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PRESENT STATUS AND PERSPECTIVES OF CO-COMBUSTION IN GERMAN POWER PLANTS

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Various approaches to the future waste management policy in Germany are currently under discussion. One problem arising in this connection, this is the suitability of existing furnaces for the co-combustion of waste. The use of sewage treatment sludge in power plants is already being practiced on a technical scale. Co-combustion in power plants is of interest also because of the CO_2 problem, as renewable resources can also be used for this purpose.
This article documents the technical status of co-combustion in Germany and the available quantities of selected supplementary fuels. Moreover, experience accumulated in German coal fired power plants in using supplementary fuels is compiled. Future possibilities are assessed.

Introduction

As a consequence of political criteria, waste management in Germany will be characterised in the future by a high degree of separation of waste streams for which optimum ways of utilisation will be sought after. Where recycling makes no sense, thermal treatment of waste is a possibility.

Until the late eighties, emissions constituted the main point in debates about thermal waste treatment. Nowadays, it is the costs of waste management, which are becoming more and more important. Moreover, greater attention is being devoted to the efficiency of waste management plants against the background of the CO_2 problem and the greenhouse effect.

One possibility of thermal waste treatment or regenerative fuel combustion with high efficiency and at relatively low cost is co-combustion in existing power plants. In Germany, various waste materials are used in coal fired power plants among other facilities.

In this study, the current state of knowledge about co-combustion in power plants is described. Further potentials of co-combustion are presented on the basis of existing power plants.

Electricity Generation

The studies were performed on the basis of an analysis of the German electricity market. In 1998, 982 German power plants generated a total of 520,000 million kWh of electricity for use in industry and private households. A 27% share was generated by the combustion of hard coal, a 25% share by the combustion of brown coal [1]. These quantities did not change greatly throughout the nineties.

Analysis of the installed electric capacity of German power plants shows by far the largest fraction (89.5%) to be owned by public electricity utilities. *Table 1* shows more detailed information about electricity generation.

In considering the possibilities of more extensive co-combustion of waste materials, the furnace technology and plant sizes must be taken into account. According to [2], public utilities in Germany generate 99% of their power output on sites with more than 50 MW electric power. The furnace technologies used by public utilities are listed in *Table 2*.

According to *Table 2*, the dominating firing systems used are pulverised-fuel furnaces, for which two modes of operation are possible. Wet-bottom furnaces, in which the ash is removed as molten slag and dry-bottom firings in which the ash is present as solid particles. In

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Table 1 Installed Electrical Capacity and Power Production in German Coal-fired Power Plants

	public power utilities	industry	German railways	total
		installed capacity 1998		
brown coal	17861 MW (36.2 %)	780 MW (1.6 %)	110 MW (0.2 %)	18751 MW (38.0 %)
hard coal	26248 MW (53.2 %)	3700 MW (7.5 %)	595 MW (1.2 %)	30543 MW (62.0 %)
Total	44109 MW (89.5 %)	4480 MW (9.1 %)	705 MW (1.4 %)	49294 MW (100 %)
		power production 1998		
brown coal	122450 million kWh (45.7 %)	4790 million kWh (1.8 %)	550 million kWh (0.2 %)	127790 million kWh (47.7 %)
hard coal	122000 million kWh (45.6 %)	15530 million kWh (5.8 %)	2470 million kWh (0.9 %)	140000 million kWh (52.3 %)
total	244450 million kWh (91.3 %)	20320 million kWh (7.6 %)	3020 million kWh (1.1 %)	267790 million kWh (100 %)

Table 2 Firing Systems in Germany

firing system	share
stoker furnace	2,2 %
fluidised-bed furnace	2,3 %
multi-fuel furnace	6,9 %
pulverised-coal furnace	89,1 %

Germany, dry-bottom furnaces dominate, holding a share of 59.2%. Wet-bottom furnaces are installed on 40.8% of the sites. Because of this dominating role, this study will concentrate on pulverised-coal furnaces.

A look at the geographic distribution of power plants over the territory of Germany shows the expected relationship with the population density. Highly populated areas mainly have hard-coal-fired power plants, while brown-coal-fired power plants are to be found in brown-coal mining areas so as to avoid long transport routes. New coal-fired plants are being built mainly to replace old brown coal fired units [1] [3].

The liberalisation has caused an upheaval in the electricity market in Germany. It is safe to assume that existing overcapacities will result in power plants being shut down. Particular some power plants installed as standby facilities to guarantee the continuity of electrical power supply are no longer required as a consequence of mergers of large electricity companies. However, no reliable data are available for this ongoing process.

Legal Framework

In Germany, power plants and waste incineration plants must meet different emission limits. Emissions from power plants with thermal powers in excess of 50 MW_{th} are regulated by the Ordinance on Large Power Plants [4], while waste incineration plants must meet the lower limits of the Ordinance on Incinerators for Waste and Similar Combustible Materials [5].

Where waste materials are used as fuels in power plants, the emission limits must be calculated on the basis of the emission limits and criteria contained in the two ordinances. This calculation, the so called mixing rule, takes into account the calorific values, specific flue gas volumes, and other data. One problem arising in this connection is that the Ordinance on Incinerators for Waste and Similar Combustible Materials contains requirements on pollutants not listed in the Ordinance on Large Power Plants. For this reason, extensive measurements of emissions of a power plant may be necessary to obtain a permit for co-combustion of waste. A summary of chosen limits is included in *Table 3*.

The EU has decided a new directive on waste incineration with criteria about the co-combustion of waste in power plants. As far as waste incineration is concerned, the limits contained in the EU [6] directive are based on the requirements of Ordinance on Incinerators for Waste and Similar Combustible Materials. In co-combustion the emission limits for heat shares of recovered fuels up to 40% are calculated by a mixing rule always starting at a minimum share of 10 %. The EU directive states emission limit values for the power plants $C_{process}$ to be used in the mixing rule together with the emission limit values for waste incineration C_{waste} to calculate the allowed emission limit value. For the pollutants not listed in the Ordinance on Large Power Plants, the directive contains total emission limit values.

Supplementary Fuels and their Properties

In Germany, various management pathways exist for sludge arising in the treatment of municipal and industrial sewage. In Germany, sewage sludge is covered by waste management legislation. Next to agricultural uses, composting, and landfilling, thermal treatment has become an established disposal pathway. Especially municipal sewage treatment sludge is important when it comes to co-combustion in power plants, because most of the residues from industrial sewage treatment plants are being incinerated already.

Relatively exact data exist about the treatment of municipal sewage in Germany. Accordingly, the 10 522 municipal sewage treatment plants in operation [7] annually produce 2 642 200 t of dry sludge. Treatment plant sizes and sewage sludge arising yield/output differ regionally and, as expected, depend on the population density. Taking into account the sludge fraction from municipal sewage treatment plants already incinerated,

Table 3 Emission limits for waste incineration plants and power plants

Compound	Unit	13th BImSchV Power Plants Daily Average (6 % O_2)	17th BImSchV Waste Incineration Daily Average (11 % O_2)	17th BImSchV Waste Incineration Half Hour Average (11 % O_2)	EU-Directive Waste Incineration (C waste) Daily Average (11 % O_2)	EU-Directive Waste Incineration (C waste) Half Hour Average (11 % O_2)	EU-Directive Co-Combustion Power Plants >300 MW_{th} Daily Average (6 % O_2)	EU-Directive Co-Combustion Cement Kilns Daily Average (10 % O_2)
CO	mg/m^3 (1	250	50	100 150 (2	50	100	X (13	X (9
org. compounds as total Carbon	mg/m^3 (1	-	10	20	10	20	X (13	10 (11
Particulate Matter	mg/m^3 (1	50	10	30	10	30	30 (12	30 (11
SO_2 / SO_3 as SO_2	mg/m^3 (1	400	50	200	50	200	200 (12	50 (11
Sulfur emission factor	%	15					5 (12	
NO u. NO_2 as NO_X	mg/m^3 (1	800 (3	200	400	200	400	200 (300 (10) (12	800 (11
HCl	mg/m^3 (1	100	10	60	10	60	X (13	10 (11
HF	mg/m^3 (1	15	1	4	1	4	X (13	1 (11
Σ Tl and Cd	mg/m^3 (1		0.05 (4		0.05 (6		0.05 (6, 11	0.05 (6, 11
Hg	µg/m^3 (1		0.03	0.05	0.05 (6		0.05 (6, 11	0.05 (6, 11
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/m^3 (1		0.5 (4		0.5 (6		0.5 (8, 11	0.5 (8, 11
PCDD/PCDF	ng/m^3 (1		0.1 (5		0.1 (7, (8		0.1 (7, 11	0.1 (7, 11

(1 reference Standard Cubic Meter, dry
(2 concentration based on the mass which can't be violated by more than 10 % of all measurements within a time period of 24 hours
(3 for the emission control the state of the art should be applied
(4 average over sampling time (at least 0.5 h; maximum 2 h)
(5 average over sampling time (at least 6 h; maximum 16 h)
(6 average over sampling time (at least 0.5 h; maximum 8 h)
(7 average over sampling time (at least 6 h; maximum 8 h)
(8 without Sn
(9 to be set by the competent authority
(10 biomass
(11 total emission limit value for this process (C emission)
(12 emission limit value to be used for mixing rule (C process)
(13 mixing rule with the limits as stipulated and C waste

a maximum of 2.3 million t of sewage treatment sludge (dry) can be available for co-combustion in power plants.

The consideration of wood for co-combustion in coal-fired power plants demands a distinction among very different wood fractions. Forest wood residues, arising in the tending of woods normally contain no pollutants. The quantities available are influenced by forest areas in a region, weather conditions, such as heavy storms, and by other factors.

The quantities of forest wood residues available in Germany are based on statistical calculations in which, among other factors, the forest areas of the regions considered, the tree species, and ecological aspects are taken into account. It may be assumed that approximately 7.5 million t of raw wood can be used in power plants in Germany. [8] [9]

Moreover, the optimum solution to the disposal of waste wood is being discussed in Germany. Waste wood arises in a variety of industrial sectors or private households and may carry a variety of pollutants, such as wood preservatives or paints containing heavy metals.

Determining the quantities of waste wood in Germany is difficult for a variety of reasons. Different interpretations of the term "waste wood" are used and sawdust and similar materials from the wood industry are not always taken into account. Additional new legal regulations, in particular on regional level have to be taken into account. Moreover, the amount of waste wood is influenced by local waste management. The quantities of waste wood which can be used for co-combustion, consequently, can be determined only with major uncertainties. An estimate conducted on this basis results in a total quantity of 4.1 to 11.7 million t per annum. A breakdown into the different fractions of waste wood is shown in *Fig.1*.

Straw is another supplementary fuel of interest arising as a by-product in the cultivation of wheat, barley etc. Straw so far has mostly been left on the fields or used in stock farming. In the industrialised countries, straw has never been used for energy production, but that use is already being pushed in Denmark by law.

The quantities of straw that could be used for co-combustion are determined by the present agricultural uses of existing areas, by weather conditions, and by soil properties. The quantities of straw are determined in a similar way as the amounts of forest wood residues. In Germany, a total of approx. 41.4 million t of straw arise annually [8] which, however, cannot be fully used for co-combustion. If the quantities required in stock farming and other areas are taken into account, then, according to [8], only 15 % of the total amount, namely 5.9 million t of straw per annum, would be available for thermal utilization. Other authors assume that between 10.1 and 17.2 million t of straw can be used annually [9].

Estimates of the potential of recovered fuels from post user waste materials in Germany are shown in *Table 4*. The potential is quoted with 5.2 - 8.4 million tons/a. In this table production residues (pre-user wastes) are not quoted due to the limited data available. Estimates received from waste management companies

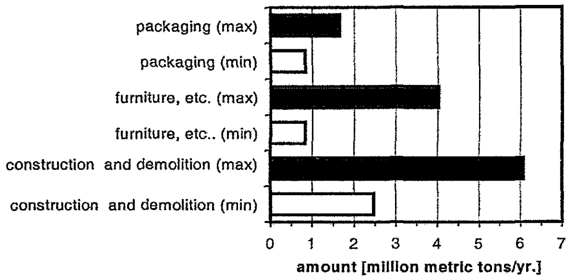

Fig.1 Range of waste wood arising from packing, used furniture and the construction sector

Table 4 Potentials for recovered fuels from high calorific fractions of selected waste materials [10]

	Total [million t/a]	High calorific fraction [%]	potential for recovered fuels [million t/a]*
household waste	11.1	40-50	2.7 - 4.4
industrial waste similar to household waste	4.8	50-60	1.4 - 1.2
bulky waste	1.8	75-85	0.8 - 1.2
sorting residues (DSD)	0.8	65-75	0.3 - 0.5
total	18.5		5.2 - 8.4

* calculated from 60% of the lower and 80 % of the higher estimate of the high calorific fraction, without considering the possible additional streams that might go into Municipal Solid Waste (MSW) incinerators

Table 5 Fuel analysis of coals and selected supplementary fuels

			hard coal	brown coal	wood	Straw	RDF**	dried sewage sludge
LHV*	(raw)	[MJ/kg]	28	9	12.4	15	23.5	10.58
moisture	(raw)	[%]	5.1	50.4	33	10.6	4.1	3
volatile matter	(dry)	[%]	34.7	52.11	83.2	74.4	82.6	49.52
ash	(dry)	[%]	8.25	5.1	0.34	6.1	12.2	45.1
Fixed C	(dry)	[%]	57.1	42.83	16.5	19.9	5.2	2.39
C	(dry)	[%]	72.48	65.9	48.7	47.4	56.8	25.01
H	(dry)	[%]	5.64	4.9	5.7	4.5	7.9	4.88
N	(dry)	[%]	1.28	0.69	0.13	0.4-0.78	0.74	3.2
S	(dry)	[%]	0.94	0.39	0.05	0.05-0.11	0.25	1.1
Cl	(dry)	[%]	0.128	< 0.1	< 0.1	0.4-0.73	0.82	< 0.1
O	(dry)	[%]	11.1	23	45	40.4	21.3	17.69
ash fusion temperature		[°C]	1250	1050	1200	850	1120	1200

*Lower Heating Value **Refuse Derived Fuel

average at 2 million tons total, which would yield about 1 million tons/a recovered fuel.

The co-combustion of sewage sludge, wood and straw in a power plant effects the power plant operation. These influences are determined by the fuel characteristics and the chemical compositions. *Table 5* lists the most important fuel data for a number of selected examples.

Most of the supplementary fuels considered mostly have lower calorific values than hard coal. As a rule, waste wood has a humidity of approx. 10% and a calorific value on the order of 17 MJ/kg. In the case of sewage treatment sludge, the calorific value is between 2 and 12 MJ/kg, depending on the water content. The water content and the ash fraction have a major influence on the calorific value of bio fuels, for which 15 to 18 MJ/kg is to be expected.
The large ash share in sewage sludge increases the amounts of fly ash by co-combustion. Although the a h content of straw can be compared to that of regular fuels, the low melting points may cause problems in operation as a result of caking. Moreover the chlorine content must be considered which has a major impact on corrosive processes. Especially straw normally has a relatively high chlorine content. Waste wood may contain up to 3% nitrogen and heavy metals.

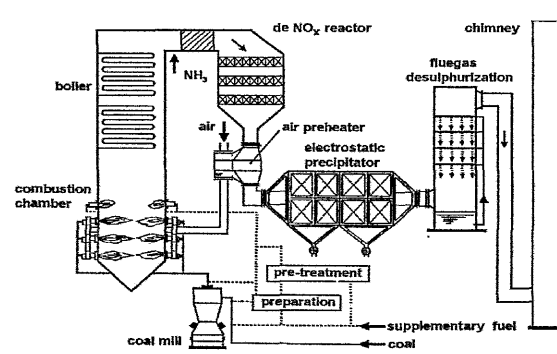

Fig.2 Schematic diagram of a typical pulverized-coal-fired power plant with flue gas treatment system

Basic Principles of Co-combustion in Power Plants

The co-combustion of supplementary fuels in power plants is based on the principle of using existing plants without major modifications. Possible ways of feeding supplementary fuels are shown in *Fig.2*.

The coal crushed in coal mills is fed into the combustion chamber by air as transport medium. Thermal energy of the hot flue gases is transferred in the boiler to the water-steam system for electricity generation or other uses. The pollutants are separated in the flue gas treatment system, which is mostly made up of a Selective Catalytic Reactor (SCR) de NO_X reactor, an electrostatic precipitator and a flue gas desulphurisation plant.

Supplementary fuels can be fed in two very different ways. One possibility, which will be the main focus in this study, is direct feeding to the combustion chamber together with the standard fuel. In this case, there may be need for an additional preparation step, i.e., drying or crushing. Another possibility is thermal pre-treatment by pyrolysis or gasification in a separate reactor. The products of this pre-treatment are then fed to the combustion chamber after passing varying steps of cleaning or heat recovery.

Existing power plants were designed for a specific fuel throughput. The influence of co-combustion on the different plant components may be very different. One example to be mentioned is the fuel volume flow increase resulting from the co-combustion of biomass. If approximately 10 % of the thermal output of the furnace system ise supplied as biomass, the fuel volume flow almost doubles. Common grinding and feeding of biomass and standard fuel may then result in problems.

The melting point of ashes produced in the combustion chamber can be reduced as a result of co-combustion. Compared to operation with the standard fuel, this may cause increased slagging and fouling in the combustion chamber and the heat exchangers. Problems of this kind may arise in particular when bio fuels are used whose ash melting point is very low. In power plants which, due to their mode of operation, generate molten slag, low melting temperatures of the ashes are desirable.

In the region of convective heating surfaces, there may be increased contamination or erosion when secondary fuels with high ash share are used. Especially for sewage sludge, this is an aspect of importance. Bio fuels, because of their lower ash fractions, are not problematic in this respect.

It should also be examined whether co-combustion of supplementary fuels results in changes in the flue gas volume and the flow rate, respectively. Any change in the flow rate influences the heat transfer in the boiler and also has an impact on the flue gas purification system. Higher flow rates may increase erosion. Another critical point is the high chlorine content of straw or other supplementary fuels, which may give rise to high-temperature corrosion and wastage of the heating surfaces.

The possible effects of co-combustion on the flue gas purification plant are determined by the placement of the DeNOx-System. In the case of the high-dust placement shown in *Fig.2*, deactivation of the $DeNO_x$ catalyst by components of the fly ash, such as alkali metals, arsenic, phosphorus, or fluorine, is quite possible.

For co-combustion of waste materials, a low-dust arrangement of the DeNOx-System downstream of the flue gas desulphurization plant is advantageous with a view to potential poisoning of the $DeNO_x$ catalyst. The price to be paid is reheating of the flue gases to the operating temperature of the catalyst.

Dust removal may cause problems especially when sewage sludge with its high ash content is used. In addition to the increased amount of ash, the removal behaviour of mixed ashes can be different from that of the ashes produced by the use of standard fuel.

The effects of co-combustion on the flue gas desulphurisation plant are determined by the chemical composition of the supplementary fuel. As a consequence of sulphur concentrations, bio fuels reduce the sulphur input, while sewage sludge tends to increase it.

In addition to sulphur, arsenic, lead, mercury, and other heavy metals can be removed in the flue gas desulphurisation plant. As a consequence, the utilisation of gypsum produced in flue gas desulphurisation can be influenced. In the case of chlorine containing supplementary fuels it must be taken into account that chlorine increases the solubility of gypsum.

Status of Co-combustion

In the course of this study, those power plant locations in Germany were listed which have experience in the co-combustion of supplementary fuels. The list is based on literature and other sources. Because of the large number of sources, no references will be indicated. *Table 6*, *Table 7* and *Table 8* show the locations plus information about the respective power plants.

At the present time, experience in the co-combustion of sewage sludge has been accumulated at 17 locations. The operating permit for co-combustion of sewage sludge was granted to twelve plants, but is being used by only nine plants. This results in an capacity for co-combustion of sewage sludge of approx. 350,000 t of sewage treatment sludge per annum.

According to *Table 7*, biomass or waste wood are being used as supplementary fuels at two locations. Experiments about co-combustion have been documented for six other sites, and conceptual design studies exist for two locations. As far as the other waste materials are concerned, these are specific solutions for industrial locations where specific wastes arise in large quantities. There have been tests in several additional power plants, of which results have not been published. After the occurrence of BSE cases on the European mainland, interest shifted and co-firing of meat and bone meal has been established in several German power plants. There is not sufficient data published to draw an accurate picture about range of co-firing and the effects of co-firing on the power plants. Depending on the legal and political developments co-firing of meat and bone meal might be a temporary solution.

Potentials

The use of supplementary fuels in electricity generation can be estimated on the basis of the primary energy of coal used, which amounted to 2708 PJ in 1998. Under the assumption that 10% of the energy could be substituted by a supplementary fuel with a calorific value of 10 MJ/kg, German power plants could use an annual 27 million t of supplementary fuels. Due to

Table 6 German power plants experienced with co-combustion of sewage sludge

Site / Company	Firing System	Boiler Size	Supl. Fuel	Status	Proportion % by wt	Proportion % -th.	Capacity
		Sewage Sludge					
Berrenrath Rheinbraun	brown coal fluidized bed	235 MW_{th}	dewatered	since 1995 cont. operation	4	3.5	max. 65 000 t TS/yr.*
Boxberg III VEAG	brown coal dry-bottom	2x500 MW_{el}	dewatered	since 1999 cont. operation	3-5 (6 % *)	approx. 1	approx. 30 000 t TS/yr.
Braunsbedra EWAG	brown coal stoker	4x7 MW_{th}	dewatered 100% wood	1996 tests performed	up to 50	approx. 25	-
Buschhaus BKB	brown coal dry-bottom	930 MW_{th}	dried dewatered	since 1998 cont. operation	5 *	< 5	approx. 80 000 t TS/yr.
Duisburg H. Stadtwerke	hard coal wet-bottom	200 MW_{th} 365 MW_{th}	dewatered	cont. operation	9	< 05	approx. 16 000 t TS/yr.
Farge Bremen Preussen Elektra	hard coal dry-bottom	356 MW_{el}	dewatered	permission but no operation	9	< 0.5	approx. 10 000 t TS/yr.
Franken II Bayernwerke	hard coal wet-bottom	1047 MW_{th}	dewatered dried	since 1998 cont. operation	5 % TS*	< 1.5	approx. 35 000 t TS/yr.
Heilbronn EnBW	hard coal dry-bottom	1933 MW_{th}	dewatered dried	since 1998 cont. operation	4	< 1.1 (4 %*)	approx. 40 000 t TS/yr.
Lausward Stadtw. Düsseld.	hard coal wet-bottom	170	dried	permission but no operation	21	11 (15%*)	1994-1996 20 000 t TS/yr.
Lünen Innovatherm	hard coal fluidized bed	9 MW_{el}	dewatered	since 1997 cont. operation	coal addition until LHV>4200 MJ/kg		approx. 100 000 t/yr.
Mumsdorf Mibrag	brown coal dry-bottom	N.A.	dewatered dried	tests performed	N.A.	N.A.	-
Karlsruhe RDK EnBW	hard coal dry-bottom	1280 MW_{th}	dewatered	1998 tests performed	1.25	0.07	-
Voerde STEAG	hard coal wet-bottom	350 MW_{el}	dried	1989 tests performed		approx. 20	-
Wahlheim Neckarwerke	hard coal wet-bottom	382 MW_{th}	dried	1996 tests performed	12.5	5	
Weiher II SaarEnergie	hard coal wet-bottom	195 MW_{th}	dewatered dried	since 1996 cont. operation	5	(15%*)	approx. 10 000 t TS/yr.
Weisweiler RWE	brown coal dry-bottom	913 MW_{th}	dewatered	cont. operation starting 5/2000	7.5	1	max. 140 000 t /yr. *
Zolling Bayernwerke	hard coal dry-bottom	1080 MW_{th}	dewatered	since 1999 cont. operation	9.6 5 %TS*	2.76	approx. 10 000 t TS/yr.
tests	permission issued	cont. operation	N.A.: Not Available				

Table 7 German power plants with co-combustion of biomass and waste wood

Site and Company	Firing System	Boiler Size	Supl. Fuel	Status	proportion %-wt	proportion %-th.	Capacity
		Biomass & Waste Wood					
Afferde El.Werke Wesertal	hard coal fluidized bed	124 MW_{th}	waste wood	since 1997 cont. operation	up to 100 %	up to 10 0%	N.A.
Berrenrath Rheinbraun	brown coal fluidized bed	235 MW_{th}	waste wood	1999 tests cont. operation	test with approx. 8 t/h		N.A.
Heilbronn EnBW	hard coal dry-bottom	1933 MW_{th}	wood straw	feasibility study 1996		8	20 t/h 80 000 t/yr.
Jänschwalde VEAG	brown coal dry-bottom	N.A.	waste wood	tests running	N.A.	N.A.	possible: 100 000 t/yr.
Lübbenau VEAG	brown coal dry-bottom	100 MW_{el}	wood chips	1993 tests	7	N.A.	-
Moabit BEWAG	hard /brown c. fluidized bed	240 MW_{th}	wood	1995 tests performed	N.A.	1 to 13	-
Pforzheim Stadtwerke	hard coal fluidized bed	29 MW_{el} 42 MW_{th}	wood, waste wood, hay	feasibility study 1997	substitution of about 20 MW_{th} possible		
Schwandorf Bayernwerke	brown coal dry-bottom	Block B 280 MW_{th}	straw	1996 tests		up to 20 %	-
		Block D 316 MW_{el}	waste wood chips	since 6/1999 cont. operation	8	12	100 000 t/a
tests	permission issued	cont. operation	* value stipulated in the license issued				

Table 8 German power plants experienced with co-combustion of waste materials

Site and Company	Firing System	Boiler Size	Supl. Fuel	Status	Technique & Proportion		Capacity
			Waste Materials				
Bremen Entsorg.betrieb	-	-	several wastes materials	conceptional study	-	-	-
Jänschwalde VEAG	brown coal dry-bottom	N.A.	RDF	tests running	N.A.	N.A.	possible 100 000 t/yr.
Leverkusen HKW Bayer AG	hard coal fluidized bed	105 MW_{th}	polystyrene resin	concepts	0.375	0.5	330 t/a
Schwarze Pumpe VEAG	brown coal dry-bottom	N.A.	tar residues	12/94-6/98 cont. operation	< 1		until 6/98 250 000 t
Wolfsburg VW	hard coal wet-bottom	N.A.	lacquer sludge used oil	cont. operation			up to 30 000 t/yr.
			Gasification / Pyrolysis				
Berrenrath Rheinbraun	brown coal		plastics, RDF, sewage sludge	tests since `86	fluidized bed gasification		up to 30 t/h
Hamm VEW Energie	hard coal wet-bottom	770 MW_{th}	plastics, car shred, industrial waste	Start up phase	rotary kiln pyrolysis 60MW (10 %)		2x50 000 t/yr.

tests | permission issued | cont. operation | * value stipulated in the license issued

Table 9 Fuel and energy potentials of the chosen supplementary fuels

	fuel potential	heating value	energy content	share on primary energy consumption [3]: hard coal	brown coal	total
	[million t/a]	[MJ/kg]	[PJ]	[%]	[%]	[%]
sewage sludge	2.3 (TS)	12	28	2.0	2.1	1.0
waste wood	8.5 [1]	16.5	140	10.2	10.4	5.2
Straw	5.9	14.5	86	6.3	6.4	3.2
forest residue	7.5	10 [2]	75	5.5	5.6	2.8
RDF-fuels	4,5	17 [4]	76	5.6	5.7	2.8
		Total	404	29.6	30.2	15.0

1) average of 4.1 – 12.7 Mio. t/a
2) depending on storage time 10 - 60 % moisture, or 6-15 MJ/kg; here: 40 % moisture or 10 MJ/kg
3) primary energy consumption 1998: hard coal = 1363 PJ; brown coal = 1345 PJ; total = 2708 PJ
4) assumed average heating value

logistical and operational limitations these heat shares might not be achieved in operation.

The results of the calculation of energy potentials on the basis of the calorific values of the supplementary fuel quantities listed in this work are shown in *Table 9*.

The supplementary fuel potential incorporates an energy volume of approx. 404 PJ, which corresponds to approx. 15 % of the energy input into German coal-fired power plants. If this supplementary fuel were used exclusively in lignite or hard-coal fired power plants, a nearly 30 % contribution would be possible. Of all the fuels considered, waste wood constitutes the largest single item. The potential CO_2 reduction as a percentage of the total releases by coal-fired power plants is between 12.2 % for the substitution of hard coal only, and 17.7 % for brown coal. The reason is the higher specific CO_2 emission of brown coal.

Comparison of the capacities of co-combustion in German power plants on the basis of *Table 6*, *Table 7* and *Table 8* with the fuel potential in *Table 9* indicates a major discrepancy. Co-combustion capacities exist for approx. 15 % of the arising sewage sludge. In the case of waste wood, a co-combustion capacity of approx. 200,000 t per annum must be compared with an annual amount of approx. 8 million t per annum.

Obstacles

Co-combustion of waste in power plants in Germany on a larger scale is hampered by a variety of obstacles.

First and foremost, the fuel supply of power plants must be guaranteed to maintain continuous operation. In the case of coal and other standard fuels, supply on international markets is easy. In some regions of Germany, the supply of sewage sludge is organised by industrial associations or municipal authorities. On the other hand, however, there are no institutions in Germany which could reliably supply power plants with biological fuels, such as forest wood waste or straw.

Availability is influenced also by the fuels themselves. While sewage sludge arises continuously the year over as a residue from sewage treatment, seasonal differences and risks resulting from climatic influences affect the availability of straw and other bio fuels.

In addition to these problems, also the requirements to be met in recycling combustion residues must be borne in mind, because the use of these materials in the cement and building industries must meet specific criteria. The high ash content of sewage sludge affects the properties of fly ash even at low contributions to the thermal power plant capacity.

Moreover, the co-combustion of sewage sludge, waste wood or other supplementary fuels requires amendments to the operating permits which may entail considerable expenses. In this connection, the lack of a precise definition of the terms "utilization" and "disposal" in German legal requirements represents an additional problem, with "disposal" implying considerably more stringent regulations. In Germany, the co-combustion of sewage sludge is considered both, utilization and disposal, depending on the permit stipulated in the specific case.

Where waste materials are used, the legal requirements from waste incineration must additionally be taken into account in Germany. Applications for permits require measurement programs, which may be quite extensive, on the basis of which emission limits are determined by the mixing rule.

Another problem is the capital costs. In addition to the costs for the storage and transport of supplementary fuels, the use of waste materials gives rise to costs also for modifying emission measurement systems and instrumentation and control systems. As a consequence of deregulation in the electricity market, capital investments are made only with great reluctance at the present time. Because of the mergers of power companies, which give rise to increasingly tougher competition, long-term planning is not possible at the present time.

Another important item is fuel costs. While a cost benefit is likely to arise from the combustion of waste material, biomasses, such as forest wood residues or straw, give rise to costs between DM 75 and 225/t (dry) [10].

Summary

At first sight, the work performed confirmed that the co-combustion of sewage sludge is a technology established on an industrial scale. Although there are precise regulations about permits for co-combustion, the use of sewage sludge should be examined critically with respect to highly volatile pollutant residues, such as mercury and mercury compounds.

In addition, the existing power plant spectrum in Germany offers possibilities for the co-combustion of forest wood residues, straw, recovered fuels or waste wood. The co-combustion of these materials is technically feasible even though altered compositions of residues and other details have not yet been clarified.

In addition to the technical aspects, activities seeking to further co-combustion are influenced by economic concerns against the background of the deregulation of the electricity market in Germany. The expected financial benefits make co-combustion attractive for the use not only of sewage sludge, but also of other waste materials.

There are two main reasons why co-combustion of biomasses has not yet been carried out on a technical scale in Germany. For economic reasons, co-combustion is possible only with financial support by the government. Moreover, there are no fuel markets to supply power plants with these fuels.

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