beyond the simple thickening of the sludge. This process increases dry solids content and produces a solid filter cake by sludge filtration through fabric filter cloths in filter presses, or by using decanter centrifuges or screw presses. The increased calorific value of the sludge cake makes subsequent thermal treatment more cost effective.

Mechanical dewatering of sewage sludge results in solids concentrations usually amounting to 20 to 45 %, measured as dry residue. The success of mechanical dewatering mainly hinges on the machinery used, the nature and properties of the sludge, as well as any conditioning it may undergo. Dewatering at ratios typically higher than 10 % will first require some form of chemical conditioning through the use of flocking and flocking agent additives. They assist in the separation of the bound and entrained water from within the sludge. A distinction is made between inorganic flocking agents such as iron or aluminium salt, lime, and coal on one hand, and organic flocking agents (organic polymers) on the other. Iron and aluminium salts are often used as dewatering precipitates for phosphate removal. The dry solid content after drainage can be increased by up to 5 % and more through phosphate reducing measures. The application of salts substantially increases the non-combustible material (i.e. ash) content of dewatered sludge, however. Organic conditioning agents are therefore used where thermal sewage sludge treatment is foreseen.

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

III. 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 respectively the possibility of a better dosing in their further utilization.

The main drawback of drying is the additional energy needed. Tremendous amounts of energy are required as residual sludge water is evaporated using thermal energy. In the process, the drying gradient is determined by the intended sludge use. Hence 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.

35 % dry solids content is generally sufficient to allow for a self-sustained incineration of sewage sludge The counterpart minimum value for digested sludge is 45 to 55 % dry solids, since digestion leaves behind a lesser amount of organic material for incineration. Sewage sludge combusts spontaneously at a heat value of around 4,500 to 5,000 kJ/kg, drying increases the calorific value sewage sludge up to 13,000kJ/kg. Thus, the calorific value of dried sewage sludge is on a par with that of dry wood or lignite.

Drying of sewage sludge is carried out in separate or connected installations. Generally, the following drying methods for sewage sludge and combinations of these 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,

Solar drying entails heating the sludge and then drying it in a greenhouse-like construction using solar energy. This process has come into greater use in recent years. (see fact sheet on "Solar drying"). The throughput of solar sludge dryers is considerably lower than that of most other dryer technologies, and is generally lower than that of thermal methods, however. Drying sewage sludge is practically applied to the following extent:

- 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_20 using contact and convection drying techniques.

Partial drying is especially an option where drying in subsequent energetic utilization process reactors (e.g. fluidized bed incinerator; see fact sheet on "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.

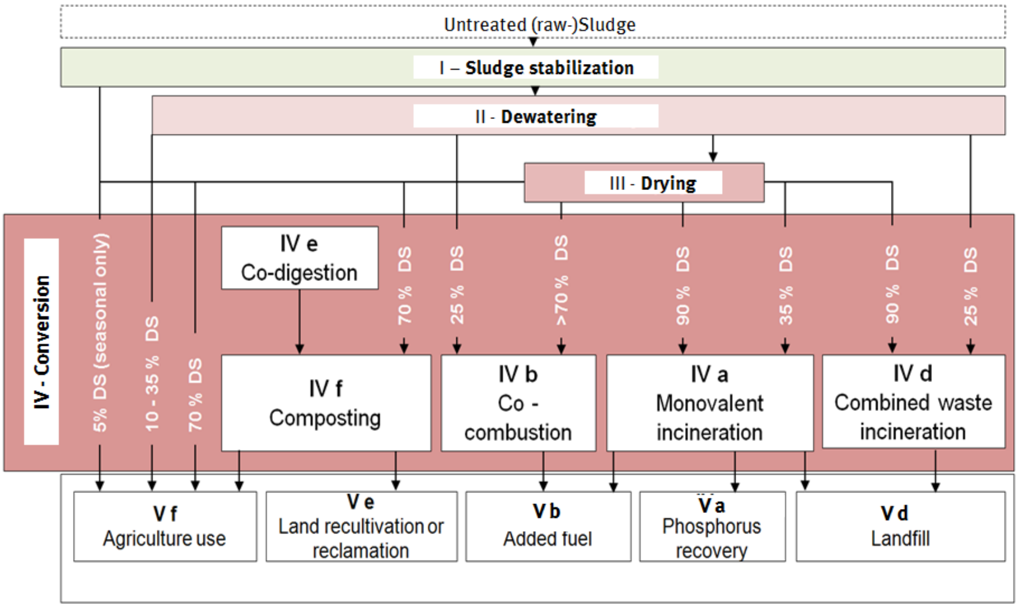
Dried sewage sludge represents free-flowing granulate which can be used as added fuel especially in power plants and cement kilns. Sewage sludge in cement plants needs to be both dewatered and fully dried. Fully dried sludge can also be used in power plants. Often such plants have coal grinding systems that allow for integrated sewage sludge drying, however. In these cases sewage sludge with a solids content ranging from 20 to 35 % dry residue is normally used for incineration purposes. Waste incineration plants are usually capable to handle dewatered, partly dried and fully dried sewage sludge. In places where mixed municipal waste of higher calorific value (9,000 kJ/kg and more) is generated and burnt, a mixture ratio of drained sewage sludge to municipal waste of in maximum 10 % weight of drained sewage sludge is typical.

APPROPRIATE RECYCLING TECHNOLOGIES

There exists quite a wide range of processes in which a material transformation of sewage sludge can be undertaken for the purpose of using its ingredients and neutralizing the potentially hazardous components it contains substantially. Many of these processes correspond to standard treatment techniques applied to different types and streams of waste materials.

Since sewage sludge loses its original properties and then comes to use in another form these practices can be referred to as processes of conversion. 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: Role of conversion processes in sludge management and their basic requirements



To make effective use of the available conversion capacities and further ways for sludge utilization in a country, it is advisable that waste water treatment plant operators maintain separate storage space or secure access to such. A storage capacity equivalent to one year is considered optimal; in the minimum it should be good for a period of 3-6 months at least.

IV a-c. 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 (landfill disposal, agricultural use) are successively 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. Particularly important factors to take into account when incinerating sewage sludge are:

- the composition of the sludge as primary, secondary, bio-sludge, etc.,
- the dry residues content and therewith the calorific value (typically this varies but has major impact on the incineration process),
- the state of stabilisation (for necessary precautions during sludge storage and feeding)
- was the sludge digested or not,
- contents of conditioning agents in the sludge.

Monovalent incineration is dedicated exclusively to sewage sludge combustion with the aim to effectively destroy harmful organic compounds in the sludge and to generate energy. Such installations are usually erected at waste water treatment sites and have the advantage for the plant operator that waste water treatment and sludge disposal can be done independently from other offers and in the way that offers the highest benefit to the waste water treatment plant itself (e.g. generation of energy and heat for own plant processes).

Different process technologies showing different advantages and disadvantages are applied for the furnace system used in monovalent incineration facilities. In recent years, the stationary fluidized bed (see fact sheet on "Fluidized bed incinerator") has become a preferred technology for monovalent incineration. Monovalent sludge incineration opens up the possibility for a recovery of phosphorus (see fact sheet on "Phosphorus recovery") from the ash of the incinerated sludge.

Table 4: Comparison of the main furnace systems used for dedicated sewage sludge combustion

	Fluidized bed	Multiple-hearth	Multiple-hearth fluidized bed	Cycloid
Attributes	No moving parts and minimal wear and tear	No separate pre-drying phase needed; more complex design with moving parts and cooled hollow shafts	No separate pre-drying phase needed; moving hollow shafts; low fluidized bed volumes	No moving parts and minimal wear and tear; needs no fluidized bed materials
Operating performance	Rapid start up and shutdown thanks to short heating-up and cooling cycles; can be operated intermittently	Lengthy heating-up times; needs to be operated continuously	Medium heating – up and cooling times	Similar to fluidized bed; compatible with a broad range of fuels
Combustion	Only minimal excess air needed; complete burn-up only occurs above the fluidized bed	Burn-up difficult to control; impervious to fluctuations in load volumes and to large elements	Requires minimal excess air; burn-out readily manageable; most combustion occurs in the fluidised bed; as compared to fluidized bed furnace, impervious to sludge quality fluctuations	Solids content, long an gaseous elements, short dwell times, variable primary and secondary air intake at various levels
Waste gas ash content	High	Low	High	High
Ash discharge	Via waste gas flow and sand removal	At the bottom-most hearth	Via waste gas flow and sand removal	Cia waste gas flow; large ash particles on the bottom
Residues	Ash; fluidized bed materials	Ash	Ash; fluidized bed material	Ash; in some cases large ash particles

Lately, the ***co-combustion*** of sewage sludge in power plants and industrial furnaces has taken an increasing share of 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 (see fact sheet on "Industrial Co-combustion"). In most incinerating facilities there is no substantial problem with feeding, conveying and combustion of appropriately pre-treated sludge (see above under *Drying*). 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. In addition to sewage sludge, other wastes from the waste water treatment process are often incinerated, e.g. swim scum, screenings, and extracted fats.

For most power stations a share of sludge of up to 5% of the total fuel mass is so far seen. Pulverized coal injection or fluidized bed firing systems are mainly used for co-combustion in power stations. Power stations in general accept only stabilised sewage sludge for incineration since raw sludge is associated with greater difficulties and risks in handling and storage.

Table 5: Features of the co-combustion of sludge in coal-fired power stations

	Fuel properties	Combustion mode	Sewage sludge co-incineration
Coal-fired power plants	Coal water content: 7–11% Calorific value: 27–30 MJ/kg	Pulverized-coal firing, cyclone melting chamber, circulating, fluidized bed firing	The extent to which dewatered sewage sludge can be used is limited owing to low coal grinder drying capacity
Lignite fired power plants	Lignite water content: 46–60% Calorific value: 8.5–12.5 MJ/kg	Pulverized-coal firing, circulating fluidised bed firing	Sewage sludge use is limited owing to sludge heavy-metal content

The main drawback of co-incineration/co-combustion is that it precludes recovery of the phosphorous in sewage sludge (see fact sheet on "Phosphorus recovery").

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. One example from this technology segment is the PYREG®-process. That aforementioned techniques have more advanced in this sector has to do with the sludge's homogenous nature. For other waste streams where this is more seldom the case, the success both processes have on the market is rather limited with rarely any functional application at larger scale seen until to date.

IV e-f. Biological conversion:

The ***production of biogas from sewage sludge*** is well-known from the techniques mentioned in the treatment chapter above for *biological sewage sludge stabilisation*. Mixed with other biodegradable waste, sludge can also be a suitable input material in co-digestion processes. Brought in a mix with other biogenic substances such as kitchen and food waste and introduced into modern bio-digester installations (see fact sheet on "Anaerobic digestion"), 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.

Figure 3: Co-digestion facility for sewage sludge during construction phase (left) and after completion (right) (Photos: INTECUS GmbH)

The ***application of sludge to land*** is only an option for sludge that has been fully stabilised, converted into an environmentally safe product, thoroughly examined and certified for this. Mostly, the countries have regulations and criteria in place which also contain limits as to the places and times of use and maximum allowable application per unit of area.

An additional option is to supply suitable sludge to composting where it is sterilized (see fact sheet on "Composting"). Sludge or residues from sludge digestion are added to other composting input only at proportions, which permit allowable pollutant levels to be kept. Certified 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. In the interest of completely ruling out the transmission of infectious agents, the use of sludge as fertilizer has been banned for organic farming, in forests, in grassland, and for fruit and vegetable cultivation. The material quality, environmental quality and hygienic safety of the finished compost are to be secured by external and internal supervision, and wherever possible participation in a quality assurance scheme. Important elements of a compost quality assurance are regular lab analyses, which often make up a mandatory requirement in many countries anyway, and a reliable certification system.

The ***inclusion of sewage sludge in MBT processes*** (see fact sheet on "Mechanical-biological waste treatment") makes sense only where combinations of mechanical treatment with digestion processes are used or where the output is a stabilised material which is going to be used as waste-derived fuel in thermal processes. MBT exclusively for sludge is an uneconomical solution.

APPROPRIATE DISPOSAL STRATEGIES

Combined incineration of sewage sludge with other residual waste is usually performed as a mere disposal method where harmful content is safely destroyed, organic matter mineralized and sludge volume therefore reduced to a minimum. Ideally energy is recovered from this process. Municipal waste incinerators equipped with standard furnace technology (see fact sheet on "Grate combustion"), flue gas cleaning and emission control devices provide appropriate facilities. Where added to these incinerators, the feeding techniques often make the major difference to other incinerators and represent a significant proportion of additional investment costs. For higher amounts of sewage sludge and limited piling capacity it represents a possible solution to spread well-structured, dewatered sewage sludge continuously on the refuse in the bunker with a spreading machine. Spraying sludge through special nozzles above the waste bed (often in the gas burnout zone) may provide benefits for some waste incinerators (especially such that deal with wastes of higher calorific value) in that the water content of sludge provides an additional means of controlling temperature and the primary NO_x generation. In order to ensure a good process management and control over the emissions in mass burn waste incinerators it is general practice to limit the share sewage sludge takes in the combustion input in the maximum to approx. 10%. 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 (see fact sheet "Flue gas cleaning").

Landfill disposal of sludge is generally not a good option since the sludge introduces additional moisture and organic matter to the landfill body and hence adds to the emission potential and leachate generation. On well-constructed and secured landfills (see fact sheet "Landfill for non-hazardous wastes") operating with modern management standards it is however possible to deposit dewatered sludge as temporary solution until other management options are fully developed. The same is the case for ashes from sludge incineration.

Table 6: Indicative range of sludge management costs (based on reference values given in various sources for Germany [1]

Sewage sludge management method	Disposal costs [EUR/Mg wet sludge] (German price level of 2011/12)		Sludge type (DS = dry substance)
	Min.	Max.	
Co-incineration at coal fired power plants	80	130	Dry: greater than 85%
Cement plant co-incineration	90	100	Dry: greater than 85%
Mono-incineration	80	120	Mechanically dewatered: 20–45 % DS
Waste incineration plant co-incineration	80	100	Mechanically dewatered: 20–45 % DS
Co-incineration at coal fired power plants	75	100	Mechanically dewatered: 20–45 % DS
Co-incineration at lignite fired power plants	50	75	Mechanically dewatered: 20–45 % DS
Recultivation	30	45	Mechanically dewatered: 20–45 % DS
Farming, trans-regional	33	45	Mechanically dewatered: 20–45 % DS
Farming, regional	25	30	Mechanically dewatered: 20–45 % DS
Farming, liquid	8	12	Mechanically dewatered: 20–45 % DS

REFERENCES AND PROVIDER FIRMS

(Important note: the list of firms does not constitute a complete compilation of companies active in the specified fields)

Providers of specific technologies for sludge treatment are listed in the fact sheets referenced at the corresponding sections. To obtain detailed insights about suitable arrangements of different techniques and equipment, their operational parameter and performance in practice it is particularly worth to visit reference plants and speak with practitioners. To the recommendable ones in Germany belong:

- for stabilisation techniques: WWTPs in Blümeltal/City of Pirmasens; Rhineland-Palatinate
- for drying techniques including heat exchanger: WWTP Weissach, Baden-Wuerttemberg
- for drying using solar energy: WWTP Penzing Weil, Bavaria
- for monovalent incineration with multiple hearth furnace : WWTP Sindlingen, Hesse
- for monovalent incineration with circulating fluidized bed: WWTP Steinhäule, Bavaria
- for co-combustion of sewage sludge in cement kilns: Cemex plant Rüdersdorf, Brandenburg
- for sludge gasification: WWTPs Balingen and Mannheim, Baden-Wuerttemberg
- for sludge co-digestion: WWTP Radeberg and WWTP Dresden-Kaditz, Saxony
- for phosphor elimination and recovery: WWTP Berlin-Waßmannsdorf, Brandenburg

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