Sewage sludge management

in Germany

Umwelt Bundesamt

Authors:
Dipl.-Ing. Benjamin Wiechmann
Dipl.-Ing. Claudia Dienemann
Dr. Christian Kabbe
M. Sc. Simone Brandt
Dr. Ines Vogel
Dr. Andrea Roskosch

Order brochures address:
Umweltbundesamt c/o GVP
Postfach 30 03 61 | 53183 Bonn | Germany

The brochure is free.

Telephone service: +49 (0)340 2103-6688
Fax service: +49 (0)340 2104-6688

www.umweltbundesamt.de

Sewage sludge management

in Germany

Publisher: Umweltbundesamt (UBA) | Postfach 1406 | 06844 Dessau-Roßlau | Germany

Contents

Preface

Germany's municipal sewage treatment plants generate some two million tons of dry sewage sludge annually, with the proportion of thermally treated sewage sludge increasing from 31.5 per cent in 2004 to more than 54 % in 2011.

Sludge, which is usually incinerated or used as agricultural fertilizer, contains a whole series of harmful substances that complicate the task of sludge management. But sludge also contains a number of nutrients such as phosphorus, nitrogen and potassium. Hence the goal of sewage sludge management is to remove sludge pollutants while retaining sludge nutrients. Sewage sludge undergoes thermal recycling at facilities such as sewage sludge mono-incineration plants, cement plants and coal fired power plants.

Sewage sludge utilization for farming purposes has plateaued of late (2006 to 2011) at around 29 %, an evolution attributable to more stringent quality standards for sewage sludge. However, sewage sludge is set to take on greater importance as a raw material, mainly due to the increased concentrations of phosphorous it contains.

This pamphlet discusses the potential offered by sewage sludge and the ways it can be used sustainably. The pamphlet also describes the current status of sewage sludge management in Germany, with particular emphasis on the extent to which sludge use as a fertilizer can be reduced without foregoing phosphorous and other sludge nutrients. Over the next one to two decades, Germany needs to wean itself away from using sewage sludge for farming and at the same time efficiently leveraging the potential for using sewage sludge as a low cost fertilizer.

Introduction

01

What is sewage sludge?

In Germany, daily water use now reaches 120 litres per person. All of this water ultimately ends up in the sewage system, and from there is channelled to sewage treatment plants. At such plants, the sewage passes through screens and sieves and undergoes mechanical and biological purification, the goal being to remove impurities from the sewage and to then channel the resulting purified water into waterbodies. The residue of this process is known as sewage sludge, which can occur in anhydrous, dried or other processed forms.

Raw sludge is sewage sludge that is removed from sewage treatment plants without being treated. Sewage sludge is generated by both municipal and industrial sewage treatment plants. When it comes to material recycling within the meaning of the Sewage Sludge Ordinance (Klärschlammverordnung, AbfKlärV), only sewage sludge from municipal sewage treatment plants is usually suitable. Under the said ordinance, sewage sludge compost and mixtures also qualify as sewage sludge. Sewage sludge mixtures are mixtures of sewage sludge and other conformant substances, in accordance with Appendix 2 tables 11 and 12 of the Fertilizer Ordinance (Düngemittelverordnung, DüMV). Sewage sludge compost comprises composted sewage sludge mixtures [ABFKLÄRV].

Sewage sludge can be characterized based on various physical, chemical and microbiological parameters, using the characteristic values listed in table 1. It should also be noted that apart from these parameters, there are others such as the sludge volume index and digestion time that are also used to characterize sewage sludge.

For example, elevated loss on ignition indicates a high organic substance concentration in sewage sludge. One of the purposes of sewage sludge incineration is to expunge the organic substances from the sludge. Hence loss on ignition is one of the key parameters when it comes to characterizing sewage sludge combustibility, whereby water content is also an important factor, since unduly high water content reduces the calorific value of fuel. And finally, sewage sludge should never be characterized on the basis of only a single parameter, because the parameters are always interrelated.

Table 1: Sludge parameters and their significance [Kopp; Räbiger]

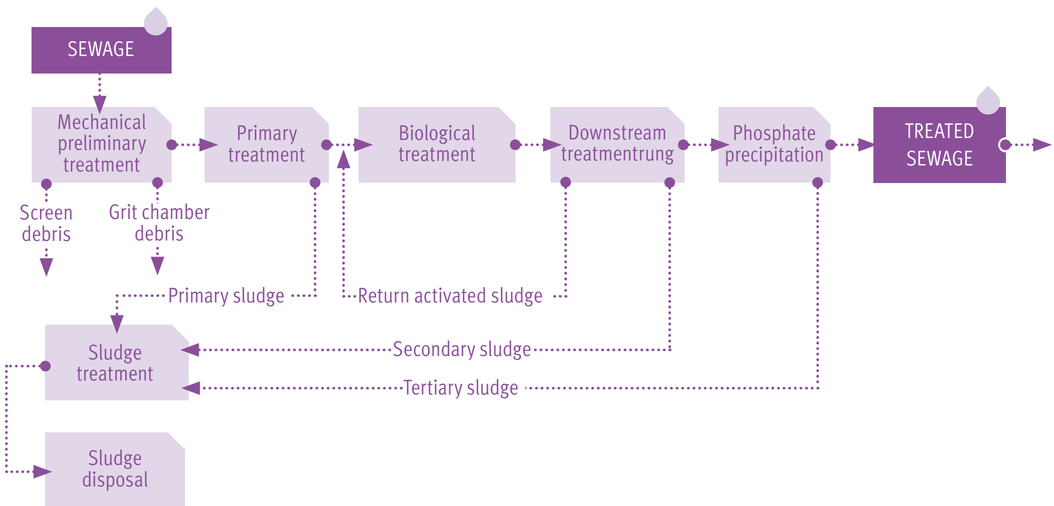
Parameter	Unit of measure	Explanation
Dry solids (DS)	e.g. kg, g, mg	The drying process results in a dry-mass/-solids residue in dry sludge. Determined by subtracting water content.
Total solids (TS)	e.g. kg/m^3, g/l	The dry mass content in a given volume.
Dry residue (DR)	%	Unit of measure for the solid content of a non-filtrated sludge sample; dry mass portion of given volume of sludge. Determined by vapourizing water content.
Water content (WC)	%	Unit of measure for the water content of a given volume of sludge. Determined via vapourizing water content.
Residue on ignition (ROI)	%	Unit of measure for the inorganic or mineral content of dry solids in sewage sludge. Determined by burning up the dry solids.
Loss on ignition (LOI)	%	Organic substance content of a given volume of sewage sludge dry solids. Determined by burning up the dry solids.
pH	-	Negative decimal logarithm for hydrogen ion activity.
Sludge type	-	Operational data. Classifying sewage sludge according to where it occurs.
Sludge age	-	Operational data. Determined by the ratio between the bacteria mass in the basin and the daily bacteria mass removed from excess sludge.

Where does sewage sludge occur?

Sewage sludge is a generic term that provides no indication as to the origin and/or type of sludge involved; and thus even dried or dewatered sludge qualifies as sewage sludge under Germany's Sewage Sludge Ordinance (AbfKlärV). Each of the various types of raw sludge has a specific designation, depending on the juncture in the purification process at which the sludge is generated.

Figure 1 shows the juncture in a sewage treatment plant's purification process at which the various types of sludge are generated.

Figure 1: Sludge occurrence relative to treatment phase [original graphic]



Raw sludge comprises primary, secondary and tertiary sludge in any given mixture that occurs at a sewage treatment plant. Raw sludge is untreated sludge prior to stabilization.

Primary sludge occurs in the mechanical preliminary treatment (primary treatment) phase and thus results from the physical process used to filter particulate substances out of wastewater. The colouration of primary sludge ranges from greyish black to greyish brown to yellow. Sludge mainly contains easily recognizable debris such as toilet paper. After being removed from the system without being treated, it putrefies rapidly and emits an unpleasant odour. Secondary or surplus activated sludge, which occurs during biological treatment, is generated by microbial growth, is usually brownish in colour, and is far more homogenous than primary sludge. After being removed from the system, secondary sludge is digested more rapidly than is the case with primary sludge.

The sludge that occurs in municipal sewage treatment plants resulting from phosphate precipitation (removing phosphorous from a solution using iron salt, aluminium salt, or lime) is known as tertiary sludge. The precipitation process is usually carried out in conjunction with primary or biological sewage treatment, rather than in a structurally separate treatment system. Hence tertiary sludge often occurs not separately, but rather mixed in with primary or secondary sludge. The colouration of tertiary sludge is determined by the substance reactions that come into play, whereby the chemical properties of tertiary sludge differ considerably from those of primary and secondary sludge. Tertiary sludge is normally stable and does not emit an unpleasant odour. The other sludge designations are digested sludge (sludge that undergoes an anaerobic sludge stabilization process) and stabilized sludge (sludge that undergoes a chemical or biological sludge stabilization process) [BISCHOFSBERGER ET AL.].

A list and brief description of all sewage treatment legislation can be found in Appendix II.

Composition of sewage sludge

02

Sewage sludge can be regarded as a multisubstance 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, which is mainly composed of organic substances. Sewage sludge (i. e. stabilized primary, secondary or tertiary sludge that occurs in a mixture at the end of the treatment process) contains plant nutrients such as nitrogen and phosphorous, as well as harmful substances such as pathogens, endocrine disrupters and heavy metals.

Table 2 below list the attributes that are used to characterize municipal sewage sludge. The data in this table is derived from a German Association for Water, Wastewater and Waste (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V., DWA) publication [DWA]. At the time of publication of this pamphlet, the only other available relevant data was a study by Environmental Agency Austria. This data was incorporated into the table in the interest of completeness.

Table 2: Sewage sludge composition [dwa; oliva et al.]

Substance	Unit of measure	Value range according to DWA
pH value	–	7.7*
Dry solids (DS)	wt %	30.5*
Loss on ignition (LOI)	%	45–80**
Water	wt %	65–75
Volatile matter	wt %	30
Net calorific value (NCV)	MJ/kg DM	10–12
Carbon (C)	%	33–50
Oxygen (O_2)	%	10–20
Hydrogen (H_2)	%	3–4
Nitrogen (N_2)	%	2–6
Sulphur (S)	%	0.5–1.5
Fluorine (F_2)	wt %	‹0.01
Chlorine (Cl_2)	%	0.05–0.5
Phosphorous (P)	g/kg	2–55
Antimony (Sb)	mg/kg DS	5–30
Arsenic (As)	mg/kg DS	4–30
Lead (Pb)	mg/kg DS	70–100
Cadmium (Cd)	mg/kg DS	1.5–4.5
Chrome (Cr)	mg/kg DS	50–80
Copper (Cu)	mg/kg DS	300–350
Manganese (Mn)	mg/kg DS	600–1,500
Nickel (Ni)	mg/kg DS	30–35
Selenium (Se)	mg/kg TS	1–5
Thallium (Th)	mg/kg TS	0.2–0.5
Vanadium (V)	mg/kg TS	10–100
Mercury (Hg)	mg/kg TS	0.3–2.5
Zinc (Zn)	mg/kg TS	100–300
Tin (Sn)	mg/kg TS	30–80
AOX	mg/kg TS	350
PCDD/F	mg/kg TS	0.000035
Molybdenum (Mo)	g/kg TS	3.9*
Cobalt (Co)	g/kg TS	6.53*
Calcium (Ca)	g/kg TS	71*
Potassium (K)	g/kg TS	2.63*
Magnesium (Mg)	g/kg TS	9.17*

* Werte stammen aus [Oliva et. al.]; Median
** Werte stammen aus [Oliva et. al.]

Heavy metals in sewage sludge

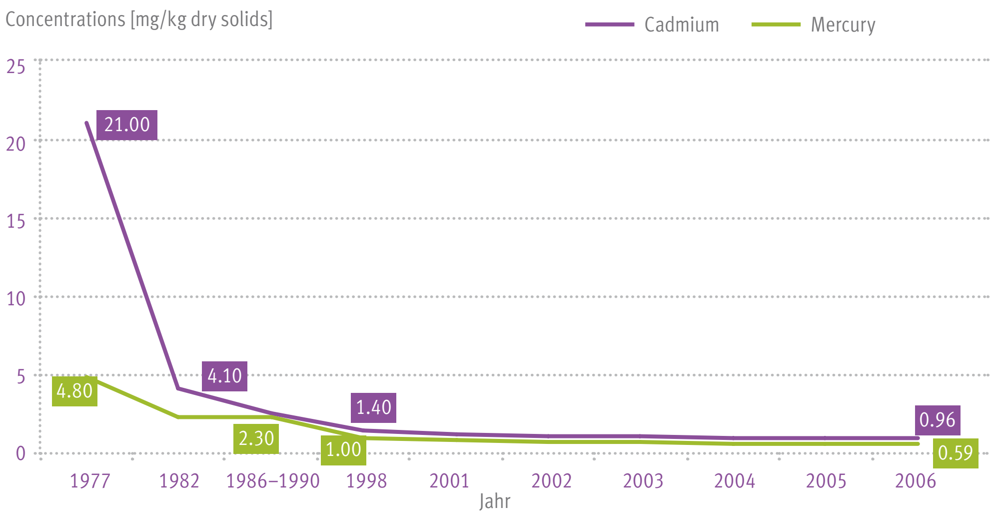
Most of the heavy metals found in municipal wastewater treatment plant sludge are attributable to inputs from the surfaces of man-made urban elements. Thus for example, substances such as lead, cadmium and copper end up in the sewage system and thus in sludge, via building surfaces, pipes, brake linings and electric lines [OLIVA ET AL.]. Table 3 lists the concentrations of heavy metals in sewage sludge in recent years (data available up to 2006 only). The heavy metals that fall within the scope of the Sewage Sludge Ordinance (AbfKlärV) are expressed in mg per kg of dry solids.

Table 3: Sludge concentrations of selected heavy metals and of nitrogen and phosphorus between 1977 and 2006.

mg/kg of dry solids	1977	1982	1986–1990	1998	2001	2002	2003	2004	2005	2006	Change between 1977 (=100%) and 2006	Change between 2001 (=100%) and 2006
Lead	220	190	113	63	53	50	48	44.3	40.4	37.2	-83.09	-29.81
Cadmium	21	4.1	2.5	1.4	1.2	1.1	1.1	1.02	0.97	0.96	-95.43	-20.00
Chrome	630	80	62	49	45	45	42	40.7	37.1	36.7	-94.17	-18.44
Copper	378	370	322	289	304	306	305	306.3	306.4	300.4	-20.53	-1.18
Nickel	131	48	34	27	27	27	27	25.8	25.2	24.9	-80.99	-7.78
Mercury	4.8	2.3	2.3	1	0.8	0.7	0.7	0.62	0.59	0.59	-87.71	-26.25
Zinc	2,140	1,480	1,045	835	794	750	746	756.7	738.2	713.5	-66.66	-10.14
Total nitrogen	n/a	n/a	n/a	n/a	39,357	38,846	40,328	42,025	42,457	43,943	ns	+11.65
Total phosphorous	n/a	n/a	n/a	n/a	27,337	22,019	22,559	23,581	24,312	24,531	ns	-10.26

As table 3 shows, sludge concentrations of lead, cadmium, chrome, mercury and zinc have been decreasing steadily since 1977. Copper and zinc concentrations have remained at around 305 mg/kg and 24 mg/kg dry solids respectively. It is noteworthy that nitrogen concentrations have increased in recent years. Since 2001, phosphorous concentrations have dropped by around 10 %. The graphics below show sludge heavy metal concentrations from 1977 to 2006. Figure 2 shows cadmium and mercury sludge concentrations.

Figure 2: Sludge concentrations of cadmium and mercury [bmu]



The decrease in mercury and cadmium concentrations is mainly attributable to the reduced use of various products, but also to factors such as the use of amalgam separators in dentistry. The European Commission has also elaborated a mercury strategy aimed at reducing mercury use. Additional sewage sludge copper, zinc, nickel, chrome and lead statistics can be found in Appendix III.

Organic compounds in sewage sludge

Concentrations of organic substances in sewage sludge dry solids can range anywhere from 45 to 90 %. Most such substances comprise a bacterial mass that is mainly composed of carbon, hydrogen, oxygen, nitrogen and sulphur (see table 2). Sewage sludge also contains impurities from a host of organic pollutants, the most harmful being polychlorinated dibenzodioxins/furans (PCDD/F), halogen compounds and organic tin compounds. Tensides and polycylic aromatic hydrocarbons (PAHs) are also found in sewage sludge. All of these various organic substances often stem from numerous household products including household detergents and cleaners, as well as body care products. Other sources attributable to human activity include DIY products such as wood protection agents, as well as pharmaceutical products [OLIVA ET AL.].

Table 4 shows the results of a 2006 North Rhine-Westphalia study that measured organic substance concentrations in sewage sludge.

Table 4: Organic-compound concentrations in sewage sludge, from a north rhine-westphalia study [Fragemann]

Substance group	Organic pollutant	Mean value in [mg/kg dry mass] [FRAGEMANN]	90. Perzentil In [mg/kg TM] nach [FRAGEMANN]
Chlorophenols	Triclosan	3.4	5.5
Musk compounds	Musk xylol Galaxolide Galaxolide	0.0053 5.92 2.65	0.0084 11.8 4.9
Organic tin compounds	Dibutyl tin Di-octyl tinn Monobutyl tin Monooctyl tin Tetrabutyl tin Tributyl tin	0.22 0.056 0.17 0.031 0.0067 0.033	0.35 0.05 0.32 0.043 0.0025 0.065
Polychlorinated dibenzodioxins/furans	PCDD/F I-TEQ	14 ng TE kg TR	22 ng TE kg TR

Substance group	Organic pollutant	Mean value in [mg/kg dry mass] [FRAGEMANN]	90. Perzentil In [mg/kg TM] nach [FRAGEMANN]
Polybrominated diphenyl ethers	Tetrabromodiphenyl ether Pentabromodiphenyl ether Hexabrominated diphenyl ether Heptabrominated diphenyl ether	0.026 0.048 0.011 0.013	0.037 0.063 0.011 0.0058
PAC	Decabrominated diphenyl ether Benzo(a)pyrene Chrysene EPA PAC (excluding acenaphtylene	0.57 0.47 0.64 6.64	1.06 0.73 1.11 9.52
PCB (polychlorinated biphenyls)	Total PCB 6	0.091	0.17
Phthalates	DEHP Dibutyl phthalate	27.5 0.55	57.5 1
Tenside	Linear alkyl benzene sulfonate (LAS) Nonylphenol	1,723 21.5	4,000 44.2

The aforementioned pollutants and the concentrations thereof were mainly determined in accordance with their catchment areas, as well as population size and numbers of businesses [OLIVA ET AL.].

Pathogens and health hazards arising e. g. from EHEC

Pathogens such as bacteria, viruses, parasites and worm eggs are also found in sewage sludge. If such sludge is used as fertilizer, the pathogens in it can enter the human and animal food chain, thus endangering the health of both [GUJER].

This potential health hazard is the subject of an ongoing debate concerning the possible transmission of EHEC to humans as the result of the utilization of sewage sludge and other organic substances as fertilizer. The 2011 EHEC epidemic, which was provoked by the EHEC pathogen O104:H4, raised public awareness of the importance of such risk assessments. Two requirements need to be met in order to conduct such assessments: (a) the survival capability of the pathogen must be known; and (b) it must be possible to determine the probability that humans and livestock will come into contact with sewage sludge. The pathogens with the greatest survival capability are (a) spore producing bacteria such as clostrida; (b) parasites that form a long term phase or that produce spores (e. g. giardia and cryptosporidia); (c) plus worm eggs. Bacteria that do not produce spores normally survive for only anywhere from a few weeks to a few months.

Very little is known about the ability of the EHEC pathogen O104:H4 to survive in the environment. Inasmuch as the epidemic strain contains two E. coli pathogens (EHEC and EAggEC), the relevant risk can at present only be assessed based on the characteristics of these E. coli pathogens, and of apathogenic E. coli . Inasmuch as EAggEC bacteria tend to exhibit bacterial cell aggregation and form biofilms, the E. coli epidemic strain O104:H4 could potentially persist in environmental biofilms. Moreover, it is safe to assume that the E. coli epidemic strain O157:H7 can potentially survive for months in the ground, as it has been shown to possess the capacity to survive over a period of many months in various types of soil and under various sets of experimental conditions.

In view of the fact that the EHEC pathogen O104:H4 exhibits a high level of survival capability, it is essential that humans and animals not be exposed to it. Hence in drafting the Sewage Sludge Ordinance's (AbfKlärV) health and safety provisions, minimizing possible risk for humans and livestock was a top priority. Another way to avoid such exposure would be through hygienization of sewage sludge by reducing pathogen concentrations before sludge is used as fertilizer. But as the Sewage Sludge Ordinance (AbfKlärV) takes a different approach to this problem, it contains restrictive regulations concerning sewage sludge application on land. Hence section 4 of this ordinance contains application restrictions such as that sewage sludge cannot be used as fertilizer for fruit and vegetable growing, or on permanent grassland. The ordinance also sets forth sludge application limitations for fields that are used to grow forage or cultivate sugar beets (in cases where the beet leaves are used as forage). Thus sewage sludge cannot be used as fertilizer for food or animal feed that is eaten raw.

Hence the Sewage Sludge Ordinance (AbfKlärV) is in effect predicated on the assumption that insofar as sewage sludge is utilized properly, neither fruit/vegetable crops nor forage will be contaminated.

Sewage sludge utilization is also prohibited in zone I and II protected drinking water areas (containment facilities and protected areas per se), and in up to ten meter wide buffer strips. The presence of sewage sludge and the utilization thereof as fertilizer in zone III water protection areas (i.e. the catchment area of a protected containment facility) are banned in certain cases at the regional level.

Experts believe that the existing ordinances are sufficient to prevent EHEC from entering the food chain, groundwater or surface water-bodies via sewage sludge application on land, provided that sludge is used in accordance with the Sewage Sludge Ordinance (AbfKlärV). However, this belief in turn presupposes that sludge monitoring will be 100 % effective.

Pharmaceutical drug residues in sewage sludge

More than 30,000 tons of pharmaceutical drugs are used in Germany annually [RÖNNEFAHRT]. After being used for therapeutic purposes or being disposed of improperly (in toilets), residues of these drugs end up in municipal sewage systems.

Depending on the sewage treatment methods used, a greater or lesser portion of the pharmaceutical drug residues removed from sewage are deposited in sewage sludge. The downside of more efficient removal of such residues from sewage (thanks to the use of advanced treatment technologies) is rising concentrations of pharmaceutical drug residues in sewage sludge. And when such sludge is used as fertilizer, the pharmaceutical drug residues contained in it are applied to the ground, along with the sludge's nutrient load. Such substances can then seep into the soil (where they accumulate) and groundwater, or can be directly incorporated into waterbodies through surface runoff. While extensive research has been done on pharmaceutical drug residues in sewage treatment plant runoff and surface waterbodies, little in the way of scientific data is available on drug residue concentrations in sewage sludge and the behaviour of these concentrations in the soil. Apparently, this is because scientifically demonstrating the presence of pharmaceutical compounds in soil is complicated by the fact that many of these substances are fixed to the organic soil matrix (i.e. the various solids in soil) and can only be removed through lengthy extraction processes.

The elimination rates of pharmaceutical drug residues in sewage sludge via breakdown, as well as sorption (i.e. input into or adhesion to the organic components of sewage sludge) vary greatly. According to one study [BOXALL ET AL.] pharmaceutical drugs (e.g. certain antibiotics) that are non-polar and have a high molecular weight tend to exhibit elevated sorption. Another study [GOLET ET AL.] observed an 88 to 92 % elimination rate, mainly through input into sewage sludge, and demonstrated up to a 3.5 mg/kg sewage sludge concentration of the fluoroquinolone antibiotics ciprofloxacin and norfloxacin. According to the study authors, the soil in fields fertilized with sewage sludge contains up to

0.45 mg per kilogram of the relevant substances that are also highly persistent, i.e. remain in the environment for a lengthy period.

According to an IWW literature review (commissioned by the UBA) of the monitoring data for pharmaceutical drugs in the environment [BERGMANN ET AL.], apart from the aforementioned antibiotics ciprofloxacin and norfloxacin, the antibiotics doxycyclin, clarithromycin, roxithromycin and trimethoprim, the anticonvulsant carbamazepine, the hyperlipidemia drugs bezafibrate, fenofibrate and gemfibrozil, and the beta blocker metroprolol occur in sewage sludge in concentrations exceeding 100 µg/kg. Oestrogens such as 17-beta-estradiol and 17-alpha- ethinylestradiol have also been detected in sewage sludge samples.

Another study [STUMPE] concerning the soil breakdown and mineralization of steroid hormones that end up in fields as the result of sewage sludge fertilization (among other applications) found that oestrogen is a stable compound in the soil. The study's lab experiments showed that oestrogen in soil is subject to vertical displacement and should thus be factored into risk assessments concerning groundwater as well as surface waterbodies that are affected by groundwater.

Another subject of debate among scientists concerning sewage sludge application on land is the spread of pathogens that are resistant to antibiotics. There is evidence that in part owing to the elevated bacterial concentrations found in sewage treatment plants, antibiotic resistance can be exchanged between bacteria that are input with sewage from facilities such as hospitals [UBA]. This phenomenon could potentially give rise to new constellations of antibiotic resistance being transmitted to heretofore nonresistant bacteria. According to another study [EIBISCH], the continuous input of antibiotics into soil over a prolonged period can result in elevated concentrations of bacteria that promote the growth of antibiotic-resistant bacteria, resulting in the possibility of gene transfers of the resistance genes of such antibiotics. Expert reports issued by the German Advisory Council on the Environment (SRU) concerning pharmaceutical drugs in the environment indicate that the spread of antibiotic resistance in the environment resulting from resistant-bacteria inputs poses a greater public health hazard than antibiotic inputs per se [SRU].

Antibiotics can be absorbed in the soil by plant roots and can be absorbed by plant tissues down to the seed level [GROTE ET AL.]. However the concentrations that have been detected in such settings are lower than the health reference values that apply to products such as food of animal origin.

There are various indications that pharmaceutical drugs remain and accumulate in the soil as the result of sewage sludge fertilization. Although generally speaking such inputs are not currently regarded as serious hazard for soil, soil organisms or human health, the data concerning the long term impact of these inputs on soil organisms, the environment as a whole, and on human health is currently insufficient. According to a German Advisory Council on the Environment (Sachverständigenrat für Umweltfragen, SRU) report on pharmaceutical drugs in the environment, although only a handful of pharmaceutical drugs accumulate in sewage sludge, it would be advisable to gradually phase out the use of sewage sludge as a fertilizer so as to avoid diffuse loads of potentially harmful substances in soil [SRU].

Sludge treatment

03

The term sludge treatment encompasses all processes that improve the suitability for use, transport or storage of sewage sludge. Sludge treatment methods include thickening, hygienization, biological stabilization, dewatering, drying and incineration [GUJER; BRANDT]. The latter process will be discussed in a separate chapter.

Thickening

The purpose of sludge thickening is to reduce sludge volume by removing as much water as possible from the sludge. In thickeners (which are very similar to sedimentation tanks in terms of their design and processes), sludge particles naturally sink to and are deposited on the bottom. In addition, a mixer expedites particle flocking so as to enable the particles to be deposited more rapidly. The sludge is removed from the bottom of the thickener, and is discharged to the surface of the excess water [GUJER].

Hygienization

Hygienization reduces the concentrations of pathogens such as viruses and worm eggs in sewage sludge, the goal being to minimize the risk of human and animal contamination when sludge is used as a fertilizer. A draft of a proposed amended version of the Sewage Sludge Ordinance (AbfKlärV) stipulates that sewage sludge may only be discharged or applied insofar as it has been hygienized. Appendix 2 of this draft bill contains a list of the allowable hygienization methods that allow for compliance with the mandated physical and chemical parameters for sewage sludge hygienization [BRANDT] (see table below).

Table 5: Chemical, physical and thermal stabilization methods for sewage sludge

Process type	Method	Description
Reaching treatment temperature through heating	Sludge pasteurization	The sludge is kept at a temperature exceeding 70 °C for 60 minutes [BMU].
	Thermal conditioning	Thermal conditioning is performed at 15 bar at a minimum, a minimum temperature of 80 °C, and for at least 45 minutes in a sludge reaction tank [BMU].
Reaching treatment temperature through spontaneous heating/ chemical reaction heating	Aerobic-thermophilic sludge stabilization (ATS)	Exothermic microbial breakdown and digestion processes are triggered by active air/oxygen input, resulting in heating and a pH increase to around 8 in sewage sludge. ATS systems that are run semi-continuously need to be composed of two stages at a minimum. Only with a minimum temperature of 55 °C and at least 22 hours of treatment time in a second tank can sufficient reduction of harmful organisms be assured [BMU].
	Sludge composting in windrows or reactors	Microbial aerobic rotting allows for sludge composting. The heat needed for this process is supplied by breakdown process itself. Elements such as straw and wood shavings are added to the sludge. Baseline water content ranging from 40 to 60 % is ideal for a successful composting process [BMU].
	Adding unslaked quicklime	Adding CaO to dewatered sewage sludge heats the mixture (secondary to exothermic reactions of calcium oxide and the water therein) to 55 °C at a minimum, provided that the reactor has adequate thermal insulation. Also, the baseline pH needs to be 12.8 at a minimum and dwell time must be at least three hours, during which a minimum temperature of 55 °C must be maintained [BMU].
pH value increase	Adding calcium hydrate during sludge conditioning	DAdding Ca(OH)2 in the guise of quicklime or the like can result in a pH increase, and also reduces harmful-organism concentrations. A minimum of 0.2 kg Ca(OH)2/kg dry mass must be added and the baseline pH of the quicklime-sewage sludge mixture needs to be 12.8 at a minimum. The mixture needs to be stored for at least three months prior to use [BMU].
Long term storage processes that reduce concentrations of harmful organisms	Treatment carried out in plant beds	Reeds or tule absorb and mineralize the organic elements in liquid sludge, resulting in a soil-like substrate containing the organic elements from the sludge and the rotted roots. The reed helps to aerate the substrate and promotes sludge dewatering thanks to its high evaporation capacity. The process is best carried out in modular treatment beds that are loaded in phases, which allows for minimum dwell times and load-free periods [BMU].
Drying processes	High temperature drying	The sewage sludge is dried by heating the air, water or other drying medium to a temperature exceeding 100 °C [BMU].

Biological sludge stabilization

Biological sludge stabilization reduces concentrations of organic substances that break down rapidly, so as to avoid the unpleasant odours associated with such substances. A distinction is usually made between anaerobic biological sludge stabilization (digestion) and its aerobic counterpart. These processes are normally carried out in the psychrophilic, mesophilic or thermophilic temperature ranges.

Large-scale biological sludge stabilization facilities in Germany normally use the anaerobic process, which is done in what are known as digesters. Sewage sludge digestion allows for sludge stabilization, i.e. reduced odour emissions and biological activity. It is also essential that digestion improve sewage sludge dewatering capacity, among other things. Another advantage of anaerobic treatment is that it produces a gas that can be used to generate energy. Other biological sludge stabilization methods are compostation and soilification.

The dewatering induced by digestion is advantageous for subsequent thermal recycling in that digestion raises the heat value of the sludge. However, this is also a drawback in that the anaerobic breakdown process reduces organic-substance concentration and thus the calorific value of the sludge.

Sludge dewatering

Mechanical sludge dewatering, which reduces the volume of the sludge mixture by reducing its water content, is particularly important in settings where sewage sludge is transported to another site for treatment or disposal. Dewatering reduces the volume of sewage sludge that needs to be transported. What's more, sludge cake (solid sludge) is far easier to process than liquid sludge. Dewatering also makes sludge combustion more cost effective by increasing the calorific value of the sludge.

Mechanical dewatering of sewage sludge in decanters, centrifuges, or belt or chamber filter presses results in solids concentrations 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.

Upstream sludge conditioning improves sludge dewatering capacity, through the use of flocking and flocking agent additives, whereby 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. As these salts substantially increase the noncombustible material (i.e. ash) content of dewatered sludge, organic conditioning agents are normally used prior to thermal sewage sludge treatment.

Sewage sludge drying

Dried sewage sludge has a number of

advantages over wet sludge that stems directly from the treatment process. Sludge dewatering and subsequent drying are preferable for the following reasons:

- Reduced sewage sludge volume
- More conducive to storage and transport
- More amenable to conveyance and dosing
- Microbiological stabilization & health safety
- Increased calorific value

The main drawback of drying is the additional energy needed for drying and dewatering.

Mechanical dewatering is only the first step in the drying process, during which various methods are used in order to increase sewage sludge solids content to more than 50 %. There are basically two types of sludge drying: partial drying to around 85 % dry residue; and complete drying to around 95 % dry residue. Sewage sludge is deemed partly dry insofar as it has undergone the paste phase, i.e. its solids content equates to more than 50 to 55 % dry residue.

The key factor for subsequent thermal treatment is increasing the calorific value. In many cases the level of total solids achieved through mechanical dewatering does not allow for self-sustaining sludge incineration; or for technical reasons additional drying is necessary for sludge incineration. The most energy efficient method in this regard is to dry the sludge at the incineration site using a method such as waste heat recovery [Beckmann]. Sewage sludge drying uses a tremendous amount of energy, as residual sludge water is evaporated using thermal energy. In this process, the drying gradient is determined by the intended use of the sludge.

For spontaneous incineration (without an auxiliary combustion system) in sewage sludge mono-incineration plants, dewatering and drying of raw sludge to a total solids of 35 % dry residue are normally sufficient. The counterpart minimum value for digested sludge is 45 to 55 % dry residue, since digestion leaves behind a lesser amount of organic material for incineration. Waste incineration plants handle dewatered, partly dried and fully dried sewage sludge. For power plants, sewage sludge with a solids content ranging from 20 to 35 % dry residue is normally used for incineration purposes. Such plants have coal grinding systems that allow for integrated sewage sludge drying. Fully dried sludge can also be used in power plants. Sewage sludge in cement plants needs to be both dewatered and fully dried.

Sewage sludge combusts spontaneously at a heat value of around 4,500 to 5,000 kJ/kg; or if hot exhaust air from the boiler is used to prewarm the combustion air, spontaneous combustion can occur at 4,000 kJ/kg. Drying increases sewage sludge calorific value to 13,000 kJ/kg; thus the calorific value of dried sewage sludge is on a par with that of dry wood or lignite. Various heating media can be used for sludge dryers. Table 6 lists the heating media and drying systems that are used.

Table 6: Heating media and drying apparatuses used [Hepke]

Heating medium	Drying apparatus
Flue gas	Drum dryer
District heating power plant flue gas	Fluidized bed dryer
Air	Drum dryer or belt dryer
Steam	Thin layer dryer, disc dryer, fluidized bed dryer
Pressurized water	Thin layer dryer, disc dryer, fluidized bed dryer
Thermal oil	Thin layer dryer, disc dryer, fluidized bed dryer
Solar energy	Solar dryer

The choice of drying method for a particular situation depends, however, on numerous parameters, such as integration into the process as a whole, the desired end-product characteristics, as well as economic and particularly ecological considerations.

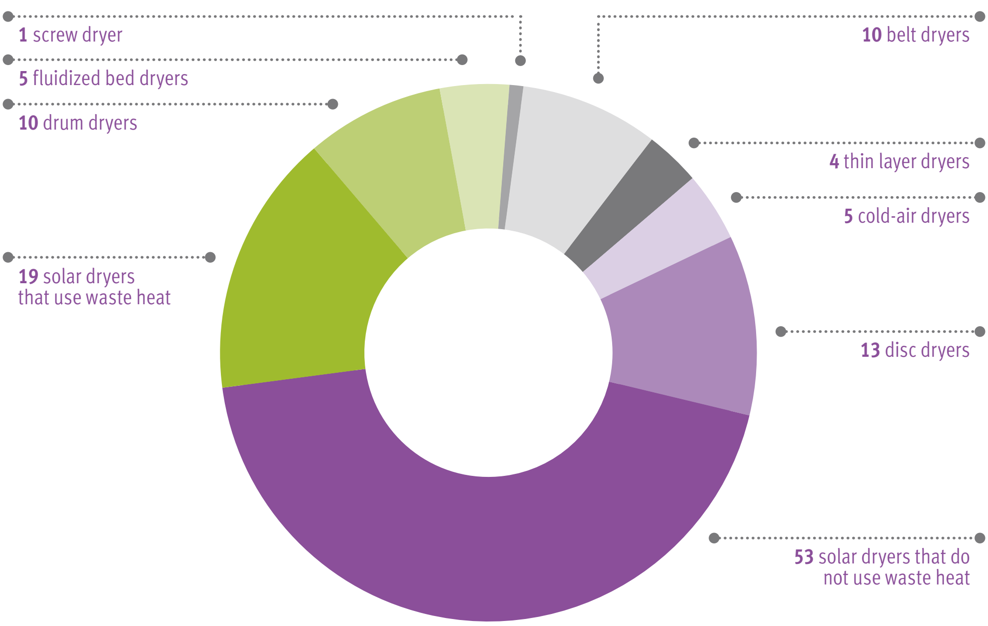
Drying methods can be classified as either direct or indirect processes. Direct dryers (also known as convection dryers) dry sewage sludge directly by exposing it to the heating medium, usually air or flue gas. The vapour generated by the drying process is a mixture of water vapour, air and the gases expelled from the sludge. This vapour requires subsequent scrubbing. In the interest of avoiding odour emissions and endangering the health of nearby residents, dust particles are filtered out of the vapour before it is released into the atmosphere through biofilters.

In indirect drying systems (also known as contact dryers), the necessary heat is provided by a steam generator, or by a thermal oil apparatus that uses oil as a heating medium. The heat in contact dryers is transferred between a hot dryer surface and the sludge, whereby the heating medium and sludge are kept separate. The advantage of this technology is that it prevents the vapour from mixing with the heating medium, and this in turn facilitates subsequent purification of the two substance flows. Contact dryers normally achieve solids content ranging from 65 to 80 dry residue. The only impurities in the water that is evaporated by the drying process are leakage air and trace amounts of volatile gases. Virtually all of the steam can be condensed out of the vapour, and the remaining gases are then deodorized by the boiler.

Solar drying, which as the name suggests dries sewage sludge using solar energy, has come into greater use in recent years. This process entails heating the sludge and then drying it in a greenhouse-like construction. In order for evaporation and thus drying of the sewage sludge to proceed in an optimal manner, the sludge needs to be well aerated and turned repeatedly [Felber and Fischer]. Solar drying can be expedited through the use of floor radiation heating or radiators or the like, so as to allow for the use of waste heat from power plants or waste incineration plants [Lehrmann 2010].

As of 2012, some 114 sludge drying facilities were in operation in Germany. Figure 3 contains a list of some of the sewage sludge dryers that are used, whereby in Germany numerous other systems also exist, some of which were decommissioned in 2011.

Figure 3: germany's sewage sludge dryer fleet, broken down by type

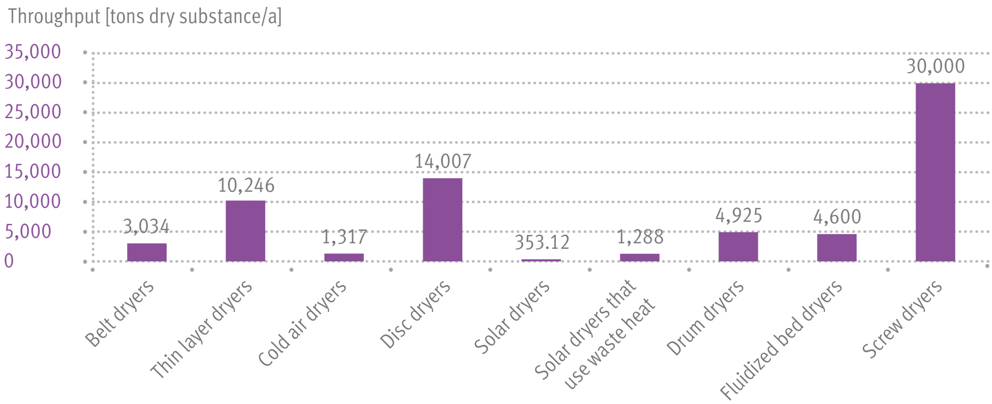


Source: proprietary data

The number of solar dryers in operation rose by more than 60 installations between 2004 and 2010. Apart from the drying methods used, sludge dryers are classified according to their mean throughput (see Figure 4). A detailed list with technical details concerning all types of sludge dryers used in Germany can be found in Appendix IV, table 23.

Figure 4: Mean sludge dryer throughput

Source: proprietary data



Sludge drying capacity has not kept pace with the percentage rise in sewage sludge drying facilities. The throughput of solar sewage sludge dryers is considerably lower than that of disc or thin layer dryers, and is generally lower than that of thermal methods, regardless of whether waste-heat recovery capability is available. Despite this drawback, solar sewage sludge dryer use is definitely on the rise. Use of these apparatuses is mainly advantageous in settings where no waste heat is available and the nearest mono-incineration plant is too far away. However, as noted, the choice of dryer hinges on many different factors.

Thermal sewage sludge treatment

04

The term “thermal disposal” in connection with sewage sludge pertains to incineration at mono-incineration plants (including gasification installations), at coal fired power plants and cement plants, and at certain waste incineration facilities. Moreover, the search for alternative sewage sludge treatment methods has intensified in recent years.

Mono-incineration

Sewage sludge mono-incineration facilities are operated at temperatures ranging from 850 to 950 °C; temperatures below 850 °C can result in odour emissions, and at temperatures above 950 °C ash sintering can occur. The temperature that is reached during incineration depends on the energy content and quantity of the sewage sludge being used, as well as by the amount of available combustion air. By law (Federal Imission Control Ordinance – 17. Bundes-Immissionsschutzverordnung, 17. BImSchV), a minimum of 6 volume per cent oxygen content must be maintained, afterburning must be carried out at 850 °C at a minimum, and at least two seconds of waste gas dwell time must be allowed in the afterburning chamber so as to allow for efficient combustion. Germany currently has (a) around 20 sewage sludge mono-incineration plants with aggregate combustion capacity of 580,000 tons dry solids annually; and (b) seven private sector sewage sludge mono-incineration plants with aggregate combustion capacity of 830,000 tons of original sewage sludge substance annually. These facilities use either raw sludge or digested sludge, which can be provided in a dewatered, partly dried or completely dried state. Further information in this regard can be found in table 22.

Combustion systems

The following types of combustion systems are used for sewage sludge mono-incineration plants:

- Fluidized bed furnaces
- Multiple-hearth furnaces
- Multiple-hearth fluidized bed furnaces
- Cycloid furnaces

The following table lists the particularities of these various types of furnaces:

Table 7: Comparison of the various combustion systems

	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 material
Operating performance	Rapid startup 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 fluidized bed; as compared to fluidized bed furnace, impervious to sludge quality fluctuations.	Solids content, long and 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 bottommost hearth	Via waste gas flow and sand removal	Via waste gas flow; large ash particles on the bottom
Residues	Ash, fluidized bed material	Ash	Ash, fluidized bed material	Ash; in some cases large ash particles

Sewage sludge incineration plant emissions

Sewage sludge incineration in sewage sludge mono-incineration plants and co-incineration combustion plants is governed by the Federal Imission Control Ordinance (17. BImSchV), which promulgates a number of air emission limit values. In the interest of adhering to these values through emission abatement, all sewage sludge mono-incineration plants have flue gas leaning systems.

The Federal Imission Control Ordinance (17. BImSchV) contains provisions concerning various types of emissions such as dust, NO_X, and mercury. All incineration processes and all types of incineration plants generate dust. All such plants are equipped with a filtering dust collector that efficiently reduces dust emissions. The mean dust content of cleaned flue gas ranges from 0.2 to 2.5 mg/m³; the statutory limit for this parameter is currently 10 mg/m³. NO_X formation in sewage sludge mono-incineration plants is mainly attributable to two sources. First, sewage sludge contains substances such as ammonium. NO_X can be formed through ammonium oxidation, as well as through ammonium input via incineration air in the form of oxygen and nitrogen, which at high temperatures can react with each other to form NO_X. The mean value of the emissions is around 80 mg/m³, although values ranging up to 180 mg/m³ have been measured on rare occasions. The limit value for nitrogen is 200 mg/m³.

Apart from the two aforementioned emissions, mercury plays a key role in environmental policy. According to UBA figures, the total mercury load from all sewage sludge mono-incineration plants for 2010 was around 39 kg, which is negligible compared to the around 5.5 ton figure for German coal fired power plants.

Other processes

Apart from the aforementioned incineration methods, a sewage sludge gasification plant has been in continuous operation in Balingen since 2004. This plant, whose annual incineration capacity is 1,250 tons of dry mass, converts dried sewage sludge into syngas, which is used for fuel by a district heating power plant and thus allows for co-generation of heat and electricity. There is also a gasification plant in Dinkelsbühl, which is currently shut down, as well as one in Mannheim that is slated to go into continuous operation in the near future.

Co-incineration

Apart from incineration in sewage sludge mono-incineration plants, sewage sludge can also be incinerated at power plants. Known as co-incineration, this process is mainly carried out at coal fired power plants, waste incineration plants and cement plants. One advantage of cement plants over sewage sludge mono-incineration plants is that they reduce fuel and additive use for the cement industry.

Coal fired power plant co-incineration

Sewage sludge incineration in power plants has accounted for an ever growing proportion of sewage sludge disposal in recent years, whereby licensed available capacity in this regard is currently around 716,000 tons dry mass/a – the equivalent of 26 German power plants. Sewage sludge can be co-incinerated at both coal and lignite fired power plants.

The main combustion methods currently used are dust and fluidized bed combustion.

As a rule, only stabilized (i.e. digested) sewage sludge is incinerated. The use of raw sludge entails too many handling and storage problems, particularly owing to its low dewatering capacity, as well as gas formation and odour emissions. As it is technically feasible to incinerate both dried and dewatered sewage sludge, most co-incineration power plants currently incinerate dewatered sewage sludge with total solids ranging from 25 to 35 % dry residue. Some power plants only incinerate fully dried sewage sludge, while others burn this type of sludge in a mixture.

Before dewatered sewage sludge is incinerated, an integrated sewage sludge drying process is carried out. For pulverized-coal firing, the sewage sludge is normally incorporated into the process via a coal grinding system that dries and pulverizes the sludge along with the coal. Only one German power plant currently uses a separate disc dryer. Oftentimes coal grinder drying capacity is limited owing to the fact that only a relatively low percentage of dewatered sewage sludge can be used in such apparatuses. This holds true in particular for coal-fired power plants, where the low coal water content severely limits dryer capacity. Figure 8 contains an overview of coal-fired power plant co-incineration.

Table 8: Coal fired power plant co-incineration

	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 fluidized bed firing	Sewage sludge use is limited owing to sludge heavy-metal content

The mineral content of sewage sludge is, as compared to coal, relatively high (around 40 to 50 % higher). Hence the amount of ash that needs to be disposed of is accordingly higher, and the total dry mass calorific value is accordingly lower. The calorific value of fully dried sewage sludge ranges from 9 to 12 MJ/kg, which is similar to that of lignite on delivery

(i. e. with 50 % water content). On being mined, coal water content ranges from 7 to 11 % and its heat value ranges from 27 to 30 MJ/kg.

On delivery (i. e. with water content ranging from 65 to 75 %), dewatered sewage sludge has no heat value. Once it has been dried using low temperature power plant waste heat, it is conducive to incineration, with an energy gain. Waste heat that would otherwise be released via a cooling tower can also be used for sewage sludge drying, in order to obtain high quality energy in the guise of electricity and steam. Hence a small percentage of power plant fossil fuel can be replaced by sewage sludge, which thus can likewise be regarded as sewage sludge energy recovery.

Sewage sludge is used in power plants that meets the relevant requirements of the Sewage Sludge Ordinance (AbfKlärV). However, the additional heavy-metal load entailed by sewage sludge use is a significant factor when it comes to emission values. This is why sewage sludge can be used for power plant co-incineration to a limited degree only. Using larger amounts of sewage sludge requires the installation of waste gas scrubbing equipment. Moreover, fly ash, which is mainly recycled for use in construction materials, needs to comply with the applicable construction materials standards. This is another important reason why sewage sludge is used for co-incineration to a limited extent only.

For most power plants, sewage sludge content ranging up to five per cent of fuel mass has proven to be a viable solution. Experience has shown that co-incineration of such quantities causes no serious problems. If all German power plants covered a mere five per cent of their firing needs with sewage sludge co-incineration, this would allow for incineration of double the amount of sewage sludge currently generated in Germany.

Waste incineration plant co-incineration
Municipal sewage sludge is disposed of in a number of waste incineration plants. The amounts of such sludge have fallen off in recent years, as some of these plants have discontinued sewage sludge incineration. Some waste incineration plants have seen sewage sludge delivery volumes decline or no longer receive any sludge at all.

The following processes are used for the co-incineration of waste and sewage sludge:

- Dried and pulverized sewage sludge is blown into the combustion chamber.
- Dewatered sludge is loaded into the combustion chamber separately by dispersion machines and is distributed on the gratings. Churning the waste on the gratings then allows the sludge to be incorporated into the bed material. Experience has shown that this process is viable with up to 20 mass per cent of sludge (25 % dry residue).

- Dewatered or dried sewage sludge is mixed with the residual waste and is then incinerated with it. This can be done through homogenization in a separate apparatus, in a waste bunker via targeted dosing by the crane operator, or can be carried out in a controlled manner in a feed hopper.

Cement plant co-incineration

For decades, cement manufacturers have been using alternative fuels derived from waste in order to save energy, since cement manufacturing is extremely energy intensive. Cement plants use dried sewage sludge as a substitute for fossil fuel. Moreover, the minerals contained in sewage sludge can be used as a substitute for mineral raw materials such as sand and iron ore that are needed for cement manufacturing. Sewage sludge co-incineration in cement plants contributes to climate protection and resource conservation in that it saves fuel and reduces carbon emissions since sewage sludge co-incineration counts as a climate neutral process. Under the amended version of the Federal Imission Control Ordinance (17. BImSchV) of 14 August 2003, the heavy-metal limit values for waste management also apply to sewage sludge co-incineration in cement plants.

Table 9 show the quantities of sewage sludge that are incinerated in cement plants, according to statistics in Bundesverband der Deutschen Zementindustrie e. V. environmental reports.

Table 9: Amounts of sewage sludge incinerated in cement plants, 2003–2010

Year	2003	2004	2005	2006	2007	2008	2009	2010	
Use	4	48	157	238	254	267	263	276	kt/a
Heat value	11	4	3	4	4	4	4	4	MJ/kg

Co-incineration in cement plants increased forty-fold between 2003 and 2005, and has continued to rise steadily ever since. This momentous increase is mainly attributable to the ban on using all types of raw waste as landfill, pursuant to the Technical Instruction on Municipal Waste (Technische Anleitung Siedlungsabfall, TASi) that was in force during the said period.

Despite the increase in cement plant co-incineration, only a negligible amount of sewage sludge is co-incinerated at cement plants and waste incineration plants.

Pros and cons of sewage sludge co-incineration

Sewage sludge co-incineration saves fossil fuel and thus reduces costs. Substituting sewage sludge for fossil fuel reduces carbon emissions, as sewage sludge can be regarded as a climate neutral material.

The cement industry also uses sewage sludge as an aggregate, thus allowing for cost savings and contributing to resource conservation.

A downside to co-incineration, however, is that the phosphorous content of the sewage sludge becomes irrecoverable, by virtue of the fact that the phosphorous is either incorporated into the cement or is highly diluted in slag and other incineration residues. Phosphorous recovery and its significance for sewage sludge disposal going forward is discussed in section 6.

A complete list of all German installations that incinerate or co-incinerate sewage sludge can be found in Appendix I.

Alternative sewage sludge treatment methods

Processes such as wet oxidation, hydrolysis, hydrothermal carbonization (HTC), low temperature conversion and supercritical water oxidation are regarded as possible alternatives to thermal sewage sludge treatment methods. Various sewage sludge gasification and pyrolysis processes are in the development phase, or only a handful of these processes have been used on a large scale thus far.

Sewage sludge use in the agricultural sector

05

Sewage sludge is one of the most commonly used and regularly controlled secondary raw material fertilizers, that has the capacity to meet part of the nutrient requirements of crops. Sewage sludge can also improve the humus balance, particularly for farms that do not generate their own manure. However, sewage sludge fertilizer is also a pollution sink for harmful sewage components from households, businesses and diffuse sources, concerning whose environmental impact too little is known. The extent of the possible soil, plant, groundwater, and surface-water pollution resulting from these sources is difficult to determine, even in cases where relatively small amounts of sewage sludge are used.

Only sewage sludge from municipal sewage treatment plants can be used as fertilizer for conventional farm crops. 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. Sewage sludge use as a fertilizer for forage cultivation is limited (seeding followed by deep tilling; see the Sewage Sludge Ordinance (AbfKlärV)).

Also, new breakdown products of pharmaceutical drugs are discovered in sewage sludge all the time. These breakdown products are incorporated into sewage sludge via human excretion and in other ways. It is simply not humanly possible for scientists to develop specific detection processes for and assess the environmental impact of all of these substances, whose combined impact is particularly difficult to characterize and assess. Scientists can merely estimate the theoretical hazards posed by these substances; and unfortunately, by the time the relevant hard facts become available, the pollutants in question will already have found their way into the biosphere [BRANDT].

Nutrients in sewage sludge

Depending on its origin and dewatering gradient, sewage sludge contains varying amounts of nutrients such as nitrogen, phosphorous and potassium. For instance, 100 tons of wet sludge with 5 % dry substance contains an average of around 190 kg of nitrogen, 55 kg of which is ammonium-N; plus 195 kg of phosphate and 30 kg of potassium [LfL].

The bonding structure of the phosphorous contained in sewage sludge depends on factors such as the phosphorus precipitation method used by the sewage treatment plant. Depending on whether a chemical or biological phosphorous precipitation method is used, anywhere from 60 to 80 % of phosphorous occurs in an inorganic form, and around 1 to 38 % of it is water soluble [KRATZ/SCHNUG].

The actual phytoavailability of phosphorous is determined by various factors such as soil and fertilizer pH and sewage sludge iron and aluminium content. Inasmuch as an unfavourable phosphorous-iron ratio can greatly reduce phytoavailability [ABD EL-SAMIE], during the treatment process biological phosphorous precipitation rather than chemical phosphorous precipitation should be used for sewage sludge destined for use as fertilizer. When sewage sludge is used as fertilizer, its actual nutrient content (which often deviates greatly from mean content data) should be taken into consideration and factored into nutrient balance assessments. Actual weights and nutrient contents attributable to a given lot can be found in the documents which are to accompany each lot (Düngemittelrechtliche Begleitpapiere).

The Sewage Sludge Ordinance (AbfKlärV) stipulates that up to five tons of dry sewage sludge may be used for each hectare of land over a given three year period. This represents, for instance, 100 m³ of sewage sludge with 5 % dry solids (wet sludge).

Users are required to indicate on the delivery note the amount of sludge fertilizer used, whereby the volume limit and ban on combinations must be observed. During the said three year period, no fertilizer containing organic waste may be applied in addition to sewage sludge fertilizer. A copy of the delivery note is given to the grower, to the carrier and to the district administrative authority (Kreisverwaltungsbehörde), whereby the sewage treatment plant operator keeps the original and is required to archive it for 30 years.

Sewage sludge from various sewage treatment plants is not to be admixed. Mixing sewage sludge with liquid manure or the like is allowable, although the amount of such mixture that is used may not result in the sewage sludge component exceeding five tons dry solids over a three year period (see the Sewage Sludge Ordinance, AbfKlärV). In cases where sewage sludge is placed in liquid-manure pits, the liquid manure-sewage sludge mixture is subject to the restrictions and all other provisions of the Sewage Sludge Ordinance (as is the case with all other sewage sludge mixtures), and its use is subject to prior soil and mixture analysis. Insofar as in addition to sewage sludge nutrient and pollutant content, aggregates content is also known and the composition of a given mixture can be determined with certainty, mixture analysis can be foregone. Using such mixtures for grassland and other aforementioned areas subject to sewage sludge utilization bans is prohibited.

Sewage sludge pollutants

The heavy-metal load in sewage sludge has by and large remained relatively low over the past 15 to 20 years. On the other hand, considerable attention has been focused on organic pollutants in sewage sludge of late, whereby sewage sludge analyses are required for a relatively limited number of substances. In elaborating the amended version of the Sewage Sludge Ordinance (AbfKlärV), new recommended limit values were investigated, resulting in the pollutants in question being classified into four categories [Bergs].

Table 10: Sewage sludge pollutant classifications that were used to elaborate recommended limit values [Bergs]

Category	Pollutant/statutory requirement
1	Previously regulated pollutants that are still relevant to some extent (e. g. PCDD/-F, PCB, AOX); limit values unchanged
2	Pollutants that still exhibit relatively high wastewater or sewage sludge loads; new limit values (e. g. PACs)
3	Pollutants with a high level of ecotoxicological relevance, but that have decreased considerably in recent years (e. g. TBT, DEHP), or whose concentrations are extremely high; monitoring only
4	No limit value or monitoring (e. g. LAS, nanoparticles)

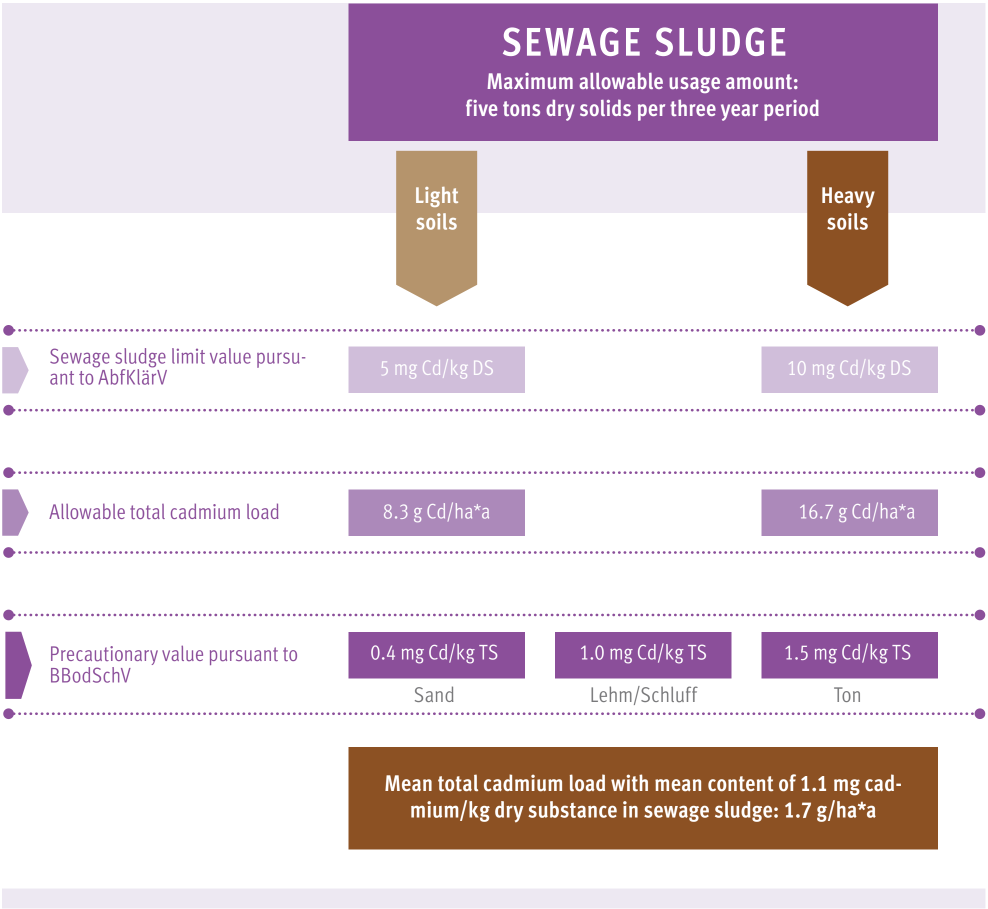
Perfluorinated tensides (PFTs) are an example of a substance group that only recently was recognized as a relevant sewage sludge component from a public health standpoint. Given the fact that, owing to its properties, it is widely used in many different ways, a limit value for PFTs was incorporated into the amended version of the Sewage Sludge Ordinance (AbfKlärV).

Using cadmium as an example, it will now be explained why the Sewage Sludge Ordinance (AbfKlärV) limit values need to be revised and why this revision should be taken into consideration for the amended ordinance. Cadmium, along with zinc, is the only heavy metal whose transmission from the soil to grain seeds can be detected to a relevant degree. As the result of a toxicity assessment revision, the EFSA reduced the weekly tolerable intake of cadmium from 7 µg/kg of body weight to 2.5 µg/kg of body weight, with the goal of minimizing overall cadmium intake. This also applies to the use of sewage sludge as fertilizer. The current allowable cadmium loads for sewage sludge fertilizing can be found in Figure 5.

A maximum of 5 mg of cadmium per kilogram of dry solids is currently allowable in sewage sludge that is applied to so called light soils (Figure 5, first line). For a maximum usage volume of 5 tons dry solids over a three period, this equates to a maximum allowable load (Figure 5, line 2) of 8.3 g of cadmium per hectare and year. The allowable amount for “other soils” is currently 16.7 mg of cadmium input per hectare and year.

The allowable total load greatly exceeds the actual load amounting to around 1.7 g of cadmium per hectare and year (bar at bottom of graphic). Hence leaving the current limit values unchanged would allow for a sizeable sewage sludge quality range. Establishment of quality assurance instruments (as called for

Figure 5: Allowable total cadmium load for maximum usage amounts pursuant to the sewage sludge ordinance (AbfKlärV), compared with actual mean cadmium loads [Ruppe et al.]



Source: Proprietary data; mean cadmium content and total cadmium load 1.1 mg cadmium/kg dry substance (Ruppe et al. 2009)

by the amended version of the Sewage Sludge Ordinance, AbfKlärV), together with revision of the limit values, would go a long way toward achieving greater quality uniformity for sewage sludge. The precautionary values pursuant to the Federal Soil Protection and Contaminated Sites Ordinance (Bundesbodenschutzverordnung, BBodSchV) are shown in purple, for purposes of comparison.

Pros and cons of using sewage sludge as a fertilizer

The importance of phosphorous and the state of the art of phosphorous recovery, which are discussed below, can be better understood in light of the pros and cons of using sewage sludge, as exhibited in table 11. The problem with the handling and disposal of sewage sludge lies in its role as a pollutant sink and nutrient point source.

Table 11: Pros and cons of using sewage sludge as a fertilizer

Pros	Cons
Exhaustive sewage sludge pollutant tests are carried out; the Sewage Sludge Ordinance (AbfKlärV) sets limits values for heavy metals and organic pollutants in sewage sludge.	The Sewage Sludge Ordinance (AbfKlärV) contains no provisions concerning what are to date presumably unknown or non-regulated sewage sludge pollutants such as nanoparticles, thallium, tributyl tin (TBT), mineral hydrocarbons, and various pathogens.
Sludge contains high concentrations of organic substances, which promote humus formation.	Humus formation can be promoted using other methods such as crop rotation.
Low cost source of necessary nutrients	Low cost nutrients can be obtained using other manure and other fertilizers.
Low cost phosphorous fertilizer, no import dependence	The direct phytoavailability of phosphates is mainly determined by the precipitation method used.
Soil testing prior to the use of sewage sludge as a fertilizer. However, such tests are carried out on request from and at the cost and expense of sewage treatment plant operators.	

Phosphorous recovery

06

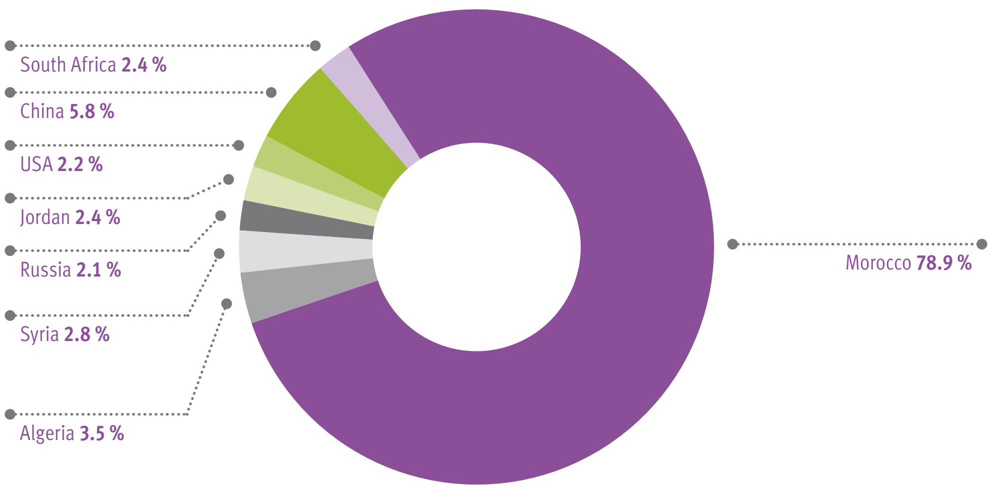
Sufficient phosphorous remains in currently exploited continental phosphorous reserves for worldwide use for around 360 years [U. S. GEOLOGICAL SURVEY]. However, the quality of this phosphorous is declining, particularly for raw phosphate that is obtained from sediment reserves, owing to increasing contamination from toxic heavy metals (mainly cadmium: up to 147 mg per kg of phosphorous) [SCHEIDIG] and radionuclei (mainly uranium: up to 687 mg/kg of phosphorous) [RÖMER ET AL.] and the consequent environmental and health risks. According to a recent study, the phosphorous peak is likely to be reached in 2033 [CORDELL ET AL.].

Worldwide phosphate fertilizer demand is set to increase by two per cent annually (i. e. around four million tons a year), with around 90 % of this demand stemming from Asia and North America [FAO]. The most important drivers of this trend are world population growth and efforts on the part of developing nations to achieve a high standard of living. The consequent increase in meat consumption will be the major driver of increased phosphorous use, since livestock raising entails considerably more energy use for feed than livestock provides after being slaughtered.

Around 90 % of phosphorous reserves are controlled by only five nations, and nearly half of the world's proven continental phosphorous reserves are located in Africa (see Figure 6). The fact that Morocco's phosphorous reserves are attributable to the country having annexed Western Sahara (an action not recognized by the UN) is already a conflict waiting to happen and is a matter of concern for Germany's raw materials security situation.

An additional 35 % of proven phosphorous reserves are located in China and the US, which themselves need a large amount of phosphorous; and thus these reserves are available for global trading to only a limited extent.

Figure 6: Global distribution of explored raw phosphate reserves as of 2013 [U.S. geological survey]



German imports all of its raw rock phosphate and the mineral fertilizers obtained therefrom. Hence phosphorous, particularly in its capacity as a crop nutrient, is a strategic resource, 138,000 tons of which were used as phosphate fertilizer in fiscal year 2007/2008 [IWMI].

Phosphorous recovery potential and processes

In view of population growth and the consequent rising demand for phosphate [FAO], recovery technologies are set to take on considerably greater importance for resource supply security, human health and natural resource conservation. In keeping with the government's resource conservation initiative, the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for the Environment (BMU) promoted the development and use of new methods that allow for large scale recycling of phosphorous from municipal sewage sludge and sewage, excess liquid manure, animal meal, and other phosphorous containing organic materials. The table below exhibits the recycling potential of selected substance flows in Germany.

According to studies comparing the phytoavailability of various recycled products with that of commercial fertilizers, elevated iron content secondary to the use of iron salt as a precipitate has a negative impact on phytoavailability.

Table 12: Estimated phosphorous recycling potential for various substance flows in germany [proprietary compilation]

Substance flow	Estimated recoverable phosphorous, expressed in tons per year
Municipal sewage	*54,000
Industrial sewage	15,000
Municipal sewage sludge	*50,000
Sewage sludge ash	*66,000
Manure	444,000
Animal byproducts: (classes 1 through 3, excluding animal fat) (up to 6 % phosphorous)	20,000
Estimated phosphorous demand in Germany	170.000

* These potentials do not lend themselves to tallying, as they represent various competing recovery paths within the sewage treatment cycle.

When it comes to substance recycling for electrothermal phosphorous manufacturing purposes (Thermophos, NL), the molar Fe:P ratio needs to be lower than 0.2. On the other hand, recycling substances from sewage treatment plants that use biological phosphorous precipitation has proven to be very cost effective. Further research in this domain is currently ongoing via various research projects.

Wet chemical processes using magnesium ammonium phosphate (MAP) as a precipitate, as well as thermal metallurgical processes, are regarded as being particularly promising. The MAP process allows for the recovery of around 40 to 70 % of the phosphorous contained in wastewater treatment plant sewage input, and allows for production of a low pollution nitrogen phosphate fertilizer, as well as a highly suitable raw material for fertilizer manufacturing – both of which are outstanding particularly owing to their good phytoavailability. However, the residual organic content of MAP fertilizers is relatively high, depending on the gradient of the subsequent purification process.

Although thermal-metallurgical processes are more technically complex than MAP precipitation, they allow for the following: (a) recovery of more than 90 % of the phosphorous in wastewater treatment plant sewage input; (b) concurrent use of the thermal energy in sewage sludge; and (c) elimination of the organic pollutants in sludge during incineration. In order for thermal-metallurgical phosphorous recovery from sewage sludge and sewage sludge ash to be efficient, sewage sludge needs to be incinerated separately owing to the fact that it contains relatively high phosphorous concentrations, as well as manageable levels of pollutants such as heavy metals.

The main drawback of co-incineration is that it precludes recovery of the phosphorous in sewage sludge. But if, on the other hand, all of Germany's sewage sludge were incinerated separately (around 2 million tons of dry mass annually), i. e. solely via mono-incineration, around 66,000 tons of phosphorous could potentially be recovered from the residual ash. This represents around 55 % of agricultural use of mineral phosphorous. Table 13 provides an overview of the worldwide and in some cases already established phosphorus recovery methods, the majority of which were developed in Germany. However, only a handful of these methods has been implemented thus far as either pilot installations or on a large scale.

For further information visit www.phosphorrecycling.de

Table 13: Methods for recovering phosphorous from sewage flows [Montag et al. and proprietary data]

Aqueous phase	Sewage sludge	Sewage sludge ash
Adsorption method	Air Prex/MAP method	Ash Dec (SUSAN)
CSIR fluidized bed reactor	Aqua Reci	BioCon
DHV Crystalactor®	CAMBI	ATZ iron bed reactor
Kurita fixed bed	KEMIKOND	EPHOS
Magnetic separator	KREPRO	PASCH
Secondary precipitation/flocking filtration	LOPROX	SESAL(-Phos)
NuReBas process	Mephrec	SEPHOS
Ostara PEARL™	Peco	Bioleaching
Phosiedi	Phostrip	Mephrec
P-RoC (Prophos)	PRISA	Thermphos
RECYPHOS	Seaborne	PhosRec (Koop Schiefer)
REPHOS	Stuttgart method	RECOPHOS
RIM NUT ion exchanger	Unitika-Phosnix®	LEACHPHOS
Sydney Water Board reactor	FIX-Phos	Eberhard method
Phostrip	Gifhorner method	RecoPhos (Germany)
Phosnix	PROXNAN	EPHOS
	Kemira-KREPRO	Inocre
PRISA	POPROX method	
NuReSys	Aqua Reci	
Ebara	MEPHREC	
MAP crystallization Treviso	ATZ iron bed reactor	
RECYPHOS	RecoPhos (AT)	

Cost efficient phosphorous recycling in Germany

Table 14 lists the phosphorous recovery installations that have been completed or that are in the pipeline, along with their key parameters.

Current R&D activities reflect the increased interest in technologies that would allow for recovery and recycling of the phosphorus contained in various wastewater flows. As the May 2009 International Conference on Nutrient Recovery from Waste Water Streams conference showed, Germany is in the forefront of R&D in this field – although Canada, Japan and the US are in the vanguard when it comes to bringing large scale projects to fruition. Legislation is pending in Switzerland requiring that phosphorus be recovered from waste water flows and animal meal, the goal being for Switzerland, which now imports phosphorous, to become a phosphorous exporting nation.

This requirement was slated to take effect in 2011/2012. The bill calls for a phosphorous recovery rate ranging from 50 to 100 % by 2015. The use of sewage sludge as fertilizer has been banned in Switzerland since 2008.

Sweden aims to recover a minimum of 60 % of wastewater phosphorous by 2015 and use it for farming [SWEDISH EPA].

Numerous methods have already been developed in Germany that are still in the experimental stage. But intensive efforts are underway to implement one or more of these methods on a large scale, for the purpose of establishing legal and economic frameworks that will enable these new methods to become economically viable.

Such projects can potentially be funded through subsidies and/or via sewage charges. Inasmuch as the greatest phosphorous recovery potential lies in recovery from waste water and sewage sludge, the Sewage Sludge Ordinance (AbfKlärV) should stipulate that phosphorus is to be recycled through phosphorus recovery, as an incentive to sewage treatment plant operators to install suitable recovery equipment. In the interest of promoting even more efficient use of the phosphorous in sewage sludge, the capacity of mono-incineration plants should be increased from their current level of 500 tons dry solids/year to around 2 million tons dry solids/year. Recognition of exclusive mono-incineration of sewage sludge as a source of renewable energy, together with funding of this technology under the Renewable Energy Act (Erneuerbare-Energien-Gesetz, EEG), would presumably expedite this capacity increase.

In the interest of promoting even more efficient use of the raw materials in sewage sludge (phosphorous, plus the important metals), phosphorous recovery-enabled landfill sites and facilities at such sites that are specifically designed for phosphorous recovery should be established, until sufficient capacity is available to process the volumes of sewage sludge ash that are generated.

All of the processes described here generate products that can be used as fertilizer that is less polluting than conventional mineral fertilizers made from raw phosphate of sedimentary origin. This is attributable to the fact that the cadmium and uranium levels of their recycled products are considerably lower than those in raw phosphate of sedimentary origin [RÖMER ET AL.]. All products provide the requisite phytoavailability, i. e. they fertilize the plants to a satisfactory degree. MAP products tend to exhibit greater phytoavailability than ash products. Table 15 lists the pros and cons of the MAP process versus thermal recovery.

Inasmuch as only two such processes are currently in use at large scale installations, no valid conclusions concerning the economic efficiency of the various processes can be reached.

Table 14: Large scale german installations that have been realized or are in the pipeline, as at 2010 [proprietary compilation]

Operator/location	Method	Input	Output	Phosphorous volume, in litres/year	Status/comments
Seaborne EPM AG/ KA Gifhorn	Seaborne (MAP precipitation)	120 m^3/d fermentation substrate			In operation since 2007
Remondis Aqua/ Altentreptow (MV)	Rephos® MAP precipitation	Dairy waste water (80 mg P/l)			In operation since 2007
Berliner Wasserbetriebe/KW Waßmannsdorf and ABA Neuwerk-Mönchengladbach	AirPrex® Commercial name: Berliner Pflanze MAP precipitation	Digested sludge (100 m^3/h)	2.5 tons MAP/d		As at 2013
KW Neuwerk-Mönchengladbach	AirPrex® MAP precipitation	Digested sludge (50 m^3/h)	MAP		As at 2013
Braunschweig- Steinhof	AirPrex® MAP precipitation (prospective)		MAP		As at 2013
Lingen	AirPrex®		MAP		As at 2013
Hildesheim	FIX-Phos		CaP		As at 2013
Mainz	Budenheim process		CaP		Experimental phase. As at 2013
KA Offenburg (Baden-Württemberg)	Stuttgart process (MAP precipitation)	Digested sludge	50 kg MAP/d		As at 2011
Ash Dec, now Outotec (RETERRA) (Brandenburg)	SUSAN Thermochemical	Sewage sludge ash | (around 9 % phosphorous) | (12,000 t/a)	Around 10,000 t/a phosphorus fertilizer	Around 1,000 tons planned	Rollout set for 2014 or 2015
Ingitec (Nuremberg)	Mephrec® (metallurgical method)	Sewage sludge (25 % dry substance), 60,000 tons/year (or sewage sludge ash)	Phosphorus slag, 12,000 tons/year	Around 500 tons planned	Rollout set for 2014
RecoPhos (Schönebeck)	Thermochemical	Sewage sludge ash	Phosphorus fertilizer	Unknown	Rollout set for 2014
P-RoC (Neuburg)	Crystallization	Sludge	CaP	Around 20 tons	As at 2012

Conversion of the following phosphorous content: P_2O_5 = 43.64 % and MAP ($MgNH_4P_4 \cdot 6H_2O$) = 12.62 %

Remondis Aqua's Rephos process and the Air-Prex® process have proven to be economically efficient at a number of sewage treatment plants. According to their developers and potential users, on paper the Ulophons®, Mephrec® and ReceoPhos® processes are economically efficient under the required operating conditions, including in cases involving low product sales revenues. However, none of these processes has ever been used in a large scale installation, although such applications are in the pipeline in certain cases such as for Mephrec®. Hence phosphorous recycling processes that are currently not economically efficient may become so in three to 20 years, at the currently projected world market prices and assuming that systematic implementation of phosphorous recycling gets underway in 2012 [SARTORIUS]. Application of an admixture level would not promote phosphorous recovery using current state of the art technologies. Nonetheless, in the interest of promoting technological advances in this sphere and achieving high phosphorus recovery levels, a report titled Evaluation of Options for the Sustainable Use of Secondary Phosphorus Reserves issued by the Länder Workgroup for Waste (Länderarbeitsgemeinschaft Abfall) recommends a number of instruments such as voluntary measures and establishment of a fund or the like.

Sewage sludge ash recycling paths

As noted, industry experts are currently discussing the possibility of storing sewage sludge ash in dedicated facilities from which it would be readily recoverable.

Unfortunately, current ash management methods preclude ash recovery, and

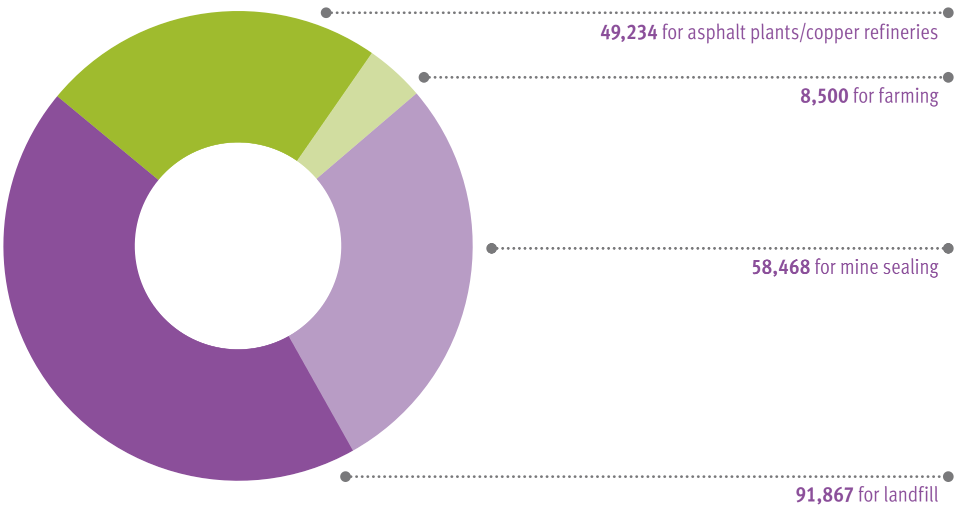
http://www.laga-online.de/servlet/is/23875/Bericht_Phosphorr%C3%BCckgewinnung_engl.pdf?command=downloadContent&filename=Bericht_Phosphorr%FCckgewinnung_engl.pdf

Table 15: Comparison of wet-chemical map processes and map thermal processes

	MAP	Thermal
Advantages	• Less cost intensive • More conducive to retrofitting • Superior phytoavailability	• Higher recovery rate (90 %) • Simultaneous material and energy use of sewage sludge • More versatile, i. e. suitable for all types of sewage sludge and other substances • All organic pollutants are expunged • Considerably lower volumes of waste (residual substances)
Drawbacks	• Only up to 40 % recovery at present • Only compatible with biological phosphorous installations	• Higher investment costs • More cost intensive process

thus in turn phosphorous recovery. Figure 7 shows that the vast majority of landfill ash is recovered or is used as mine sealing (underground mine backfilling). Lesser amounts of this ash are used as agricultural fertilizer, as ash meets the statutory requirements for this application.

Figure 7: Disposal paths of sewage sludge ash from 18 mono-incineration plants in 2009 [proprietary data]



Sewage sludge quantities, management and recycling

07

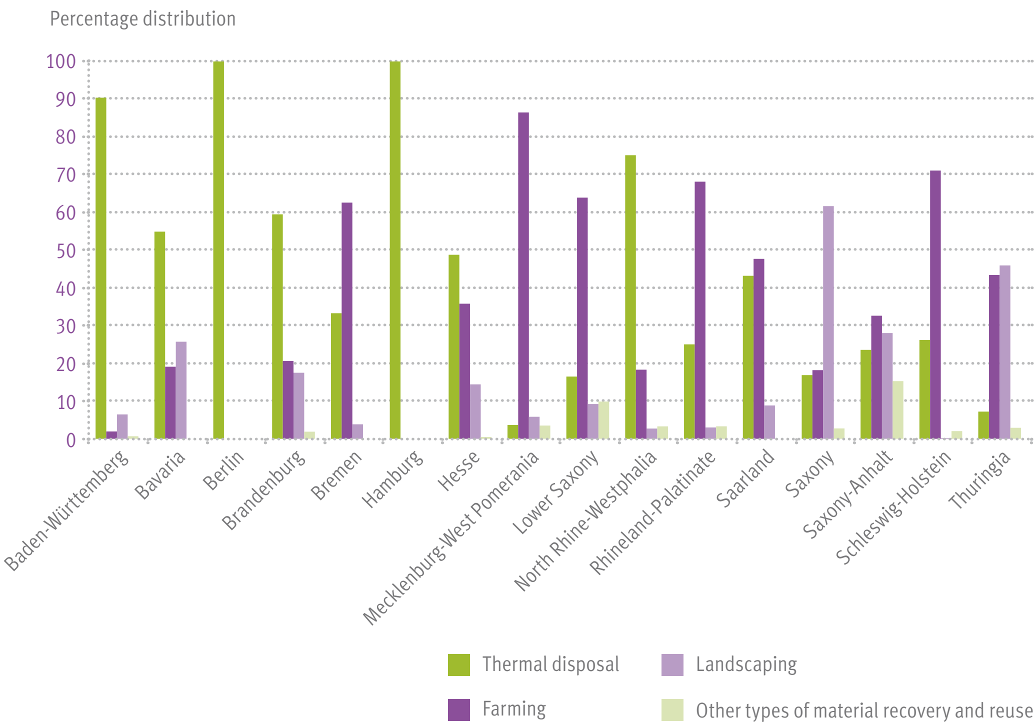
Around two million tons of sewage sludge dry mass (TDM) were disposed of in Germany in 2010. Around 50 % of this sludge underwent thermal disposal, while 883,659 TDM were used for farming, landscaping and other purposes such as composting and recultivation (see table 16 and Figure 8 for the regional states' disposal pathways and methods).

Table 16: Sewage sludge disposal volumes and methods in 2011 in germany's regional states [Destatis g]

Regional state	Total sewage sludge disposal volume	Used for farming	Used for landscaping	Other types of material recovery and reuse	Thermal disposal	Landfill
	[TDM/a]	[TDM/a]	[TDM/a]	[TDM/a]	[TDM/a]	[TDM/a]
Baden-Württemberg	244,505	5,306	16,304	2,219	220,676	-
Bavaria	273,161	52,582	70,608	-	149,971	-
Berlin	44,351	-	-	-	44,351	-
Brandenburg	89,403	18,560	15,788	1,883	53,172	-
Bremen	19,011	11,894	772	-	6,345	-
Hamburg	46,700	-	-	-	46,700	-
Hesse	157,481	56,510	22,994	1,132	76,845	-
Mecklenburg-West Pomerania	35,407	30,578	2,139	1,319	1,371	-
Lower Saxony	200,648	128,169	18,869	20,193	33,417	-
North Rhine-Westphalia	468,729	86,571	13,766	16,479	351,913	-
Rhineland-Palatinate	89,114	60,676	2,875	3,143	22,420	-
Saarland	19,751	9,425	1,784	-	8,542	-
Saxony	85,449	15,679	52,671	2,539	14,560	-
Saxony-Anhalt	59,569	19,486	16,761	9,204	14,118	-
Schleswig-Holstein	76,057	54,019	312	1,717	20,009	-
Thuringia	40,790	17,732	18,759	1,278	3,021	-
Total	**1,950,126**	**567,187**	**254,402**	**61,106**	**1,067,431**	**-**

Regional states such as Baden-Württemberg and North Rhine-Westphalia incinerate more than 60 % of their sewage sludge. The greatest amount of sewage sludge is used as agricultural fertilizer in Mecklenburg-West Pomerania, Rhineland-Palatinate and Schleswig-Holstein. It is noteworthy that in the regional state of Bremen, a higher proportion of sludge is used as fertilizer than is the case in the city-states of Berlin and Hamburg.

Figure 8: Percentage distribution of disposal methods in germany's regional states for 2011 [Destatis g]



Sewage sludge volumes in selected years since 1998

Around 2.2 million TDM were disposed of in 1998, since which time sludge volumes have declined continuously. By 2009, the figure was just under 2 million TDM, and only in 2004 was a slight increase of a few 10,000 TDM registered. This evolution is mainly attributable to the increased use of anaerobic sludge treatment methods, which reduce sewage sludge volumes. The graphic below illustrates this evolution.

These sewage sludge statistics are based on Federal Statistical Office (Statistisches Bundesamt) figures concerning biological sewage treatment [DESTATIS A, B, C, D, E]. In the interest of allowing for statistical comparisons, the amounts of sewage sludge that were transferred to other sewage treatment plants were subtracted from the respective tallies for 1998, 2001 and 2004, because the statistics below do not take these volumes into account. Moreover the "Interim storage" rubric no longer appears in statistical compilations of more recent vintage. Table 17 lists sewage sludge management methods and volumes over the years, and clearly shows the trend toward thermal disposal and away from farming and landfill use.

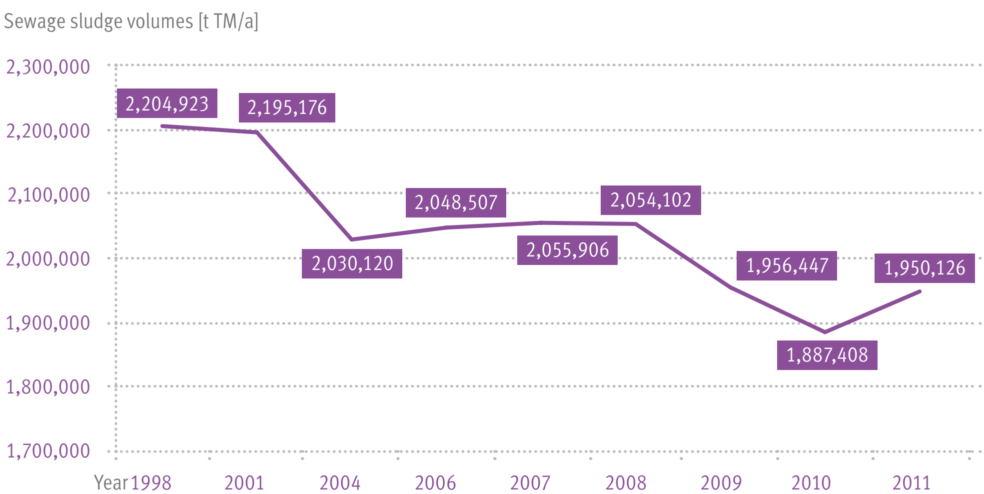
Figure 10 illustrates the various sewage sludge management methods. Between 1991 and 2009 thermal disposal of sewage sludge rose from 9 to 52.5 %, while the use of sewage sludge for landfill declined from 42 % to practically zero, owing to the ban on the use of sewage sludge for landfill that took effect on 1 June 2005. The use of sewage sludge for landscaping has likewise declined, from 628,550 TDM in 1995 to 282,455 TDM in 2009. The use of sewage sludge for farming has remained relatively constant over the years (627,989 TDM and 589,149 TDM in 2004 and 2009 respectively).

Theoretical sewage sludge incineration capacity

Transitioning from the use of sewage sludge for farming to thermal disposal of all sludge will require an expansion of incineration capacity, which according to experts' estimates was around 1.2 million TDM in Germany in 2009. Table 18 shows incineration capacity distribution in Germany.

According to one author [SCHMITZ], authorized (i. e. potential) sewage sludge incineration capacity in Germany is around

Figure 9: Sewage sludge volumes in selected years [Destatis a, b, c, d, e, f, g]



* The sewage sludge volumes indicated here for 1998, 2001 and 2004 are based on aggregate Federal Statistical Office (Destatis) figures, minus the volumes (likewise from this source) of sewage sludge handled by other sewage treatment plants.

Table 17: Sewage sludge volumes and management methods, for selected years [Destatis a, b, c, d, e, f, g]

	Total sewage sludge volume	Recycling					
		Total	Farming		Landscaping		
Year	TDM	TDM	TDM	%	TDM	%	
2011	1,950,126 [1]	882,695	567,187	29.0	254,402	13.0	
2010	1,887,408 [1]	883,659	566,295	30.0	259,312	13.7	
2009	1,956,447 [1]	927,516	589,149	30.1	282,455	14.4	
2008	2,054,102 [2]	973,997	587,832	29.0	331,556	16.0	
2007	2,055,906 [2]	1,036,844	592,561	29.0	368,912	18.0	
2006	2,048,507 [2]	1,078,264	611,598	30.0	399,712	20.0	
2004	2,260,846	1,175,694	627,989	-	492,768 [3]	-	
2001	2,429,403	1,399,456	754,837	-	583,269 [3]	-	
1998	2,459,177	1,490,074	783,662	-	628,550 [3]	-	

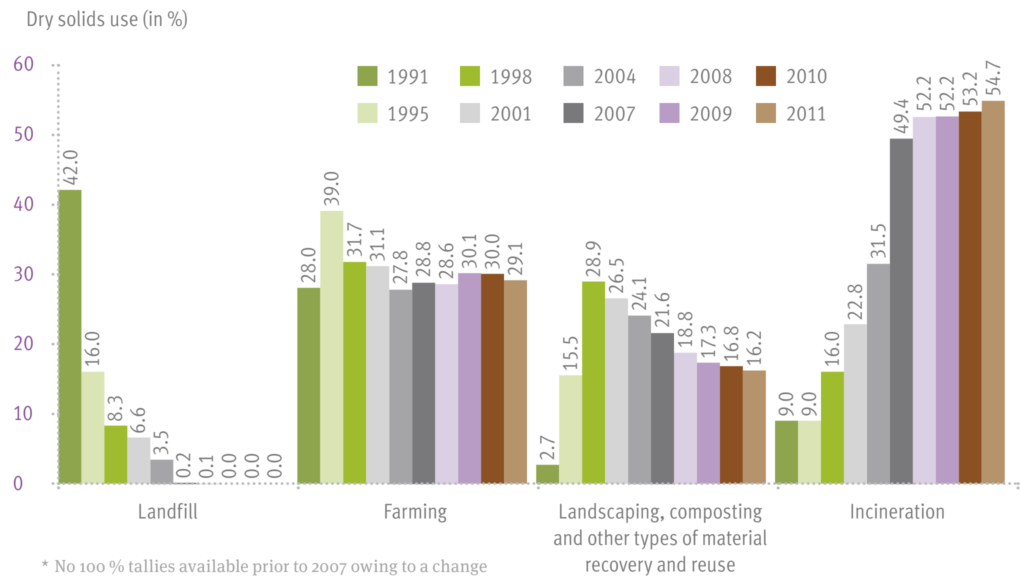
1) Including management carried out by other sewage treatment plants, but excluding sludge transferred to other such plants.
2) Excluding sludge transferred to other sewage treatment plants
3) Composting and farming uses have been combined.

Table 18: Incineration capacity in germany, 2009 [Schmitz]

Installations	Authorized capacity [in TDM/a]	Availability [in %]	Capacity use [in TDM]
EnBW power plants	69,375		
E.ON power plants	170,475		
RWE power plants	213,700		
Vattenfall power plants	126,750		
Other operators' power plants	136,200		
Total power plant capacity	716,500	70	501,550
Sewage sludge mono-incineration plants	554,750	90	499,275
Cement plants	89,000	95	84,550
Waste incineration plants	119,300	80	95,440
Total sewage sludge incineration capacity in Germany	1,479,550		1,180,815
Thermally treated sewage sludge volumes, 2009			1,028,034
Authorized sewage sludge volumes, 2009			1,956,447

			Thermal disposal		Landfill		Abgabe an andere Abwasserbehandlungsanlagen	Interim storage
	Other types of material recovery and reuse							
	TDM	%	TDM	%	TDM	%	TDM	TDM
	61,106	3.0	1,067,431	55.0	0	0		
	58,052	3.1	1,003,749	53.2	0	0	-	-
	55,912	2.9	1,028,034	52.5	897	0	-	-
	54,609	3.0	1,077,624	53.0	2,481	0	-	-
	75,371	4.0	1,015,014	49.0	4,048	0	-	-
	66,954	3.0	965,115	47.0	5,128	0	-	-
	54,937	-	711,170	-	79,052	-	230,726	64,204
	61,350	-	554,924	-	159,673	-	234,227	81,123
	77,862	-	395,859	-	205,140	-	254,254	113,850

Figure 10: Sewage sludge management, 1991–2010 [uba, Destatis f]



* No 100 % tallies available prior to 2007 owing to a change in statistical gathering methodology;

Table 19: eu sewage sludge output and management methods in eu member states as at 2010 [eurostat; milieu; wrc; rpa]

Member state	Proportion of the population with access to municipal sewage treatment plants	Total sewage sludge volume in EU member states	Proportion of total EU volume	Farming
	[%]	[mio. kg dry solids/a]	[%]	[%]
Bulgaria	45.0	47.0	0.4	50.0
Cyprus	30.0	10.8	0.1	50.0
Czech Republic	76.0	260.0	2.3	55.0
Estonia	80.0	33.0	0.3	15.0
Hungary	57.0	175.0	1.5	75.0
Latvia	65.0	30.0	0.3	30.0
Lithuania	71.0	80.0	0.7	30.0
Malta	48.0	10.0	0.1	-
Poland	64.0	520.0	4.5	40.0
Romania	29.0	165.0	1.4	0.0
Slovakia	52.0	55.0	0.5	50.0
Slovenia	57.0	25.0	0.2	5.0
Austria	93.0	273.0	2.4	15.0
Belgium	69.0	170.0	1.5	10.0
Denmark	ns	140.0	1.2	50.0
Finland	81.0	155.0	1.3	5.0
France	80.0	1,300.0	11.3	65.0
Germany	95.0	2,000.0	17.4	30.0
Greece	87.0	260.0	2.3	5.0
Ireland	84.0	135.0	1.2	75.0
Italy	ns	1,500.0	13.0	25.0
Luxembourg	95.0	10.0	0.1	90.0
The Netherlands	99.0	560.0	4.9	0.0
Portugal	70.0	420.0	3.7	50.0
Spain	92.0	1,280.0	11.1	65.0
Sweden	86.0	250.0	2.2	15.0
United Kingdom	ns	1,640.0	14.3	70.0
Total EU 15	85.9	10,093.0	87.7	*38.0
Total EU 27	71.0	11,503.8	-	*37.3

* Mean values

Incineration	Landfill	Other
[%]	[%]	[%]
0.0	30.0	20.0
0.0	40.0	10.0
25.0	10.0	25.0
-	-	85.0
5.0	10.0	5.0
	40.0	30.0
0.0	5.0	65.0
-	100.0	-
5.0	45.0	10.0
5.0	95.0	
5.0	5.0	10.0
25.0	40.0	30.0
40.0	1.0	45.0
90.0	-	-
45.0	-	-
-	-	95.0
15.0	5.0	15.0
50.0	0.0	20.0
	95.0	
	15.0	10.0
20.0	25.0	30.0
5.0		5.0
100.0		
30.0	20.0	
10.0	20.0	
5.0	1.0	75.0
20.0	1.0	10.0
*35.8	*18.3	*33.9
*23.8	*28.7	*31.3

716,000 TDM/a, whereas from a technical standpoint only 500,000 TDM/a of this capacity is usable. Mono-incineration plant capacity in 2009 was around 500,000 TDM/a, but has grown since then due to factors such as the construction of new facilities. Hence in 2009 available capacity was around 1.2 million TDM/a (see table 18). Creating adequate incineration capacity by building new incineration facilities would go a long way toward phasing out the use of sewage sludge as fertilizer.

Sewage sludge management in EU member states

Around 11.5 million TDM is generated in the EU each year. Table 19 shows the volumes of sewage sludge requiring management in the EU member states, as well as the extent to which they use the various available management methods.

Germany generates the largest amount of sewage sludge in the EU (18 %), owing to its large population and the high proportion of households that are integrated into their local municipal sewage system. The UK also generates a large amount of sewage sludge each year. The volume of sewage sludge requiring management is likely to increase, presuming that the proportion of households incorporated into public sewage systems grows. This in turn will pose a new challenge for sewage sludge management in the EU.

Footing the bill for sewage sludge management

08

Phasing out the agricultural use of sewage sludge would mainly affect sewage sludge producers, in that they would need to transport sewage sludge over longer distances than is currently the case. The presumably higher management costs resulting from this change would probably prompt an increase in taxpayers' sewage charges [FELS ET AL.].[1)]

To analyze the extent to which such higher charges would be a burden on taxpayers, in the following a somewhat simplified approach to the issue will be taken.

Wastewater management costs are currently determined by the following factors:

- Sewage treatment plant capacity use and size
- Tourism and other seasonal factors
- Management method
- Structural characteristics such as hills in the terrain along haulage routes
- Population density per meter of channel
- Subsidies [FELS ET AL.]

According to one analysis [FELS ET AL.], sewage treatment plant and channel capital investment costs have an extremely long term impact on wastewater management costs, some 75 to 85 % of which are not determined by water consumption levels. The second highest wastewater related costs are attributable to writedowns and interest, while personnel costs are estimated to account for around 14 % of total wastewater management costs. An additional 10 % of these costs is attributable to materials and energy, while treatment and disposal account for only 3 %. Hence downstream disposal has a relatively minor impact on costs, relative to other cost factors, which in turn means that adopting new wastewater management methods or tweaking new ones would have little effect on total costs and would thus result in only a negligible increase in taxpayers' sewage charges [FELS ET AL.].

As can be seen in Figure 11, at € 120 to € 375 per ton of dry solids, using sewage sludge as fertilizer is currently the most cost effective sewage management method, whereas the figure for thermal mono-incineration is € 180 to € 400. According to another analysis, wastewater management costs range from € 8 to € 130 per ton of wet substance (see Figure 20).

1) Cf. coalition agreement between CDU, CSU and SPD, 18th legislative period, p. 120: "We will phase out sewage sludge use as fertilizer and will recover phosphorous and other nutrients."

Figure 11: Sewage sludge management costs, including dewatering and haulage costs (in euros per ton of dry residue) [dwa a, b]

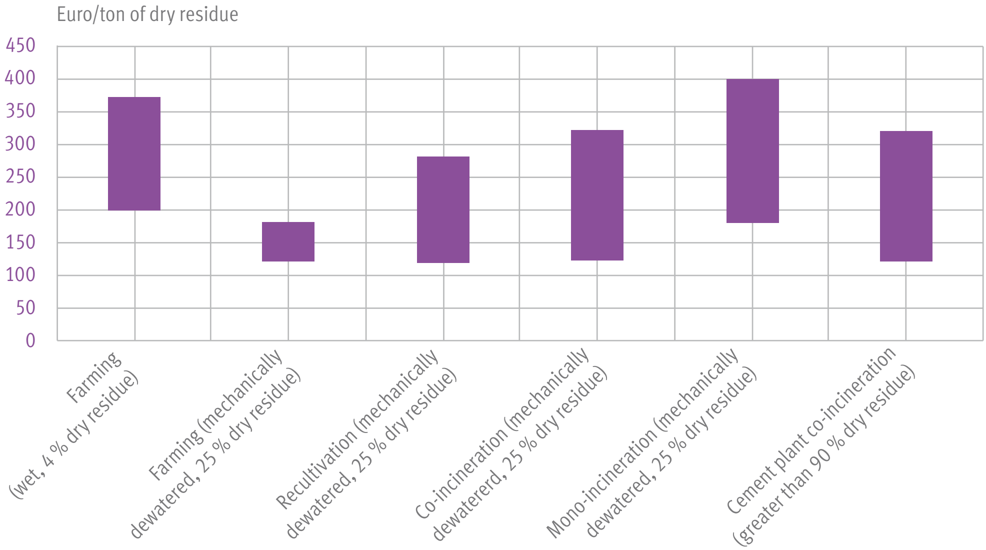


Table 20: Sewage sludge management costs [Schumacher; Nebocat]

Sewage sludge management method	Sewage sludge management costs [EUR/t of wet substance]		Sludge type
	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 % dry substance
Waste incineration plant co-incineration	80	100	Mechanically dewatered: 20–45 % dry substance
Co-incineration at coal fired power plants	75	100	Mechanically dewatered: 20–45 % dry substance
Co-incineration at lignite fired power plants	50	75	Mechanically dewatered: 20–45 % dry substance
Recultivation	30	45	Mechanically dewatered: 20–45 % dry substance
Farming, trans-regional	33	45	Mechanically dewatered: 20–45 % dry substance
Farming, regional	25	30	Mechanically dewatered: 20–45 % dry substance
Farming, liquid	8	12	Mechanically dewatered: 20–45 % dry substance

According to a study commissioned by Schleswig-Holstein's environmental ministry [FELS ET AL.], the total economic cost of using sewage sludge for agricultural use is € 7.3 million, and for thermal disposal, € 13.5 million.

According to the study [FELS ET AL.], the impact of a ban on using sewage sludge as fertilizer would be as follows: The study notes that only three per cent of total wastewater management costs are attributable to sewage sludge disposal, with the remainder stemming from plant equipment, interest and writedowns. Wastewater costs currently average around € 2 per cubic meter, and according to the study would rise by three eurocents per cubic meter. For a four-person household, this would result in an increase from € 448 to € 454 annually, i. e. € 6 per year. The increase for sewage treatment plants that do not dewater their sludge would amount to four eurocents per cubic meter. These figures were computed using a model whose results are determined by the wastewater management costs and water consumption levels that are input into the model [FELS ET AL.].

As yet unclear is the extent to which these results might apply to Germany as a whole. Phasing out agricultural use of sewage sludge would of course have advantages and disadvantages for the various actors affected. There would be an impact on sewage charges, but only a negligible one. Farmers would need to use industrial fertilizer in lieu of sewage sludge fertilizer, and this would constitute a cost disadvantage, but would reduce pollutant inputs. One of the main advantages of phosphorous recovery is that, unlike sewage sludge nutrients, those found in both mineral and recycled fertilizers have a defined composition and phytoavailability. This would promote sound, needs-oriented fertilizing practices.

The way forward

09

Owing to its extreme inhomogeneity, the quality of sewage sludge is difficult to characterize. Sewage sludge fertilizer contains the following elements, all of which are potential ecosystem pollutants: various organic substances that exert hormonal effects; various infectious agents; heavy metals; residues of pharmaceutical drugs. Sewage sludge is probably the least cost intensive source of phosphorus and nutrients of any currently available fertilizer, and also contains a high concentration of humus forming organic substances. Hence the phytoavailability of the phosphorous content of sewage sludge is mainly determined by the precipitation method used for sewage treatment. And yet, humus formation can also be attained through alternative methods such as crop rotation.

But sewage sludge fertilizer is also a pollution sink for harmful sewage components from households, businesses and diffuse sources, concerning whose environmental relevance too little is known. Notwithstanding tighter controls and stricter limit values for certain sewage sludge pollutants, uncontrolled pollutants such as hydrocarbons inevitably find their way into the soil. Incorporation of certain pollutants into the food chain cannot always be avoided, despite the fact that, for example, plants normally do not absorb organic pollutants. Nonetheless, new breakdown products of pharmaceutical drugs are discovered in sewage sludge all the time, and they are incorporated into sewage sludge via human excretion carried by the wastewater that is treated by sewage treatment plants.

Moreover, as agricultural use of sewage sludge can potentially result in the spread of pathogens to humans, animals and plants, Germany has imposed strict legal restrictions on this activity. For example, the use of sewage sludge fertilizer for fruit and vegetable crops and on permanent grassland is banned, and is subject to statutory waiting periods for use on vegetable crops, as well as for forage cultivation. The proposed amended version of the Sewage Sludge Ordinance (AbfKlärV) contains a number of new measures aimed at reducing sewage sludge related risk, such as a quality assurance system and requiring that sludge be hygienized so as to reduce pathogen concentrations. These additional sludge treatment processes will also entail additional costs that are prohibitive for smaller sewage treatment plants. In the interest of minimizing the risk that agricultural use of sewage sludge will occasion pathogen transfer, it is crucial that the new ordinance retain these tight restrictions on the agricultural use of sewage sludge. In keeping with the precautionary principle and in light of the pollutants and pathogens found in sewage sludge, the UBA deems the agricultural use of sewage sludge to be a serious public health and environmental hazard and advocates that this practice be phased out. But as sewage sludge use is an important source of phosphorous, and since use of the latter as a crop fertilizer should be intensified going forward, in tandem with the phase-out of sewage sludge as a fertilizer, the use of methods for recovering phosphorous and possibly other substances from sewage sludge needs to be stepped up. In the UBA's view, this can be achieved through direct nutrient recovery from wastewater or sewage sludge, and particularly through thermal methods that allow for the use of fly ash as fertilizer. To achieve this goal, the relevant technologies need to be optimized. In the UBA's view, there is no reason why such a recovery process could not be instituted within the next two decades.

Phasing out agricultural use of sewage sludge would mean that the organic, humus-forming substances in sewage sludge would no longer be available. In order to make up for the lack of such substances and a possible negative humus balance, it will be necessary to use substitute methods that meet the good professional practice requirements of the Federal Soil Protection Act (Bundesbodenschutzgesetz, BBodSchG). The UBA sees no reason why intelligent humus management based on crop rotation and the like, in conjunction with the planned build-out of biowaste collection and recycling, could not contribute to filling the current gaps.

Germany currently imports phosphorous, whose quality is steadily declining, however, by virtue of its high concentrations of radionucleides and heavy metals. But as phosphorous is a finite resource that is essential for human life, it must be kept in the food chain as much as possible. The current policy goal is for at least 20 % of Germany's raw phosphate to be obtained from sewage sludge or sewage sludge ash in the coming years. To this end, for many years now scientists have been developing processes that allow phosphorous to be recovered from sewage sludge and sewage sludge ash, while other processes produce ash containing phytoavailable phosphorous. But as these processes have thus far been used in only a handful of large scale installations, extensive government funding is needed in order to implement them on a large scale so as to establish them as viable solutions.

It's impossible to say which phosphorous recovery process is the "best," since the choice of the right process for a particular setting depends on myriad factors (e. g. sewage sludge ash heavy metal content; sewage treatment plant and/or mono-incineration plant operating modality and size; plant proximity to incineration and co-incineration facilities; haulage costs; phosphorous prices on world markets). That said, emphasis should be placed on the development and use of processes that pay for themselves by virtue of their high phosphorous yields.

There is no way that the currently authorized capacity of Germany's incineration facilities can compensate for the volumes of sewage sludge that are being recycled using current sewage sludge management methods. Hence the government should be working toward the construction of new incineration facilities, preferably mono-incineration plants with phosphorous recovery capacities.

Sewage sludge co-incineration has numerous relative advantages: it reduces fossil fuel use and thus carbon emissions; it is more cost effective than mono-incineration; and sewage sludge ash reduces resource use, as this material can also be used as an aggregate in cement production.

But co-incineration also removes valuable phosphorous from the food chain, because the phosphorus is either incorporated into the cement, or is irrecoverably distributed in slag and other incineration residues. Hence, wherever possible mono-incineration should be used rather than co-incineration.

A preliminary rough estimate reveals that transitioning from agricultural use of sewage sludge to the exclusive use of mono-incineration in conjunction with phosphorous recovery would engender only a minor sewage charge bump. Such a changeover would avoid soil substance and contamination risks. It would also eliminate Germany's dependence on imported phosphorous, whose quality is bound to decline, whose price will likely rise in the future, and whose contaminants need to be removed before the phosphorous can be used. And finally, such a transition would open up a new market that would very likely have a positive impact on technology transfer, whereby the requisite recovery installations and incineration capacities would also create jobs.

The main advantage of solar sewage sludge drying, which has come into increasing use in recent years, is that it entails lower capital investment and operating costs. However, drum and disc dryers currently have the largest aggregate throughput, despite the fact that the most energy saving drying method is right at the incineration site, using a process such as waste heat recovery.

Table 21 provides an overview of the pros and cons of current sewage sludge management methods.
In the UBA's view, the following measures need to be taken in order to phase out the agricultural use of sewage sludge:

- Mono-incineration capacity will need to be increased, through the construction of mono-incineration plants, which should also integrate phosphorous recovery systems. Co-incineration should only be permitted until mono-incineration capacity can be expanded to the point where green, reliable sewage sludge management is assured. Hence we regard co-incineration as a stepping stone to the exclusive use of mono-incineration.

- In creating incineration capacity, the shortest possible haulage routes should be used for sewage sludge management, so as to avoid deleterious effects on human health and the ecosphere.

- Insofar as co-incineration is preferable to mono-incineration due to the economic or logistical unfeasibility of implementing mono-incineration with a downstream phosphorus recovery system, it will be necessary to institute alternative phosphorous recovery methods such as those involving recovery not from sewage sludge ash, but rather directly from wastewater or sewage sludge. However, the phosphorus recovery potential of these methods is lower than that of phosphorous recovery from incineration ash. The low-phosphorous sewage sludge obtained using these various methods can be disposed

Table 21: Pros and cons of current wastewater management methods

	Advantages	Disadvantages
Farming, landscaping and other types of material recovery and reuse	• Allows for the use of nutrients and phosphorous • Most cost efficient of the availab-le methods	• Sewage sludge acts as a sink for pollutants and pathogens that can have deleterious environ-mental and health effects. • Pollutants accumulate in the food chain instead of being removed from it.
Mono-incineration	• Allows for long term wastewater management planning on the part of sewage treatment plant operators • Eliminates organic pollutants in sewage sludge • Allows for energy recovery • Allows for phosphorous recovery from ash • Incineration in conjunction with phosphorous recovery reduces resource use and opens up new markets	• Phosphorous recovery from ash is still a complex and cost exten-sive process. • Transport can potentially result in additional environmental pollution • The most cost intensive of the available wastewater disposal methods.
Co-incineration	• Eliminates all pathogens and organic pollutants from sewage sludge • Allows for energy recovery • Less cost intensive than mono-incineration • Reduces resource use in that it requires less fuel and is an alternative to aggregates	• Sewage sludge nutrients are unrecoverable. • Does not allow for phosphorous recovery from ash • Long haulage routes can entail deleterious environmental and health effects.

of through co-incineration. Methods that allow for phosphorous recovery from wastewater, sewage sludge and sewage sludge ash should be optimized and expanded. To this end, financial support for recovery technologies should be provided, via instruments such as subsidy programs, sewage charge revenues, sewage sludge funds, and sewage sludge compensation funds.

- The Sewage Sludge Ordinance (AbfKlärV) limit values for the transitional period in the runup to complete phase-out of agricultural sewage sludge use should be reviewed. The government also needs to determine whether, for reasons of precautionary soil and health protection, limits should be imposed on pollutants that are not currently regulated.

- The health requirements concerning sewage sludge that is used for agriculture or landscaping should be reviewed and if necessary tightened. The risk of infecting humans and livestock could be minimized through implementation of a quality management system, or alternatively through sewage sludge treatment. The current usage restrictions should be retained, at a minimum, in the new version of the Sewage Sludge Ordinance (AbfKlärV).

- Current legal requirements need to be tightened so as to ensure high yields of recovered phosphorus from the relevant substance flows such as wastewater and sewage sludge. Sewage sludge ash with a phosphorous content exceeding two per cent should be stored separately and recoverably for possible recovery, at least until adequate phosphorous recovery plants are created. To this end, additional storage capacity for this type of sewage sludge ash should be created.

- Wherever possible, processes should be used that allow for phosphorous recovery. This could be achieved, for example, by switching to a biological phosphorus elimination process, followed by reduced iron precipitation from sewage treatment plants in view of the fact that iron content determines the quality and above all the phytoavailability of recovered phosphorous.

- Sewage sludge dewatering, drying and hauling uses energy, some of which could potentially be recovered through an incineration process. Solar drying in conjunction with waste heat recovery is a sensible solution in this regard, thanks to its positive energy balance.

Ecofriendly sewage sludge management can only be achieved through intermeshing of the aforesaid measures, as this is the only way to transition to resource efficient phosphorous recovery that will also eliminate Germany’s dependence on imported phosphorous. To this end, the correct course must be set now.

Illustrations

10

Tables

11

Abbreviations

12

AbfKlärV	Sewage Sludge Ordinance (Klärschlammverordnung)
BBodSchV	Federal Soil Protection and Contaminated Sites Ordinance (Bundes-Bodenschutz- und Altlastenverordnung)
BImSchG	Federal Immission Control Act (Bundes-Immissionsschutzgesetz)
KrW-/AbfG	Closed Substance Cycle and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz)
KrWG-E	Draft of an amended version of KrW-/AbfG
DüMV	Fertilizer Ordinance (Düngemittelverordnung)
DüngG	Fertilizer Act (Düngegesetz)
DüV	Fertilizer Ordinance (Düngeverordnung)
EEG	Renewable Energy Act (Erneuerbare-Energien-Gesetz)
17. BImSchV	Implementation regulation for the BImSchG (17. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes)

Government agencies, organisations and think tanks

BMBF	German Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
BMU	Federal Ministry for the Environment (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall, e. V. (German Association for Water, Wastewater and Waste)
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization
IWW	Rheinisch-Westfälisches Institut für Wasserforschung gemeinnützige GmbH
SRU	Sachverständigenrat für Umweltfragen (German Advisory Council on the Environment)
UBA	Umweltbundesamt (Federal Environment Agency)
VDZ	Verein Deutscher Zementwerke (Association of German cement manufacturers)

Chemical compounds and elements

AOX	Absorbable organic halogen compounds
B(a)P	Benzo(a)pyrene
Ca	Calcium
$Ca(OH)_2$	Calcium hydroxide
Cd	Cadmium
CO_2	Carbon dioxide
Cr	Chrome
Cu	Copper
DEHP	Di(2-Ethyl-Hexyl)phthalate
Fe	Iron
Hg	Mercury
H_2O	Water
K	Potassium
K_2O	Potassium oxide
LAS	Linear alkyl benzene sulfonate
MAP	Magnesium ammonium phosphate
$MgNH_4PO_4$	Magnesium ammonium phosphate
MKW	Mineral oil hydrocarbon
N	Nitrogen
Na	Sodium

Ni	Nickel
P	Phosphorus
PAC	Polycyclic aromatic hydrocarbon
Pb	Lead
PBDE	Bromated diphenylether
PCB	Polychlorinated biphenyl
PCDD/PCDF	Polychlorinated dibenzo-p-dioxin and dibenzo-furan
PFC	Perfluorocarbon
P_2O_5	Phosphorous pentoxide
TBT	Tributyl tin
Zn	Zinc

Parameters

ROI	Residue on ignition [%]
LOI	Loss on ignition [%]
NCV	Net calorific value [kJ/kg, MJ/kg]
TEQ/TE	Toxicity equivalent
DM	Dry mass [mg, g, kg]
DR	Dry residue [%]
DS	Dry solids [mg, g, kg]
TS	Total solids [kg/m^3, g/L]
WC	Water content [%]

Units of measurement

a	Year
kJ	Kilojoule (103 joules)
mg	Milligram (106 kg)
MJ	Megajoule (106 joules)
m^3	Cubic meters
t	Ton (103 kg)
%	Per cent

Other abbreviations

ATS	Aerobic-thermophilic sludge stabilization
AVA	Waste incineration plant
BHKW	Cogeneration power plant
EU	European Union
EU-27	27 member states of the EU
EHEC	Enterohaemorrhagic Escherichia coli (E. coli)
EAggEC	Enteroaggrative Escherichia coli (E. coli)
HTC	Hydrothermal carbonization
ns	Not specified

Acknowledgements

13

We would like to extend our particularly heartfelt gratitude to all installation operators who provided us with data concerning their installations, and to the DWA for its support. We would also like to thank Ulrich Jacobs from EcoSystemsInternational GmbH and Matthias Jasper from IAA Ingenieurgesellschaft für Abfall und Abwasser mbH & Co. KG for their invaluable help.

Bibliography

14

Bibliography for the section titled "What is sewage sludge?"
[ABFKLÄRV] Klärschlammverordnung (AbfKlärV); Ausfertigungsdatum: 15.04.1992; Zuletzt durch Artikel 9 der Verordnung vom 9. November 2010 (BGBl. I S. 1504) geändert

Bibliography for the section titled "Where does sewage sludge occur?"
[BISCHOFSBERGER ET.AL.] Wolfgang Bischofsberger, Norbert Dichtl, Karl-Heinz Rosenwinkel, Carl Franz Seyfried, Botho Böhnke (Hrsg.): Anaerobtechnik, 2. Auflage; Springer-Verlag Berlin Heidelberg, 2005

Bibliography for the following sections: "Composition of sewage sludge;" "Heavy metals in sewage sludge;" "Organic compounds;" "Pathogens and health requirements"
[KOPP] Dr.-Ing Julia Kopp: Eigenschaften von Klärschlamm; Tagungsbeitrag VDI-Fachkonferenz Klärschlammbehandlung; 27–28.Oktober 2010, Offenbach

[RÄBIGER] Prof. Dr.-Ing. N. Räbiger: Projekt wasserwissen. Institut für Umweltverfahrenstechnik; Online abgerufen am/unter: 25.02.2011
http://www.wasser-wissen.de/

[GUJER] Prof. Dr. Willi Gujer; Siedlungswirtschaft; Institut für Umweltingenieurwissenschaften ETH Zürich, Springer-Verlag Berlin Heidelberg 1999, 2002 und 2007

[OLIVA ET.AL.] Judith Oliva, Antonia Bernhardt, Hubert Reisinger, Manfred Domenig, Hans-Jörg Krammer; Klärschlamm-Materialien zur Abfallwirtschaft; Umweltbundesamt AT; Report; Klagenfurt 2009

[DWA] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.; Entwurf zum Merkblatt DWA-M 387 Thermische Behandlung von Klärschlämmen: Mitverbrennung; Hennef; 2009

[FRAGEMANN] Hans-Jürgen Fragemann, Dr. Dietmar Barkowski; Klärschlammbelastungen mit organischen Schadstoffen – Ergebnisse der landesweiten Untersuchungen in Nordrhein-Westfalen; Vortrag auf Expertentagung in Bonn am 6. Dezember 2006
[BMU] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit; Klärschlammverwertung in der Landwirtschaft; Internetseite; Online abgerufen am/unter: 16.02.2011
http://www.bmu.de/abfallwirtschaft/doc/40230.php

Bibliography for the section titled "Pharmaceutical drug residues in sewage sludge"

[EIBISCH], Eibisch, Nina: Einträge und Verhalten von Arzneimittelrückständen in Böden. Technische Universität Freiberg 11.01.2006

[GOLET ET.AL.] Golet, E. M.; Xifra, I.; Siegrist, H.; Alder, A. C. und W. Giger: Environmental Exposure of Fluorquinolone Antibacterial Agents form Sewage to Soil. Environmental Science & Technology Vol. 37, No. 15, p. 3243-3249

[GROTE ET. AL] Grote, M.; Didem, H. Y. und R. Michel: Antibiotikaspuren im Getreide? – Analytik, Befunde, Bewertung. Vortrag 59. Tagung der Getreidechemie 18.–19.06.2008

[BERGMANN ET. AL.] Bergmann, A.; Fohrmann, R. und F.-A. Weber: Zusammenstellung von Monitoringdaten zu Umweltkonzentrationen von Arzneimitteln. Gutachten im Auftrag des Umweltbundesamtes FKZ 360 14 013; 2010

[RÖNNEFAHRT] Rönnefahrt, Ines: Humanarzneimittel in der Umwelt – Neue Ansätze in der Risikobewertung in der EU. Jahrestagung 2002 Umweltchemie und Ökotoxikologie, Tagungsband, 189.

[SRU] Sachverständigenrat für Umweltfragen: Arzneimittel in der Umwelt. Stellungnahme Nr. 12. April 2007

[STUMPE] Stumpe, B: Mineralization and sorption of the steroid hormones 17b-estradiol, estrone, 17a-ethinylestradiol and testosterone in natural and organic waste amended agricultural soils. Dissertation Ruhr Universität Bochum. 2010

[UBA] Umweltbundesamt: Hygienische Fragen der Umwelttechnik – Abwasserhygiene; in: Jahresbericht 1997 Umweltbundesamt S. 100–101

Bibliography for the section titled "Sewage sludge treatment"

[GUJER] Prof. Dr. Willi Gujer: Siedlungswirtschaft; Institut für Umweltingenieurwissenschaften ETH Zürich, Springer-Verlag Berlin Heidelberg 1999, 2002 und 2007

[BRANDT] Brandt, Simone; Nutzung von Klärschlamm als Rohstoffquelle – Akuteller Stand in Deutschland und in der Europäischen Union sowie Perspektiven für die Zukunft; Masterarbeit, 23. Februar 2011; Berlin http://www.andrakar.com/brandt/Rohstoffquelle_Klaerschlamm_Perspektiven_Br0211.pdf

[BMU] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit; Klärschlammverordnung (AbfKlärV) – Zweiter Arbeitsentwurf für eine Novelle der Klärschlammverordnung vom 20.08.2010; Online abgerufen am/unter: 12.02.2011 http://www.bmu.de/abfallwirtschaft/downloads/doc/46373.php

Bibliography for the section titled "Sewage sludge drying"

[LEHRMANN] Lehrmann, Falko: Stand und Perspektiven der thermischen Klärschlammentsorgung. Vortrag zur VDI-Fachkonferenz Klärschlammbehandlung; Offenbach; 27 und 28. Oktober 2010

[Beckmann] Prof. Dr.-Ing. Beckmann, Michael: Stoff- und Energiebilanzen bei der Verbrennung von Klärschlamm; In: Sammelband zur VDI-Fachkonferenz "Klärschlammbehandlung – Technologie, Wertstoffrückgewinnung, Entwicklung" (Hrsg. VDI); Oktober 2010

[Hepke] Dr.-Ing. Hepke, Hans-Jörg: Thermische Verfahren der Klärschlammtrocknung; Tagungsbeitrag zur VDI-Fachkonferenz Klärschlammbehandlung am 27. und 28. Oktober 2010 in Offenbach

[Felber/Fischer]. Felber, H., Fischer, M.: Klärwärter-Taschenbuch. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. 16. Auflage 2010. 2. F. Hirthammer Verlag München/Oberhaching.

Bibliography for the section titled "Cement plant co-incineration"

[VDZ A] Verein Deutscher Zementwerke e. V.: Environmental Data of the German Cement Industry 2009; Düsseldorf August 2011

[VDZ B] Verein Deutscher Zementwerke e. V.: Environmental Data of the German Cement Industry 2009; Düsseldorf Juli 2010

[VDZ C] Verein Deutscher Zementwerke e. V.: Umweltdaten der deutschen Zementindustrie 2008; Düsseldorf August 2009

[VDZ D] Verein Deutscher Zementwerke e. V.: Umweltdaten der deutschen Zementindustrie 2007; Düsseldorf September 2008

[VDZ E] Verein Deutscher Zementwerke e. V.: Umweltdaten der deutschen Zementindustrie 2006; Düsseldorf September 2007

[VDZ F] Verein Deutscher Zementwerke e. V.: Umweltdaten der deutschen Zementindustrie 2005; Düsseldorf September 2006

[VDZ G] Verein Deutscher Zementwerke e. V.: Umweltdaten der deutschen Zementindustrie 2004; Düsseldorf September 2005

[VDZ H] Verein Deutscher Zementwerke e. V.: Umweltdaten der deutschen Zementindustrie 2003; Düsseldorf November 2004

Bibliography for the section titled “Agricultural use of sewage sludge”

[ABD EL-SAMIE] Abd El-Samie IMF: Phosphordüngewirkung von Klärschlämmen aus Klärwerken mit Phosphateliminierung durch Eisensalze. Dissertation, Georg-August-Universität Göttingen

[BRANDT] Brandt, Simone; Nutzung von Klärschlamm als Rohstoffquelle – Akuteller Stand in Deutschland und in der Europäischen Union sowie Perspektiven für die Zukunft; Masterarbeit, 23. Februar 2011; Berlin http://www.andrakar.com/brandt/Rohstoffquelle_Klaerschlamm_Perspektiven_Br0211.pdf

[LFL] Bayerische Landesanstalt für Landwirtschaft (LfL): Landwirtschaftliche Verwertung von Klärschlamm. 2006; http://www.LfL.bayern.de

[BERGS] Dr. Bergs, Claus-Gerhard: Neuerungen im Abfall- und Düngerecht – Auswirkungen auf die Verwertung und Beseitigung von Klärschlämmen, Vortrag VDI-Fachkonferenz Offenbach, 27.10.2010

[KRATZ S, SCHNUG] Kratz, Sylvia; Schnug, Ewald: Agronomische Bewertung von Phosphatdüngern, Vortrag bei Symposium: Ressourcen schonender Einsatz von Phosphor in der Landwirtschaft, Braunschweig, 10./11.11.2008, www.jki.de

[RUPPE ET. AL.] Ruppe A, Bahr C, Pohl A: Fortschreibung von Beurteilungsmaßstäben für den Wirkungspfad Boden-Pflanze: Methodik zur flächenrepräsentativen Erfassung pflanzenverfügbarer Stoffgehalte in unbelasteten Böden und Stoffgehalten in Nahrungs-und Futtermittelpflanzen. Forschungsbericht; FKZ 206 74 200, Umweltbundesamt, Dessau (Veröffentlichung in Vorbereitung), 2009.

Bibliography for the section titled “Sewage sludge quantities, management and recycling”

[SCHMITZ] Erich Schmitz: Perspektiven der Mitverbrennung von Klärschlämmen; 6. Klärschlammtage der DWA; Fulda, 12 Mai 2009

[DESTATIS A] Statistisches Bundesamt: Klärschlamentsorgung aus der biologischen Abwasserbehandlung 2006; online abgerufen am/unter: 24.02.2011 http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Umwelt/UmweltstatistischeErhebungen/Wasserwirtschaft/Tabellen/Content100/Klaerschlamm,templateId=renderPrint.psml

[DESTATIS B] Statistisches Bundesamt: Klärschlamentsorgung aus der biologischen Abwasserbehandlung 2007; online abgerufen am/unter: 24.02.2011 http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Umwelt/UmweltstatistischeErhebungen/Wasserwirtschaft/Tabellen/Content100/Klaerschlamm2007,templateId=renderPrint.psml

[DESTATIS C] Statistisches Bundesamt: Klärschlamentsorgung aus der biologischen Abwasserbehandlung 2008; online abgerufen am/unter: 24.02.2011 http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Umwelt/UmweltstatistischeErhebungen/Wasserwirtschaft/Tabellen/Content100/Klaerschlamm2008,templateId=renderPrint.psml

[DESTATIS D] Statistisches Bundesamt: Klärschlammentsorgung aus der biologischen Abwasserbehandlung 2009; online abgerufen am/unter: 24.02.2011 http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Umwelt/UmweltstatistischeErhebungen/Wasserwirtschaft/Tabellen/Content100/Klaerschlamm2009,templateId=renderPrint.psml

[DESTATIS E] Statistisches Bundesamt: öffentliche Wasserversorgung und Abwasserbeseitigung; Fachserie 19, Reihe 2.1, Umwelt; 2004

[DESTATIS F] Statistisches Bundesamt: Klärschlammentsorgung aus der biologischen Abwasserbehandlung 2010; online abgerufen am/unter: 01.02.2012 http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Umwelt/UmweltstatistischeErhebungen/Wasserwirtschaft/Tabellen/Content100/KlaerschlammVerwertArt2010,templateId=renderPrint.psml#Fussnote5

[DESTATIS G] Statitisches Bundesamt: Klärschlammverwertung aus der biologischen Abwasserbehandlung 2011, online abgerufen am/unter: 14.08.2013 https://www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Umwelt/UmweltstatistischeErhebungen/Wasserwirtschaft/Tabellen/KlaerschlammVerwertArt2011.html;jsessionid=404E90E0D27330D202F7A246B409731C.cae3

[UBA] Umweltbundesamt: Daten zur Umwelt; Klärschlammentsorgung; Online abgerufen am/unter: 24.02.2011
http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/document/downloadImage.do?ident=19543

Bibliography for the section titled "Sewage sludge management in EU member states"

[MILIEU; WRC; RPA] Milieu Ltd, WRc and RPA Environmental, economic and social impacts of the use of sewage sludge on land; Final Report for the European Commission; Part I: Overview Report;

[EUROSTAT] Gesamtklärschlammaufkommen aus der öffentlichen Abwasserbehandlung. Online abgerufen am/unter: 01. März 2011, http://epp.eurostat.ec.europa.eu/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00030&language=de

Bibliography for the section titled "Phosphorous recover"

[SCHNUG/PINNEKAMP] Schnug, Ewald und Pinnekamp, Johannes (TV Beitrag 2008); online abrufbar unter: http://www.3sat.de/mediathek/mediathek.php?obj=10256

[VACCARI] Vaccari, David A.: Phosphorus: A Looming Crisis, Scientific American, 2009 Nr. 6,
S. 54–59 Droht ein Mangel an Phosphor? Spektrum der Wissenschaft, 2009 Nr. 11, S. 78–83

[SCHEIDIG] Dr.-Ing Scheidig,. Klaus: Wirtschaftliche und energetische Aspekte des Phosphor-Recyclings aus Klärschlamm, KA Korrespondenz Abwasser, Abfall, 2009 (56) Nr. 11 S. 1,138–1,146

[RÖMER ET.AL.] Römer, Wilhelm; Gründel, Michael; Friedrich Güthoff, Friedrich: U-238, U-235, Th-232 und Ra-226 in einigen ausgewählten Rohphosphaten, Phosphatdüngern, Boden- sowie Pflanzenproben aus einem P-Düngungsversuch, Journal für Kulturpflanzen, 2010 (62) Nr. 6 S. 200–210

[CORDELL ET. AL.] Cordell, Dana; Neset, Tina; White, Stuart; Drangert, Jan – Olof; Mavinic, D., Ashley, K.; Koch, F.: Preferred future phosphorus scenarios: A framework for meeting longterm phosphorus needs for global food demand, International Conference on Nutrient Recovery from Waste Water Streams, Vancouver May 10th–13th , 2009, IWA Publishing, London, New York (ISBN 1843392321)

[FAO] Food and Agriculture Organization of the United Nations; Current world fertilizer trends and outlook to 2011/12

[U.S. GEOLOGICAL SURVEY] U.S. Geological Survey, Mineral Commodity Summaries (Januar 2013)

[IWMI] International Water Management Institute: Comprehensive Assessment of water management in agriculture,2006; online abrufbar unter www.iwmi.cgiar.org\assessment

[WRAP] Waste & Resources Action Programme: The food we waste, Food waste report v2, 2008

[FRAITURE] Fraiture, Charlotte de: Future Water Requirements for Food – Three Scenarios, International Water Management Institute (IWMI), SIWI Seminar: Water for Food, Bio-fuels or Ecosystems? in World Water Week 2007, Stockholm August 12th–18th 2007

[LUNDQVIST ET. AL.] Lundqvist, J., C. de Fraiture and D. Molden: Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain, SIWI Policy Brief, Stockholm International Water Institute

[WHO] World Health Organization: Obesity and overweight, Fact sheet number 311, World Health Organisation Global Strategy on Diet, Physical Activity and Health, Genf

[Kabbe/Jakob] Kabbe, Christian und Dr. Jakob,Wolfgang, Process to recover phosphate from meat and bone meal with utilisation of waste heat, International Conference on Nutrient Recovery from Waste Water Streams, Vancouver May 10–13, 2009, IWA Publishing, London, New York (ISBN 1843392321)

[Sartorius] Sartorius, Christian; Technologievorausschau und Zukunftschancen durch die Entwicklung von Phosphorrecyclingtechnologien in Deutschland; Tagungsbeitrag zur Abschlusspräsentation im Zuge der Förderinitiative "Kreislaufwirtschaft für Pflanzennährstoffe, insbesondere Phosphor"; September 2011; Berlin

[SWEDISH EPA] Swedish Environmental Protection Agency, A Strategy for Sustainable Waste Management – Sweden's Waste Plan, Stockholm 2005 (ISBN: 91-620-1249-5)

[von HORN ET.AL.] Dr. von Horn, Jana; Dr. Dr. Sartorius, Christian; Tettenborn, Felix: Technologievorausschau für Phosphorrecyclingtechnologien (Arbeitspaket 6) Im Rahmen des Projektes „Phosphorrecycling – Ökologische und wirtschaftliche Bewertung verschiedener Verfahren und Entwicklung eines strategischen Verwertungskonzeptes für Deutschland" (PhoBe) im Auftrag des Bundesministeriums für Bildung und Forschung (FKZ 02WA0807);2010

Bibliography for the section titled "Who foots the bill for sewage sludge management?"

[FELS ET.AL] Dr. Fels, Thomas; Dr. Heid, Markus und Dr. Kersten, Malte: Ermittlung der Kosten, die mit einem Ausstieg/Teilausstieg aus der landwirtschaftlichen Klärschlammverwertung verbunden wären; Studie für das Ministerium für Umwelt, Naturschutz und Landwirtschaft des Landes Schleswig-Holstein; witra-kiel GbR; Universität Kiel; 2005

[SCHUMACHER; NEBOCAT] Werner Schumacher und Günter Nebocat: Kosten der Ersatzbrennstoffverbrennung in Monoverbrennungsanlagen; Tagungsbeitrag; Energie aus Abfall Band 6; TK Verlag, Neuruppin; 2009

[DWA A] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.; Arbeitsgruppe AK-13.4: Klärschlammentsorgungskonzepte; Fachbeitrag für Korrespondenz Abwasser, Abfall; Heft 3/10; Hennef; 2010

[DWA B] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.; DWA-Positionen; Position zur Klärschlammentsorgung; Hennef; 2010

[DESTATIS A] Statistisches Bundesamt Deutschland: Durchschnittliche Kosten für die Entsorgung von Abwasser aus privaten Haushalten 2005 bis 2007; online abgerufen am/unter: 14.02.2011, http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Umwelt/UmweltstatistischeErhebungen/Wasserwirtschaft/Tabellen/Content75/Durchschnittskosten__Abwasser__Haushalte.psml

[DESTATIS B] Statistisches Bundesamt Deutschland: Gebiet und Bevölkerung – Fläche und Bevölkerung. online abgerufen am/unter: 14.02.2011 http://www.statistik-portal.de/Statistik-Portal/de_jb01_jahrtab1.asp

[DESTATIS C] Statistisches Bundesamt Deutschland: Klärschlammentsorgung aus der biologischen Abwasserbehandlung 2007. online abgerufen am/unter: 14.02.2011
http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Umwelt/UmweltstatistischeErhebungen/Wasserwirtschaft/Tabellen/Content100/Klaerschlamm2007,templateId=renderPrint.psml

Bibliography for Appendix II
(Sewage sludge management legislation)

für die Klärschlammentsorgung“: [17.BIMSCHV] Siebzehnte Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über die Verbrennung und die Mitverbrennung von Abfällen – 17. BImSchV); Ausfertigungsdatum: 23.11.1990; In der Fassung der Bekanntmachung vom 14. August 2003 (BGBl. I S. 1633), die durch Artikel 2 der Verordnung vom 27. Januar 2009 (BGBl. I S. 129) geändert worden ist.

[ABFKLÄRV] Klärschlammverordnung (AbfKlärV); Ausfertigungsdatum: 15.04.1992; zuletzt geändert durch Artikel 9 der Verordnung vom 9. November 2010 (BGBl. I S. 1504)

[BBODSCHV] Bundes-Bodenschutz- und Altlastenverordnung (BBodSchV); Ausfertigungsdatum: 12.07.1999; zuletzt geändert durch Artikel 16 des Gesetzes vom 31. Juli 2009 (BGBl. I S. 2585)

[BMU 2011B] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit; Klärschlammverordnung (AbfKlärV) – Arbeitsentwurf für einen Referentenentwurf; Einer Verordnung zur Neuordnung der Klärschlammverwertung auf Böden; Stand 01.06.2011

[BRANDT] Brandt, Simone; Nutzung von Klärschlamm als Rohstoffquelle – Akuteller Stand in Deutschland und in der Europäischen Union sowie Perspektiven für die Zukunft; Masterarbeit, 23. Februar 2011; Berlin
http://www.andrakar.com/brandt/Rohstoffquelle_Klaerschlamm_Perspektiven_Br0211.pdf

[DÜMV] Verordnung über das Inverkehrbringen von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln (Düngemittelverordnung – DüMV); Ausfertigungsdatum: 16.12.2008; zuletzt geändert durch Artikel 1 der Verordnung vom 14. Dezember 2009 (BGBl. I S. 3905)

[DÜNGG] Düngegesetz (DüngG); Ausfertigungsdatum: 09.01.2009; zuletzt geändert durch Artikel 10 des Gesetzes vom 9. Dezember 2010 (BGBl. I S. 1934)

er die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen (Düngeverordnung – DüV); Ausfertigungsdatum: 10.01.2006; In der Fassung der Bekanntmachung vom 27. Februar 2007 (BGBl. I S.221), zuletzt geändert durch Artikel 18 des Gesetzes vom 31. Juli 2009 (BGBl. I S. 2585)

[EWG] Richtlinie 86/278/EWG des Rates vom 12. Juni 1986 über den Schutz der Umwelt und insbesondere der Böden bei der Verwendung von Klärschlamm in der Landwirtschaft

[KRW/ABFG] Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Beseitigung von Abfällen (Kreislaufwirtschafts- und Abfallgesetz – KrW-/AbfG) vom 27. September 1994 (BGB. I S. 2705); zuletzt geändert durch Artikel 8 des Gesetzes vom 11. August 2010 (BGBl. I S. 1163)

[KRWG] Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen (Kreislaufwirtschaftsgesetz – KrWG); Bundesgesetzblatt Jahrgang 2012 Teil I Nr. 10, ausgegeben zu Bonn am 29. Februar 2012.

Appendix I

15

General						
Site	Regional state	Installation operator	Capacity	Dry residue	Capacity	Commissioning
			[t/a]	[%]	[t TS/a]	[-]
Altenstadt	BY	Emter GmbH	160,000	25–30	55,000	2008
Balingen	BW	Zweckverbrand Abwassserreinigung Balingen	1,500	75–80	1,200 (Erweiterung auf 2,400)	2002
Berlin-Ruhleben	BE	Berliner Wasser Betriebe	325,000	26	84,100	1985
Bitterfeld-Wolfen*	ST	Gemeinschaftsklärwerk Betriebsgesellschaft mbH & Co. KG Greppin	50,700	25–90	15,200	1997
Bonn	NW	Tiefbauamt Bonn	29,100	23.5	8,000	1981
Bottrop	NRW	Emschergenossenschaft	110,000	40	44,000	1991
Dinkelsbühl	BY	KSV GmbH	21,425	25–30	5,326	2008
Düren	NW	Wasserverband Eifel-Rur	35,000	40	14,000	1975
Elverlingsen-Werdohl	NW	WFA E Elverlingsen GmbH	200,000	28–32	61,320	2002
Frankfurt am Main	HE	Stadtentwässerung Frankfurth am Main	188,000	28	52,560	1981
Gendorf*	BY	Infraserv	40,000	20–35	10,000	2006
Hamburg	HH	VERA Klärschlammverbrennung GmbH	197,100	40	78,840	1997
Herne	NW	BAV Aufbereitung Herne GmbH	50,000	25–90	22,200	1990
Karlsruhe	BW	Stadt Karlsruhe	80,000	25	20,000	1982
Lünen	NRW	Innovatherm GmbH	235,000	25–95	95,000	1997
München	BY	Münchner Stadtentwässerung	88,000	25	22,000	1997
Stuttgart	BW	Tiefbauamt Stuttgart	130,000	25	32,000	2007
Neu-Ulm	BY	Zweckverband Klärwerk Steinhäule	64,000	25	16,000	1979
Wuppertal	NW	Wupperverband	128,000	25	32,000	1977
Sande/Wilhelmshaven	NS	Spitz GmbH			2,250	
Straubing	BY	Huber SE	9,000 t/a dewatered sewage sludge	28	2,500 t DR/a	2012
Mannheim	BW	Kopf	10,800	ns	ns	2010

* Municipal and industrial sewage sludge incineration (hence indicated in table 23).

Table 22: Technical data for municipal sewage sludge mono-incineration plants as at 2012 [proprietary data]

		Input		Sludge dewatering	
	Operating hours, 2009	Sludge makeup (raw sludge/ digested sludge)	Sludge type	Dewatering installation	Total (mean) residual water content
	[h/a]	[-]	[-]	[-]	[%]
	7,000	ns	Municipal sewage sludge	Decanter	-
	ns	Digested sludge	Sewage sludge	Chamber filter press	69
	8,760	Raw sludge, 3.5 % dry solids	Sewage sludge	Centrifuge	74
	7,738	Raw sludge	Industrial and municipal sewage sludge	Centrifuge	74
	6,854	Digested sludge	Sewage sludge, floating sludge	Centrifuge	76.5
	7,800	Digested sludge	Sewage sludge	Membrane filter press	60
	4,309 (shut down since 2010)	gefault	Municipal sewage sludge	ns	72
	8,400	2009: digested sludge (including digested sludge as from 2010)	Sewage sludge	Centrifuge	74.00
	7,313	Digested sludge	Sewage sludge	KFP ZF	68–72
	Average 6,851 per line, total of 20,552.5 for three lines in operation simultaneously	Raw sludge	Sewage sludge	Centrifuge	71
	ns	Raw sludge	Industrial and municipal sewage sludge	Decanter	26
	23,463 h=3 lines = 7,821 per line	Digested sludge	Sewage sludge	Centrifuge	78
	ns	Digested sludge	Sewage sludge	-	10–75
	6,500	Rohschlamm	Sewage sludge, screen debris, trapped grease	Centrifuge	75
	7,850	Digested sludge	Sewage sludge, Filter cake	Centrifuge, Membrane filter press	60
	8,430	Digested sludge	Sewage sludge	Centrifuge	72
	4,809 (Linie 3)	Raw sludge, excess sludge, digested sludge	Sewage sludge, screen debris, trapped grease	Centrifuge	75
	ns	Raw sludge/Digested sludge	Sewage sludge, screen debris, trapped grease	Centrifuge	75
	8,586	Digested sludge	Sewage sludge	Centrifuge, Membrane filter press	75
	Shut down	Digested sludge	Sewage sludge	External	-
	7,500 (Design capacity)	Digested sludge	Sewage sludge, Screen debris	Centrifuge	72
	7,000 (planned)	Digested sludge	Sewage sludge, Screen debris		

General	Drying			
Site	Unit	Residual water content after drying	Incineration technology	Incineration units
	[-]	[%]	[-]	[-]
Altenstadt	Thermal oil circuit	25–30	Grate firing	2 furnaces
Balingen	Solar drying	20–25	Fluidized bed gasification	1 gasification
Berlin-Ruhleben	-	-	Stationary fluidized bed	3
Bitterfeld-Wolfen*	Disc dryer	55	Stationary fluidized bed	1
Bonn	-	-	Stationary fluidized bed	2
Bottrop	-	-	Stationary fluidized bed	2
Dinkelsbühl	Belt dryer	<10	Pyrobuster technology	1
Düren	Disc dryer	60	Stationary fluidized bed	1
Elverlingsen-Werdohl	-	-	Stationary fluidized bed	1
Frankfurt am Main	Fluidized bed	ca. 30 (Eintritt in Wirbelschicht)	Fluidized bed	4
Gendorf*	Disc dryer	50	Fluidized bed	1
Hamburg	Disc dryer	58	Stationary fluidized bed	3
Herne	-	-	Stationary fluidized bed	1
Karlsruhe	Disc dryer	55	Stationary fluidized bed	2 (1+1)
Lünen	-	-	Fluidized bed	1
München	Contact disc dryer	55	Stationary fluidized bed	2
Stuttgart	Disc dryer	55	Stationary fluidized bed	2
Neu-Ulm	Thin layer dryer	60	Stationary fluidized bed	2
Wuppertal	Thin layer dryer	55	Stationary fluidized bed	2
Sande/Wilhelmshaven	Fluidized bed dryer	15	Cycloid combustion chamber	1
Straubing	Belt dryer	35	Ash incineration	1
Mannheim	Drum dryer		Fluidized bed gasification	1

* Municipal and industrial sewage sludge incineration (hence indicated in table 23).

Incineration				
Mean annual sewage sludge calorific value	Mean theoretical capacity per unit	Amount incinerated in 2009	Incinerator manufacturer	Additional fuel
[kJ/kg]	[t TS/h]	[t TS/a]	[-]	[-]
8,000	je 2,5 t TM/h	23,000		
	0.18		Kopf	Digester gas
ca. 17 MJ/kg TR	3.20	41,128	Uhde	Fuel oil
5,950 or 10,200 kj/kg dry solids	2.00	10,262	Uhde	Natural gas
	1.42	6,600	Raschka	Digester gas, Fuel oil
4,500	3.00	46,000	Raschka	Fuel oil
10.9/11.8	0.60	1,290	Eisenmann AG	Fuel oil/Propane
2009: 14,604 KJ/kg dry solids, only raw sludge incinerated (2010: raw sludge volume 12,820, digested sludge 3,700 KJ/kg dry solids)	1.75	10,924	Lurgi	Natural gas
1,000 in OS; 10,000 – 13,000 kJ/kg dry solids	7.00	185,421 t/a	TKEC	Coal/natural gas/fuel oil/SBS
17,000 kJ/kg TS; 3,100 kJ/kg damp	2.00	33,946	Lurgi	Fuel oil (Light oil)
	1.25			Natural gas
3,650, or 13 MJ/kg dry residue in 2009; the figure for 2010 was 13.6 MJ/kg dry residue	3.40	60,256	AE & E	Fuel oil, Digester gas
	8.00		Raschka	Fuel oil
14,000–15,000	1.90/2.70	13,000	Raschka	Fuel oil
4,000	13.00	89,000	Raschka	Fuel oil
4,500/10,000	3.00	21,421	Raschka	Faulgas
13.8 MJ/kg TS	4.00	22,700	Bamag	Digester gas, Fuel oil
ns	2.00	16,389	Thyssen	Fuel oil
Mean annual (weighted) calorific value: 12,100 kJ/kg dry solids; range: 9,300 to 14,370 kJ/kg dry solids	4.60	29,557	Thyssen	Fuel oil
	0.30	0,00	Steinmüller	Natural gas
7,000 kJ/kg	530 kg/h	3,500 t/a	Fa. Zauner	
			Kopf	

General	Waste heat recovery					
Site	Aggregat	Manufacturer	Mean steam parameter	Raw electrical output	Energy use	Flue gas cleaning lines
	[-]	[-]	[bar/°C]	[MW]	[-]	[-]
Altenstadt	Boiler with thermal oil			-	Heat for drying	1
Balingen	CHP plant	Kopf/EAG	-		Heat, Electricity	1
Berlin-Ruhleben	Water-tube boiler (Natural circulation)	L. & C. Steinmüller	46/460	1 × 2.8/ 2 × 2.0	Electricity, Heat	3
Bitterfeld-Wolfen*	Natural circulation	Bertsch	10/180	-	Heat	1
Bonn	Forced-circulation waste heat boiler	Stahl	10/180		Heat, Electricity	2
Bottrop	Forced-circulation boiler	Raschka	35/400	3.5	Heat, Electricity	2
Dinkelsbühl	Waste heat steam boiler	HTA GmbH	10/184	ns	Drying	1
Düren	Heat transfer oil waste-heat boiler	Ohl	-		Heat	1
Elverlingsen-Werdohl	Steam boiler	Bertsch	17/320		Auxiliary steam for power plant use	1
Frankfurt am Main	Steam boiler	Lentjes	38/380	3	Heat, Electricity	4
Gendorf*			20/215			
Hamburg	Natural-circulation boiler	AE & E	40/400	32 ST and HRSG	Heat, Electricity	3
Herne	Coal slurry rotary drier	Hoffmeyer	-		Heat	2
Karlsruhe	Natural-circulation boiler	Raschka, Oschatz	25/300 25/300		Heat, Electricity	2
Lünen	Natural-circulation boiler	Noell-KRC	40/400	8.5	Electricity	1
München	Waste-heat boiler	Wamser	40/400	0.269869514	Heat for plant use, Electricity	4
Stuttgart	Waste-heat boiler	Bertsch	63/410	1.2 MW	Heat, Electricity	2
Neu-Ulm	Water-tube boiler	UMAG, Baumgarte	24/250 40/400	ns	Heat, Electricity	4
Wuppertal	Natural-circulation waste heat boiler	Blohm + Voss	31/355	---	Heat, Electricity	2
Sande/Wilhelmshaven	Natural-circulation waste heat boiler	Wulff	19/210		Heat	4
Straubing	Micro-gas turbine heat exchanger	Turbine: Turbec		80 kW el.	800 kW therm.	1
Mannheim	CHP plant			3.6 MW	Heat	1

* Municipal and industrial sewage sludge incineration (hence indicated in table 23).

	Waste gas scrubbing				Slag and ash recycling and management	
	Dust collector	Additional waste gas scrubbing			Recycling/elimination in	Volume
	[-]	[-]	[-]	[-]	[-]	[t/a]
	Cyclone and cloth filter downstream from entrained flow adsorber	Denitrogenation (SNCR)	Entrained flow adsorber	Two-phase scrubber	Mainly used for farming, and to a lesser extent in asphalt plants	8,500
	Cyclone and ceramic filter	Wet scrubbing	Tar condensation		Asphalt plant	500
	Electrofilter	Wet absorber	-		Mine sealing	14,400
	Electrofilter, Cloth filter	Wet two-stage scrubber	Entrained flow adsorber	-	Mine sealing	5,233
	Electrofilter	Semi-dry absorber	Entrained flow adsorber		Landfill covering	3,200
	Electrofilter	Wet two-stage NaOH scrubber	-	-	Asphalt plant	18,000
	Cyclone	Sorption agent	Dust filter		Tested for use as a construction aggregate, currently used as landfill	bis 1,700 (442 in 2009)
	Wet scrubber	SO_2 scrubber	Stationary bed filter for mercury removal	SNCR system	Landfill; landfill construction	3,467
	Electrofilter	Spray dryer, acid scrubber, SO_2 scrubber	Hearth furnace and cloth filter		Landfill; landfill construction	35,000
	Electrofilter	Wet four-stage scrubber	Festbettadsorber (ActWivated carbon)		Mine sealing	6,803
	Electrofilter	Wet pipe quencher, counter-flow scrubber	Entrained flow adsorber		Copper refinery fly ash	21,834
	Cloth filter	Dry sorption	Primary additive		Asphalt plant	8,900
	Electrofilter	Wet oxidation Venturi scrubber, three-stage	-		Mine sealing	4,000
	Electrofilter, Cloth filter	Semi-dry, two-stage scrubber	Entrained flow adsorber		Landfill; landfill construction	40,000
	Electrofilter	Cloth filter	Two-stage scrubber	Wet electro-filter	Landfill; landfill construction	8,500
	Electrofilter	Semi-dry jet scrubber, packed-bed scrubber	Entrained flow adsorber + HOK	Electrofilter 2	Mine sealing	8,220 (2009)
	Electrofilter, Cloth filter	Wet jet scrubber, packed-bed scrubber	Dry additive, cloth filter, entrained flow adsorber		Mine sealing	7,400
	Electrofilter	Wet two-stage scrubber: acid stage, no internals; base stage with packingsr	Activated coke adsorber/ cloth filter	-	Mine sealing	12,412
	Cloth filter, Hot-gas cyclone	Dry/evaporative cooler	Hearth furnace coke filer			
	Hydrocyclone	Cloth filter	SNCR	Lime injection	Phosphorous recycling planned	1,400
	Keramikfilter	Dryer	Two-step stage gas scrubbing	-		

Table 23: Technical data for on-site sewage sludge mono-incineration plants as at 2012 [proprietary data]

General							
Site	Regional state	Operator	Technology	Went live on	Operating hours	Capacity	Dry residue
	[-]	[-]	[-]	[-]	[h/a]	[t/a]	[%]
Burghausen	BY	Wacker Chemie	1 Fluidized bed	1976		20,000	21
Frankenthal-Mörsch	RP	BASF AG	2 Fluidized beds	1992	Furnace 1: 7,158 Furnace 2: 6,445	420,000	40
Frankfurt Hoechst	HE	Infraserv GmbH	2 Fluidized beds	1994	Str I: 8,164 h; Str II: 8,055 h	205,000	35
Leverkusen	NW	Currenta GmbH	1 Multiple-hearth	1988	8,000	120,000	27–40
Marl	NW	Infracor GmbH	1 Fluidized bed	1980		40,000	25
Bitterfeld-Wolfen	SH	GKW	Technical data in table 22				
Gendorf/Burgkirchen	BY	Infraserv GmbH	Technical data in table 22				

General	Incineration					
Site	Residual water content after drying	Incineration technology	Incineration units	Mean annual sewage sludge calorific value	Mean theoretical capacity per unit	Amount incinerated in 2009
	[%]	[-]	[-]	[kJ/kg]	[t TS/h]	[t TS/a]
Burghausen	60	SW	1		0.6	
Frankenthal-Mörsch	-	SW	2	2,000	7 t TR	110,000
Frankfurt Hoechst	-	SW	2	3,500	4.2	70,000
Leverkusen		EO	1	4,200	4.5	23,387
Marl		SW	1		3	
Bitterfeld-Wolfen	Technical data in table 22					
Gendorf/Burgkirchen	Technical data in table 22					

General	Waste gas scrubbing			
Site	Energy use	Waste gas scrubbing lines	Dust collector	Additional waste gas scrubbing
	[-]	[-]	[-]	[-]
Burghausen	Steam for drying	1	Cyclone	Pre-soaker and Venturi scrubber
Frankenthal-Mörsch	Heat, Electricity	2	Electrofilter	Wet/packed-bed tower
Frankfurt Hoechst	Heat, Steam	2	Electrofilter	Wet/two-stage wet scrubbing
Leverkusen	Heat, Steam	1	Scrubber	Wet/single-jet cooler, two-stage rotary scrubber, jet scrubber
Marl	Steam	4	Cloth filter	Wet and dry
Bitterfeld-Wolfen	Technical data in table 22			
Gendorf/Burgkirchen	Technical data in table 22			

	Input		Dewatering		Drying	
	Capacity	Sludge makeup (raw/ digested sludge)	Sludge type	Dewatering installation	Total (mean) residual water content	Unit
	[t TM/a]	[-]	[-]	[-]	[%]	[-]
	4,125	Raw sludge	Municipal and industrial sewage sludge	Belt filter press	80	Thin layer dryer
	110,000	Raw sludge	industrial sewage sludge	Chamber/membrane filter press	57	-
	80,000	Raw sludge	Municipal and industrial sewage sludge	Membrane filter press	65–70	-
	36,000	Raw sludge	industrial sewage sludge	Membrane filter press	60	
	10,000	Raw sludge	Municipal and industrial sewage sludge	Concentrator; belt-type filter press	75	

	Waste heat recovery					
	Incinerator manufacturer	Additional fuel	Unit	Manufacturer	Mean steam parameter	Raw electrical output
	[-]	[-]	[-]	[-]	[bar/°C]	[MW]
	Lurgi	Natural gas	Waste-heat boiler	Wehrle	16,5/200	
	Rheinstahl/ MAB-Lentjes	Coal, refuse-derived fuel, light fuel oil	Natural circulation	Lentjes	63/420	max. 13 MW (2009: 60,190 MWh (gross output))
	Uhde	Coal, natural gas, fuel oil	Natural-circulation waste heat boiler	MAN/GHH	16/280	
	Lurgi	Natural gas, fuel-oil substitute for secondary combustion chamber	Radiation pass, superheater, ECO	Lentjes	41/360	
	Raschka	Natural gas, On-site fuel gas	Waste-heat boiler	Wehrle	25/220	

		Slag recycling and disposal		
	Additional waste gas scrubbing	Additional waste gas scrubbing	Recycling/elimination in	Volume
	[-]	[-]	[-]	t/a
	Aerosol separator	Adsorption scrubber	ns	ns
			Avoidance, mine sealing in salt mines	42,736 (sewage sludge, coal, refuse-derived fuel)
	none	none	Landfill/mine sealing	33,000
	Entrained flow reactor		Elimination, HWD Leverkusen	16,992
	SCR, stationary bed adsorber		ns	ns

Table 24: Technical data for coal fired power plants that co-incinerate sewage sludge, as at 2011 [proprietary data]

Power plant name and location	General information on co-incineration			
	Regional state	Operator	Gross electrical output [MW]	Coal type
				[-]
Berrenrath/Köln Hürth	NW	RWE Power AG	107	BK
Boxberg N, P, Q	SN	Vattenfall Europe Generation AG & Co. KG	1,907	BK
Farge/Bremen	HB	GDF Suez Energie GmbH	375	SK
Deuben	SA	Mitteldeutsche Braunkohlengesellschaft mbH	86 (net maximum electrical capacity)	BK
Duisburg HKW I	NW	Stadtwerke Duisburg AG	144	SK
Ensdorf 1 und 3/Saarbrücken	SL	VSE AG	430	BaK
Hamm/Westfalen	NW	RWE Power AG	625	SK
Heilbronn 5, 6 und 7	BW	EnBW Kraftwerke AG	1,000	SK
Helmstedt/Buschhaus	NI	E.ON Kraftwerke GmbH	405	BK
Herne 2, 3 und 4	NW	Evonik Steag GmbH	950	Sk
Lippendorf R uns S	SN	Vattenfall Europe Generation AG & Co. KG	1,840	BK
Lünen 6 und 7	NW	Evonik Steag GmbH	500	SK
Mehrum 3/Hannover	NI	Kraftwerk Mehrum GmbH	750	SK
Veltheim 2, 3 und 4/Weser	NW	Gemeinschaftskraftwerk Veltheim GmbH	820	Coal and natural gas
Mumsdorf	SA	Mitteldeutsche Braunkohlengesellschaft mbH	85 (net maximum electrical capacity)	BK
Oberkirch/Köhler	BW	Koehler Energie GmbH		SK
Staudinger 1, 3, 4 und 5/Hanau	HE	E.ON Kraftwerke GmbH	1,760	Coal and natural gas
Völklingen-Fenne	SL	Evonik Power Saar GmbH	425	SK
Wachtberg-Frechen/Köln-Hürth	NW	RWE Power AG	201	BK
Weiher/Quierschied	SL	Evonik Power Saar GmbH	724	SK
Weisweiler/Aachen	NW	RWE Power AG	2,293	BK
Wilhelmshaven	NI	E.ON Kraftwerke GmbH	788	SK
Zolling-Leininger 5/München	BY	GDF Suez Energie Deutschland AG	474	SK
26. Ibbenbüren	NW	RWE Power AG	752	SK

Based on 2005 data that was updated in 2011

	Firing	Coal water content	Coal throughput	Sewage sludge fired since	No. of lines that co-incinerate sewage sludge
	[-]	[%]	[t/h]	[-]	[-]
	ZWS	51–61	30	Co-incineration in both boilers since 1994; continuous operation since 2000	2
	SF	56	-	Feb. 1999	2 Boilers
	SF	10.5	100	2001 2003	1
	SF	48–56	102	2002	5 Boilers
	ZWS	10–20	30	2002/1995	1
	SF	5–17	200	2001	2 Blocks
	SF	8–16	100	2002	1
	SF	9	280	Apr. 1999 Aug. 1998	1
	SF	45	300	1997	1
	SF	11	110	2005	1
	SF	52–54	-	2004	2 Blocks
	SF	11	160	2005	1
	SF	6–8	240	2002	1
	SF	8–12	113	2003	1
	SF	48–56	128	2000	4 Boilers
	ZWS	6–9	10	2003	1
	SF	8–12	120	2004	1
	SF	20	93	2001	One of two blocks with co-incineration
	ZWS	51–61	50	Co-incineration in both fluidized bed boilers since 2003	2
	SF	9	250	April 1999/1996	1
	SF	55–60	200	Co-incineration in two of eight blocks since August 2008	2
	SF	8.5	250	2004/2003	1
	SF	6–12	136	1999	1
	SF			Co-incineration since 2001	1

Power plant name and location	Sewage sludge			
	Shunting to combustion process	Sewage sludge throughput in as-delivered state	Sewage sludge throughput for dry mass	Solids content in as delivered state
	[-]	[1,000 t OS/a]	[1,000 t TM/a]	[% TR]
Berrenrath/Köln Hürth	Circulating fluidized bed	215	65	Mechanically dewatered sewage sludge with less than 35 % dry solids content
Boxberg N, P, Q	Coal downcomer	140	42	30
Farge/Bremen	Coal downcomer distributor	20 15	18	22 › 90 %
Deuben	In front of coal grinder	84	25	20–37
Duisburg HKW I	Circulating fluidized bed	18	5.4	25–35
Ensdorf 1 und 3/Saarbrücken	Grinder with coal dust	81	24	25–45
Hamm/Westfalen	Coal conveyor, grinder	10	9	25–95
Heilbronn 5, 6 und 7	Coal downcomer	60 mechanically dewatered sludge and 25–20 thermally separated sludge	40	25–35 › 95
Helmstedt/Buschhaus	Coal conveyor, grinder	100	50	25–95
Herne 2, 3 und 4	Coal downcomer	30	25	› 69
Lippendorf R uns S	Coal downcomer	380	93	25–35
Lünen 6 und 7	directly to the combustion process	30	25	› 69
Mehrum 3/Hannover	Coal downcomer	35	11	25–35
Veltheim 2, 3 und 4/Weser	with steam guns directly to the combustion process	45	13.5	25–35
Mumsdorf	In front of coal grinder	100	28	20–37
Oberkirch/Köhler	Ash return	20	5	18–32
Staudinger 1, 3, 4 und 5/Hanau	Coal downcomer	60	18	25–35
Völklingen-Fenne	In front of coal grinder	14	4.2	25–35
Wachtberg-Frechen/Köln-Hürth	Circulating fluidized bed	280/260	85	Mechanically dewatered sewage sludge with less than 35 % dry solids content
Weiher/Quierschied	Grinder with coal dust	6–10	5.5–9	90–95 *
Weisweiler/Aachen	Coal downcomer	140	35	22–33 max. 35 % dry solids
Wilhelmshaven	Coal downcomer	50	12.5	25
Zolling-Leininger 5/München	Coal downcomer	35	9.5	25–35
26. Ibbenbüren		90	35 (10 t/h)	20–40 % TS

Based on 2005 data that was updated in 2011

	Waste gas scrubbing					
Origin	SSewage sludge pollutant content	Dust separation	$DeNO_x$	SO_x	Miscellaneous
[-]	[-]	[-]	[-]	[-]	[-]
municipal/industrial	Requirements exceed AbfKlärV	Electrofilter	Primary CFB	pZWS	Entrained flow absorber with lignite
municipal	Municipal sewage sludge	Electrofilter, Scrubber	Primary measures	WGC	-
municipal	Lower than AbfKlärV	Electrofilter	SCR high dust	WGC	-
municipal	Lower than AbfKlärV	Electrofilter	-	WGC	-
municipal	Municipal sewage sludge	Electrofilter	Primary CFB	pZWS	-
municipal	Lower than AbfKlärV	Electrofilter	SCR low dust	SAS	-
municipal	Municipal sewage sludge	Electrofilter	SCR low dust	WGC	Alkaline scrubber
municipal	Lower than AbfKlärV	Electrofilter	SCR high dust	WGC	-
municipal/industrial	Higher than AbfKlärV	Electrofilter	Primary measures	WGC	-
municipal/industrial	Lower than AbfKlärV	Electrofilter	SCR low dust	WGC	-
municipal/industrial	Higher than AbfKlärV	Electrofilter, Scrubber	SNCR	WGC	-
municipal/industrial	Lower than AbfKlärV	Electrofilter	SCR low dust	WGC	-
municipal/industrial	Lower than AbfKlärV	Electrofilter	SCR high dust	WGC	-
municipal/industrial	Higher than AbfKlärV	Electrofilter	SCR high dust	WGC	-
municipal	Lower than AbfKlärV	Electrofilter	-	WGC	-
municipal	Lower than AbfKlärV	Cloth filter	-	-	-
municipal/industrial	Lower than AbfKlärV	Electrofilter	SCR high dust	WGC	-
municipal	Lower than AbfKlärV	Electrofilter	Firing side	WGC	
municipal/industrial	Requirements exceed AbfKlärV	Electrofilter	Primary CFB	pZWS	Entrained flow absorber with lignite coke
municipal	Lower than AbfKlärV	Electrofilter	SCR high dust	WGC	-
municipal	Lower than AbfKlärV, but Hg less than 5mg/kg dry solids	Electrofilter	Firing side SNCR	WGC (FGDP)	-
municipal	Lower than AbfKlärV	Electrofilter	SCR high dust	WGC	-
municipal/industrial	Lower than AbfKlärV	Electrofilter	SCR high dust	WGC	-
municipal					

Table 25: Technical data for german waste incineration plants that co-incinerate sewage sludge, as at 2012 [itad]

Site	Regional state	Installation operator	Incinerated sludge output from municipal sewage treatment plants (Waste Incineration Ordinance, AVV 190805 only)
			[Mg/a]
Bamberg	BY	Zweckverband Müllheizkraftwerk Stadt und Landkreis Bamberg	14,032
Coburg	BY	Zweckverband für Abfallwirtschaft in Nordwest-Oberfranken	3,314
Hamburg, Borsigstr.	HH	MVB GmbH	2,642
Hamburg, Rugenb.	HH	MVR Müllverwertung Rugenberger Damm GmbH & Co. KG	3,226
Hamburg, Stellingen	HH	Stadtreinigung Hamburg	12,150
Ingolstadt	BY	Zweckverband Müllverwertungs-anlage Ingolstadt	628
Kamp-Lintfort	NRW	Kreis Weseler Abfallgesellschaft mbH & Co. KG	3,700
Köln	NRW	AVG Köln mbH	
Krefeld	NRW	EGK Entsorgungsgesellschaft Krefeld GmbH & Co. KG	1,281/11,872
München	BY	AWM – Abfallwirtschaftsbetrieb München	9,730
Velsen	SL	AVA Velsen GmbH	125
Würzburg	BW	Zweckverband Abfallwirtschaft Raum Würzburg	8,445
Zella-Mehlis	TH	Zweckverband für Abfallwirtschaft Südwestthüringen (ZASt)	2,848.76
Burgau	BY	Landkreis Günzburg Kreisabfall-wirtschaftsbetrieb	-
Seven additional unspecified plants			4,250
			Four values
Mean value			**5,424**
Total			**65,091**

	Sludge from municipal water treatment plants (AVV 190805 only)	Sludge from industrial wastewater treatment plants	Dried separately prior to incineration	Max. capacity
	TS-Gehalt [%]	[Mg/a]		[Mg/a]
	30 % nach Entwässerung	Not applicable	No	Not applicable
	25	-	No	-
	-	-	-	-
	28	-	-	-
	25	-	-	-
	80	-	-	-
	25	-	Fluidized be	34
		10,381	No	-
	30 %/90 %	-	-	-
	-	-	Centrifuge only	-
	25	-	-	
	40	-	Flash dry system	24,000
	-	-	No	-
	-	85	-	-
	23	1.789	No	140,040
	Two values	Three values	3 × no, 3 × n/a	Three values
	34	**4,085**		**54,691**
		12,255		**164,074**

Appendix II

16

Sewage sludge management legislation

The legislation discussed governing sewage sludge management comprise the Bundesgesetze (federal statutes) and Bundesverordnungen (federal ordinances) that apply to sewage sludge incineration and to agricultural use of sewage sludge.

Closed Substance Cycle and Waste Management Act

Closed Substance Cycle and Waste Management Act (Kreislaufwirtschaftsgesetz, KrWG governs waste management and thus sewage sludge as well. The new KrWG was published in the 29 February 2012 issue of the Bundesgesetzblatt (BGBl. I p. 212) and took effect on 1 June 2012. The new law aims to sustainably improve environmental and climate protection and resource efficiency for waste management through optimized waste prevention and recycling. The law stipulates a five-level hierarchy comprising the following: prevention; preparations for recycling; recycling; other uses (e. g. energy); disposal/elimination. Enactment of this five-level hierarchy transposed Directive 2008/98/EC (Waste Framework Directive) into German law.

In cases involving the agricultural use of sewage sludge, Article 11 of the KrWg law stipulates that, in the interest of assuring proper and harmless usage, detailed usage provisions are to be governed by specific regulations known as Rechtsverordnungen (statutory instruments). This in turn will form the legal basis for the Sewage Sludge Ordinance (AbfKlärV), going forward.

For cases involving thermal disposal of sewage sludge, Article 13 of the KrWG law stipulates that operator obligations are to be governed by the Federal Immission Control Act (Bundes-Immissionsschutzgesetz, BImSchG).

Sewage sludge that is used as fertilizer is governed by fertilizer law.

Klärschlammverordnung (AbfKlärV) (Sewage Sludge Ordinance)

This ordinance governs the use of sewage sludge as agricultural or horticultural fertilizer and is without prejudice to the provisions of fertilizer law. The limit values defined in the ordinance are to be undercut wherever possible. Sewage sludge that is used as agricultural and horticultural fertilizer is not to be deleterious to the common good; such sludge is to be use only insofar as allowed by site conditions, cultivation conditions, and plant nutrient requirements.

Article 3(5) of the ordinance stipulates that sewage treatment plant operators are required to conduct the following tests of sewage sludge samples at six month intervals at a minimum:

1. Nutrient content: total nitrogen content, as well as ammonia nitrogen, phosphate, potassium and magnesium content.
2. Total organic halogen compounds, expressed as adsorbed AOX.
3. Heavy metals: lead, cadmium, chrome, copper, zinc, nickel and mercury.
4. pH, dry residue, organic substances and alkaline active ingredients.

Prior to initial use and at a maximum of two year intervals thereafter, sewage sludge is to be tested for PCB, dioxins and furans [Article 3 ABFKLÄRV].

Article 3 stipulates that wastewater treatment plant operators are also required to test soil that is to be fertilized with sewage sludge, prior to initial use and at ten year intervals thereafter. The following tests are to be conducted in such cases:

- pH value
- Nutrients: phytoavailable phosphate, potassium and magnesium
- Heavy metals: lead, cadmium, chrome, copper, zinc, nickel and mercury.

Wastewater treatment plant operators are required to defray the costs of soil and sewage sludge tests.

The use of raw sludge, industrial sludge and sewage sludge as fertilizer is strictly prohibited. Likewise prohibited is the use of sewage sludge for the following:

- Fruit and vegetable crops
- Permanent grassland and forests
- Animal forage cultivation
- Nature conservation areas, natural monuments and national parks
- Zone I and II water protection areas
- In cases where the sludge and soil limit values set forth in Article 4 cannot be adhered to.

No more than five tons of dry solids per hectare are to be applied over any given three year period. Sewage sludge compost use is limited to ten tons per hectare every three years, provided that pollutant content does not exceed one half of permissible heavy metal content [Article 6 ABFKLÄRV]. The current version of the ordinance dates back to 1992, and the Federal Ministry for the Environment (BMU) spent years elaborating the new version. A second draft of the bill was completed in October 2010. Table 26 shows the sewage sludge and soil related differences between the provisions of the current law and those of the proposed bill.

The EU sewage sludge directive
Directive 86/278/EEC aims to (a) regulate the agricultural use of sewage sludge by avoiding deleterious effects on soil, vegetation, plants and livestock, and at the same time (b) promote sound sludge use practices. The directive contains limit values for heavy metals in soil and sludge, and for the amounts of heavy metals that may be applied to soil annually. Sewage sludge use is prohibited insofar as the soil concentration of one or more heavy metals exceeds the limit values set by the directive. The member states are required to institute measures ensuring that these limit values are not exceeded for sewage sludge use.

The directive stipulates that sewage sludge must be treated before being used as fertilizer. However, the use of untreated sewage sludge is permitted insofar as the sludge is washed down or buried in the soil.

The directive furthermore stipulates that on pastures and fields used for forage cultivation, as well as during the vegetation period of fruit and vegetable crops, a waiting period must be observed prior to sewage sludge application. The directive also requires the member states to maintain a register that regularly reports on the amounts of sewage sludge produced and used for agricultural purposes, as well as the composition and characteristics of this sludge [EEC].

Fertilizer legislation
Germany's main fertilizer regulations comprise the Fertilizer Act (DüngG) and the Fertilizer Ordinances (DüV and DüMV), whose main sewage sludge provisions will now be briefly described.

Fertilizer Act (Düngegesetz, DüngG)
This law aims to achieve the following: ensure that crop plants receive adequate nutrition; preserve or improve soil fertility; avoid subjecting humans and livestock to hazards attributable to fertilizers and other substrates, within the meaning of the law. To this end, Article 11 of the law requires that a sewage sludge compensation fund be established for personal injury and property damage attributable to legally compliant agricultural use of sewage sludge. Under the law, the fund is to be financed by sewage sludge producers or owners who dispose of their sludge by making it available for agricultural use. Fertilizing is to be carried out in accordance with good professional practice that is, as regards type, amount and timing of application, commensurate with plant requirements and soil nutrient content [see Article 3(2) DÜNGG].

Fertilizer Ordinance (Düngeverordnung, DüV)
The Fertilizer Ordinance (DüV) sets forth the requirements for (a) good professional practice for fertilizer use; and (b) the avoidance of substance risk attributable to agricultural use of sewage sludge.

Table 26: Maximum sewage sludge and soil pollutant limits under current and pending german laws [abfklärv; bmu 2011b; bbodschv, modified in accordance with brandt]

	AbfKlärV 1992		Draft version of AbfKlärV 2010	
Pollutant	**Maximum allowable content in mg/kg dry solids**			
	Soil	Sewage sludge	Soil*	Sewage sludge**
Heavy metals				
As				18
Pb	100	900	40–100	150
Cd	1.5	10	0.4–1.5	3
Cr	100	900	30–100	120
Cu	60	800	20–60	800
Ni	50	200	15–70	100
Hg	1	8	0.1–1	2
Th				1.5
Zn	200	2.500	60–200	1,800
Persistent organic pollutants				
PCB		0.2 per congener		0.1 per congener 30 ng
PCDD/PCDF		100 ng/kg dry solids		TEQ/kg dry solids
B(a)P				1
PFC (PFOA and PFOS)				0,1
AOX		500		400
Salmonella spp.				No microbes per 50 g wet substance

* Maximum allowable heavy metal content is not to exceed the precautionary values pursuant to section 4.1 Appendix 2 of the current version of the Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV). The allowable content, which is determined by soil type, is lowest for sand and highest for clay, with lime/silt falling between the two.

** The current limit values (as at November 2013) for arsenic, lead, cadmium, chrome, copper, nickel, mercury, thallium, zinc and perfluorinated compounds will expire on 31 December 2014. As from 1 January 2015, the limit values set forth in Appendix 2, table 1, no. 1.4 of the Fertilizer Ordinance (DüMV) will apply.

Sewage sludge fertilizer is to be applied at intervals and in amounts that are commensurate with plant nutrition needs and that promote minimum nutrient loss.

The fertilizer needs of the crops in question are to be determined prior to application of substantial amounts of nitrogen or phosphate in sewage sludge fertilizer and other substrates, within the meaning of the Fertilizer Ordinance (DüV).

The following factors that can potentially affect nutrient conditions (e. g. crop type, previous crop, tilling, and watering) are to be taken into account in this regard: crop nutrition needs; nutrient phytoavailability in the soil and during the growth phase; lime content; soil reaction (pH); soil humus content; cultivation conditions. From 1 November to 31 January, the use of sewage sludge fertilizer on crops is prohibited, owing to the ban on the use of fertilizers with high phosphorous concentrations [DÜV].

Fertilizer Ordinance (Düngemittelverordnung, DüMV)
This ordinance governs the placing on the market of (a) fertilizer that is not designated as EU fertilizer; and (b) soil improvers, culture media and plant aids. The Fertilizer Ordinance (DüMV) classifies sewage sludge as an organic fertilizer or an organic mineral fertilizer whose use is allowed as an NPC (nitrogen phosphate, nitrogen phosphate and potassium) fertilizer.

Under Article 10(3) of the current version of the Fertilizer Ordinance (DüMV) ordinance, sewage sludge whose limit values exceed those of the ordinance's Appendix 2 table 1.4 but comply with those set forth in the sewage sludge ordinance for the same pollutant may be placed on the market until the end of 2014. Thereafter, only sewage sludge whose limit values comply with the Fertilizer Ordinance (DüMV) can be placed on the market. Sewage sludge may only be used as fertilizer via direct application in a non-mixed state [DÜMV APPENDIX 2, TABLE 7, ROW 7.4.3].

Federal Immission Control Ordinance (17. Bundes-Immissionsschutzverordnung, 17. BImSchV)

This ordinance governs the construction, characteristics, and operation of incineration and co-incineration plants that incinerate waste and that are subject to permit requirements under Article 4 of the Federal Immission Control Act (BImSchG) [Article 1, 17. BIMSCHV], which stipulates that the ordinance also applies to sewage sludge incineration and co-incineration plants.

In the interest of curbing emissions, the law sets limit values for total dust, sulphur dioxide, nitrogen oxides, mercury, carbon monoxide and heavy metals.

The ordinance lays down incineration plant construction and operation requirement concerning the following:

- Air quality measures
- Fire safety measures
- Waste management
- Heat recovery

The ordinance's key requirements are that (a) a combustion air afterburning temperature of 850 °C must be maintained for two seconds; and (b) the operator must continuously monitor emission levels and report them to the competent authorities [17.BIMSCHV].

Appendix III

17

Heavy metals in sewage sludge

Figure 12 contains data concerning copper concentrations in sewage sludge.

Figure 13 contains data concerning zinc concentrations in sewage sludge.

Figure 14 contains data concerning nickel, chrome and iron concentrations in sewage sludge.

Figure 12: Sewage sludge copper concentrations [bmu]

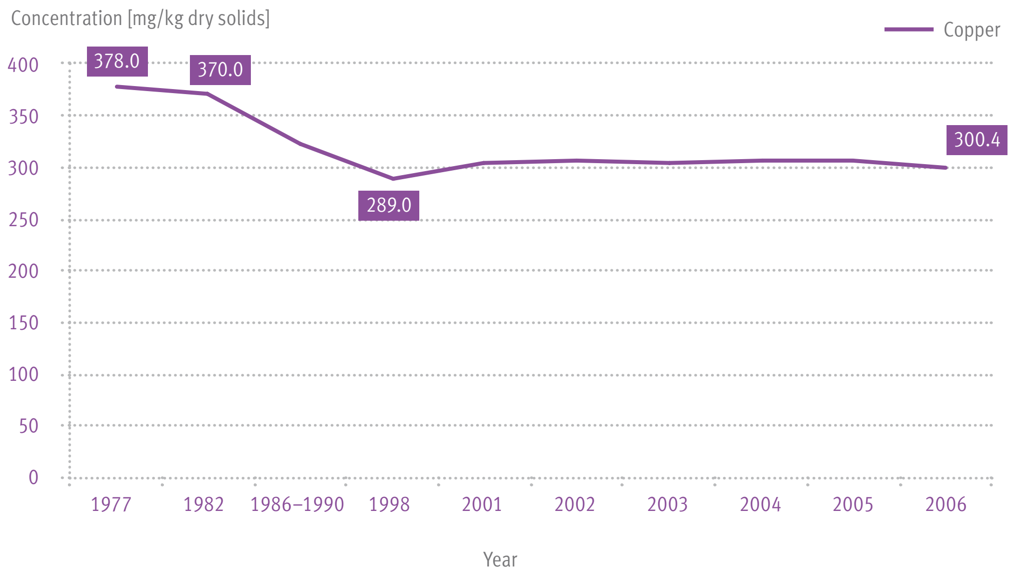
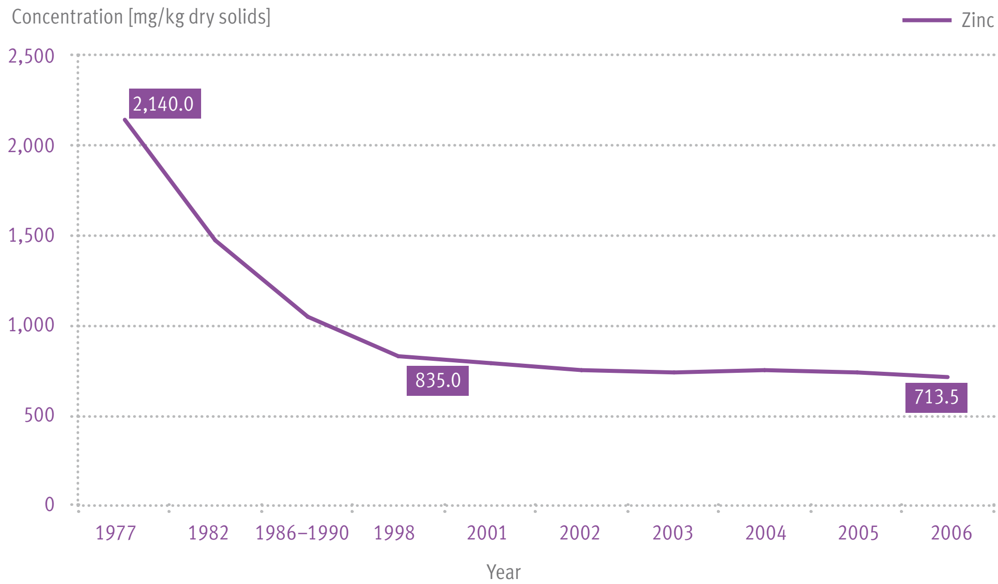


Figure 13: Sewage sludge zinc concentrations [bmu]



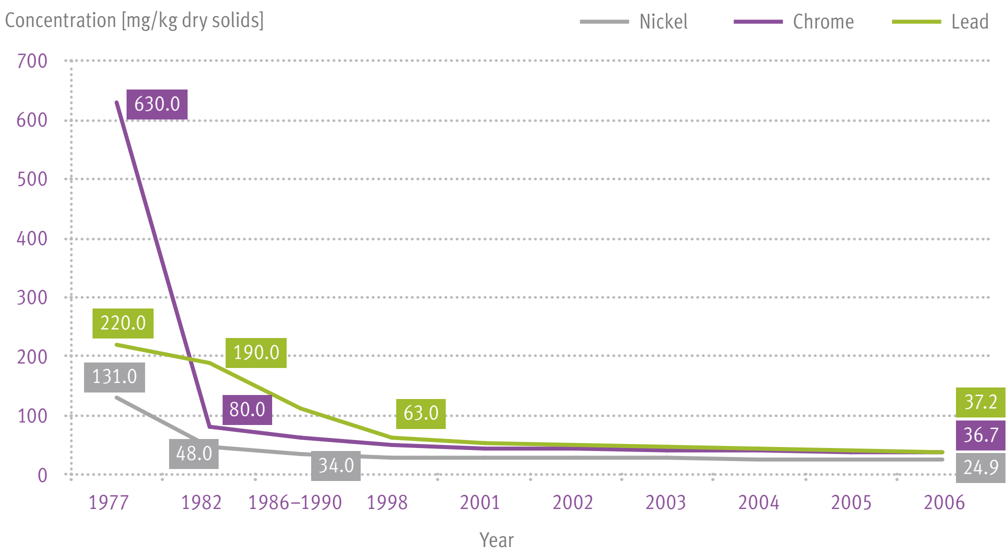
Appendix IV

18

Table 27: Technical data for sewage sludge drying installations in germany

	Site	Regional state	Drying system	Manufacturer
1	Albstadt	BW	Solar dryers that use waste heat	IST
2	Alfeld/Wettensen	NI	Drum dryers	Ammann
3	Allershausen	BY	Solar dryers	IST
4	Altenstadt	BY	Screw dryers	ns
5	Asse	NI	Solar dryers that use waste heat	Thermo-System
6	Backnang	BW	Belt dryer	Huber
7	Bad Säckingen	BW	Drum dryers	Andritz
8	Balingen	BW	Belt dryer	Huber
9	Bernstadt	BW	Solar dryers	Thermo-System
10	Bitterfeld-Wolfen	ST	Disc dryer	Wulff Atlasstord

Figure 14: Sewage sludge nickel, chrome and lead concentrations [bmu]



	Throughput [tons dry solids/a]	Dry residue (% of dry residue), after drying	Substrate use
	1,000	40–70	ns
	Currently shut down (previously 2,000)	95	Composting/recultivation
	200	60–70	ns
	30,000	90	Incineration
	88	70	ns
	4,640	92–95	Co-incineration at Heilbronn power plant
	Currently shut down (previously 3,800–4,000)	92	Incineration
	2,000	85	Proprietary thermal recycling
	220	70–90	Thermal recycling (co-incineration)
	15,167	45–50	Incineration (proprietary fluidized bed)

	Site	Regional state	Drying system	Manufacturer
11	Blaufelden	BW	Solar dryer	RATUS
12	Bodnegg	BW	Solar dryers	Thermo-System
13	Bräunlingen	BW	Drum dryers	Swiss-Compi
14	Bredstedt	SH	Solar dryers	Thermo-System
15	Bruchmühlbach-Miesau	RP	Cold air dryers	Klein
16	Bruckmühl	BY	Cold air dryers	Klein
17	Burgebrach	BY	Solar dryers	Thermo-System
18	Burgrieden	BW	Solar dryers	IST
19	Duisburg	NW	Centridry	KHD
20	Düren	NW	Disc dryer	Atlasstord
21	Düsseldorf Nord	NW	Drum dryers	Andritz
22	Düsseldorf Süd	NW	Disc dryer	Wehrle
23	Edemissen	NI	Solar dryers	Thermo-System
24	Eggenstein-Leopoldshafen	BW	Belt filters	RATUS
25	Ellwangen	BW	Solar dryers	Thermo-System
26	Elsenfeld	BY	Cold air dryers	Klein
27	Empfingen	BW	Solar dryers	ns
28	Enkenbach-Alsenborn	RP	Cold air dryers	Klein
29	Erkelenz	NW	Thin layer dryer	Buss
30	Frankenhardt	BW	Solar dryers	Thermo-System
31	Freiburg-Forchheim	BW	Disc dryer	Stord
32	Füssen	BY	Solar dryers	Thermo-System
33	Göppingen	BW	Fluidized bed dryer	VA WABAG
34	Griesheim	HE	Drum dryers	SMAG
35	Groß-Gerau	HE	Thin layer	Lineartrockner
36	Grüneck	BY	Centrifuge (solar sewage sludge drying in the future)	ns
37	Grünstadt	RP	Solar dryers	Thermo-System
38	Günzburg	BY	Centrifuge, solar dryer	Thermo-System
39	Hagen a. TW	NI	Solar dryers	IST
40	Hamburg	HH	Disc dryer	Stord
41	Handewitt	SH	Solar dryers	Thermo-System
42	Hattingen	NW	Drum dryers	Swiss Combi
43	Hayingen	BW	Solar dryers that use waste heat	Huber

Throughput [tons dry solids/a]	Dry residue (% of dry residue), after drying	Substrate use
200	50	Agriculture
90	90	Thermal recycling (co-incineration)
5,000–6,000	92	Co-incineration at Heilbronn power plant
108	70	Agricultural use
600	88	Recultivation, landscaping
266	76	Recultivation
190	70	ns
100–300	50–90	Composting, recultivation
Currently not in use	68–70	Incineration
11,000	40 (partial drying)	Incineration (proprietary fluidized bed)
5,000	92	Thermal recycling
7,000	94	Thermal recycling
288	75	ns
600	75	Recultivation, incineration
700	70	Thermal recycling (co-incineration)
5,300	80–90	Incineration
ns	ns	ns
220	85	Agriculture, landscaping, composting
Currently not in use	90	Agricultural wet sludge; or alternatively, dewatering using decanters for subsequent use in composting installations
143	75	Thermal recycling (co-incineration)
8,000	92	Thermal recycling, landfill
625	70	Thermal recycling (mono-incineration)
2,500	93	Power plant incineration
Used solely during peak demand periods	95	Composting (wet sludge)
600	80–90	Agriculture
20 m^3/h for 8 hours of operation	27 (70–80 % in the future)	Co-incineration at coal fired power plants
363	50–70	ns
1,400	50–60	Agriculture, composting, thermal disposal
180	70	ns
45,000	42	Proprietary incineration
220	75	Agricultural use
5,000	93	Thermal recycling
88	80–90	Agriculture

	Site	Regional state	Drying system	Manufacturer
44	Herdwangen	BW	Solar dryers	Thermo-System
45	Herzebrock-Clarholz	NW	Screen belt dryer	Dornier
46	Hetlingen	SH	Drum dryers	SCT
47	Hiddenhausen	NW	Centrifuge	ns
48	Hochdorf Assenheim	RP	Solar dryers that use waste heat	Roediger Bioenergie
49	Höhr-Grenzhausen	RP	Cold air dryers	Klein
50	Holzminden	NI	Thin layer, drum dryers	Buss
51	Huglfing	BY	Solar dryers	IST
52	Iffezheim	BW	Solar dryer	IST
53	Ingolstadt	BY	Belt dryer with waste incineration waste heat	Huber
54	Jerxheim	NI	Solar dryers that use waste heat	Thermo-System
55	Juist	NI	Solar dryers	Thermo-System
56	Kamp-Lintford	NW	Steam fluidized bed drying	
57	Kandern-Hammerstein	BW	Solar dryer	IST
58	Karlsfeld	BY	Solar dryers	IST
59	Karlsruhe	BW	Disc dryer	Stord
60	Karlstadt	BY	Belt dryer	ns
61	Kassel	HE	Drum dryers	Bird Humboldt
62	Kempten	BY	Belt dryer	ns
63	Krefeld	NW	Disc dryer	Wehrle
64	Kreßberg	BW	Solar dryers	Thermo-System
65	Lahr	BW	Fluidized bed dryer	Sulzer
66	Lambsheim	RP	Solar dryers	Thermo-System
67	Landstuhl	RP	Cold air dryers	Klein
68	Lauterstein-Albhof	BW	Solar dryers that use waste heat	Roediger Bioenergie
69	Leintal-Göggingen	BW	Solar dryers	Thermo-System
70	Lepoldshafen	BW	Solar dryers	ns
71	Leutershausen-Sachsen	BY	Solar dryers that use waste heat	Roediger Bioenergie
72	Leutkirch	BW	Fluidized bed dryer	Vtech
73	Lichtenfels	BY	Belt dryer	Innoplana
74	Main-Mud	BY	Solar dryers that use waste heat	IST
75	Mainz-Mombach	BW	Belt dryer	Sevar
76	Mannheim	BW	Drum dryers	Bird Humboldt

	Throughput [tons dry solids/a]	Dry residue (% of dry residue), after drying	Substrate use
	69	90	Thermal recycling (co-incineration)
	Not in operation (previously 900)	85–90	Incineration (power plants or waste incineration plants)
	6,600	90	Substance or thermal recycling
	ns	23 %	Incineration in various power plants
	1,250	90	Cement plants
	Currently not in use	80	Recultivation (wet sludge)
	Not in operation (previously 1,500)	90	Recultivation; incineration at Buschhaus power plant
	120	60–70	ns
	100–120	70–85	Agriculture, recultivation
	3,500 with 85 % dry residue	85	ns
	200	80	ns
	120	55	ns
	12,000	95	Co-incineration in proprietary waste incineration plant
	80–100	70–90	Incineration at Helmstedt lignite fired power plant
	400	60–70	ns
	10,000	40	Incineration (proprietary)
	5,100 t/a	ns	Thermal recycling at cement plant
	5,500	98	Recultivation, tendency toward thermal recycling
	14,000	87	ns
	13,720	92	Incineration at waste incineration plant
	90	75	Thermal recycling (co-incineration)
	Not in operation	85	Currently landfill
	230	70	Agricultural use
	Currently not in use	80–90	Agriculture
	1,000	90	Cement plants
	182	75	ns
	ns	ns	ns
	2,000	90	Cement plants
	1,500	96	Recultivation; landfill site shut down
	1,000	93	Agriculture/incineration
	1,000	60–70	ns
	5,200	77	Co-incineration at power plant
	10,000	95	Currently landfill

	Site	Regional state	Drying system	Manufacturer
77	Markt Au	BY	Solar dryer	Thermo-System
78	Markt Essenbach	BY	Solar dryers	Thermo-System
79	Marktbergel	BY	Solar dryers that use waste heat	Huber
80	Memmingen	BY	Fluidized bed dryer	VA WABAG
81	Miltenberg	BY	Solar dryers	ns
82	Mintaching	BY	Belt dryer	HUBER SE
83	Mönchengladbach	NW	Drum dryers	Swiss-Combi
84	München-Nord	BY	Disc dryer	Wulff
85	Murnau	BY	Solar dryers that use waste heat	IST
86	Neckarsulm	BW	Solar dryers that use waste heat	Roediger Bioenergie
87	Neufahrn	BY	Solar dryers	IST
88	Neu-Ulm	BY	Thin layer dryer	
89	Niederkrüchten	NW	Thin layer dryer	Buss
90	Nordstemmen	NI	Solar dryers that use waste heat	Thermo-System
91	Nürnberg	BY	Disc dryer	Buss
92	Oyten	NI	Drum dryers	Andritz
93	Oldenburg	NI	Solar dryers that use waste heat	Thermo-System
94	Pocking	BY	Solar dryers	Thermo-System
95	Querschied	SL	Disc dryer	Wehrle
96	Rastatt	BW	Fluidized bed dryer	CT Umwelttechnik
97	Raubling	BY	Solar dryers	Thermo-System
98	Renningen	BW	Solar dryers	Thermo-System
99	Renquishausen	BW	Solar dryers	Thermo-System
100	Riepe	NI	Solar dryers that use waste heat	Thermo-System
101	Rödental	BY	Solar dryers	Thermo-System
102	Röthenbach	BY	Solar dryers	IST
103	Rudersberg	BW	Solar dryers that use waste heat	Huber
104	Salzkotten	NW	Belt dryer	Stela-Laxhuber
105	Scheßlitz	BY	Solar dryers	Thermo-System
106	Schlitz-Hutzdorf	HE	Solar dryers	Thermo-System
107	Schlüsselfeld	BY	Solar dryers	Thermo-System
108	Schönaich	BW	Solar dryers	Thermo-System

	Throughput [tons dry solids/a]	Dry residue (% of dry residue), after drying	Substrate use
	130	70–80	1/4 Agriculture, 3/4 Recultivation
	216	70	ns
		80–90	ns
	2,500–3,500	90	Currently recultivation, but incineration in the future
	4,000 t/a	75	
	2,000	90	Co-incineration at power plant
	Not in operation (previously 8,000–12,000)	90–95	Incineration (mixed with wet sludge)
	15,000	50 (Partial drying)	Co-incineration at waste incineration plant
	476	60–70	ns
	2,000	90	Cement plant
	280	60–70	ns
	10,000	40	Incineration in proprietary facility
	382	68	Processing and recycling by RWE in Herten
	376	70	ns
	Not in operation (previously 12,000)	90	Co-incineration at coal fired power plant and cement plant, plus recultivation
	750	92	Power plant co-incineration; minor amount of landfill
	10,000	65	Thermal recycling
	360	70	ns
	30,000	95	Incineration
	3,500	90	Incineration at Heilbronn power plant discontinued
	250	60	ns
	288	70	Thermal recycling (co-incineration)
	21	90	ns
	600	80	Agricultural use
	400	75	ns
	400	40–70	ns
	250	80–90	ns
	Not in operation (previously 500)	80	Incineration
	110	75	ns
	280	70	ns
	300	75	ns
	1,000	70	Thermal recycling (co-incineration)

	Site	Regional state	Drying system	Manufacturer
109	Schönerlinde	BE/BB	Drum dryers	Bird Humboldt
110	Schongau	BY	Solar dryers	Thermo-System
111	Schwarzenbruck	BY	Drum dryers	Rödiger (Mozer)
112	Sigmaringen	BW	Solar dryers	IST
113	Sinzig	RP	Disc dryer	KHD
114	St. Peter-Ording	SH	Solar dryers	Thermo-System
115	Starnberg	BY	Belt dryer	Sevar
116	Steinbrück	NI	Solar dryers that use waste heat	Thermo-System
117	Steinen	BW	Disc dryer	Stord
118	Stockach	BW	Solar dryers	Thermo-System
119	Stuttgart-Mühlhausen	BW	Disc dryer	Wulff/Atlas Stord
120	Sulz / Vöhringen	BW	Solar dryers that use waste heat	Roediger Bioenergie
121	Tübingen	BW	Drum dryers	Andritz
122	Ühlingen-Birkendorf	BW	Solar dryers	ns
123	Unterpleichfeld	BY	Solar dryers that use waste heat (powered by a biogas facility)	Roediger Bioenergie
124	Unterschneidheim	BW	Solar dryers	Thermo-System
125	Vlotho	NW	Drum dryers	Andritz
126	Waibstadt	BW	Solar dryers	Thermo-System
127	Waldenburg	BW	Solar dryers	Thermo-System
128	Waldenburg	RP	Solar dryer, Belt filters	Thermo-System
129	Wallmerod	RP	Cold air dryers	Klein
130	Wangen	BY	Belt dryer	Klein
131	Wassmannsdorf	BE/BB	Centrifuge	ns
132	Weddel-Lehre	NI	Solar dryers	Thermo-System
133	Wegscheid	BY	Solar dryers	Thermo-System
134	Weil am Rhein	BW	Solar dryers that use waste heat	IST
135	Weißenhorn	BY	Cold air dryers	Klein
136	Wilhelmsdorf	BW	Solar dryers	Thermo-System
137	Winterhausen	BY	Solar dryers	Thermo-System
138	Wittlich-Platten	RP	Solar dryers that use waste heat	Roediger Bioenergie
139	Wolfratshausen	BY	Disc dryer	Stord
140	Wuppertal	NW	Thin layer dryer	Buss
141	Wyk auf Föhr	SH	Solar dryers	Thermo-System

	Throughput [tons dry solids/a]	Dry residue (% of dry residue), after drying	Substrate use
	8,000	95	Incineration
	496	40	Thermal recycling (mono-incineration)
	Not in operation (previously 650)	90	Composting or thermal recycling
	450	40–70	Thermal recycling (co-incineration)
	350	95	Currently landfill
	160	75	Agriculture
	Currently not in use	95–98	Currently used as landfill covering (on around 30% dewatered dry residue)
	240	75	ns
	800	90	Co-incineration at coal fired power plant
	750	70	Thermal recycling (co-incineration)
	20,000–25,000	48	Incineration
	470	90	Cement plants
	2,000	93	Incineration
	ns	ns	ns
	700	90	Thermal recycling in cement plants
	128	80	Thermal recycling (co-incineration)
	400	70	Incineration
	275	70	Thermal recycling (co-incineration)
	150	75	ns
	100–130	75	Co-incineration at lignite fired power plant
	Currently not in use	85	Agriculture
	1,500 t TS/a	90	Thermal recycling
	25,500 t/a	26,5	ns
	180	55	ns
	50	75	ns
	1,440	60–80	Thermal recycling (co-incineration)
	200	80	Recultivation
	264	75	Thermal recycling (co-incineration)
	1,100	60	ns
	Shut down (previously 1,600)	90	Cement plants
	1,050	90	Recultivation
	30,000	45	Incineration
	230	75	ns

Notes

Imprint

Publisher:
Umweltbundesamt (UBA)
Postfach 1406
06844 Dessau-Roßlau | Germany

Telefax: +49 (0)340 2103-2285
info@umwelbundesamt.de
www.umweltbundesamt.de

01.09.2013

Design: www.publicgarden.de
DTP and typesetting: Team VIERZIG A, Dessau, www.vierzig-a.de

Printed on 100 % recycled paper.