

Production and Utilisation of Solid Recovered Fuels in Germany

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Solid recovered fuels (hereafter *SRF*) is the generic term for fuels recovered from waste, that are either incinerated in plants specifically built for this purpose or co-incinerated in plants built for other fuel types. In Germany, they are produced mainly in mechanical (-biological) waste treatment plants and sorting facilities for industrial and commercial waste.

At present, 61 mechanical(-biological) waste treatment plants with a total capacity of around 6.4 million tonnes per year are operated in Germany. The average SRF yield of the plants is at around 47 per cent – the produced qualities vary substantially. Further output streams are combustible fractions, which do not meet SRF quality, value added materials (e.g. Fe scrap, NF scrap, wood fraction) and landfill fractions.

In sorting facilities for industrial and commercial waste, around 6.6 million tonnes of waste are processed per year. The SRF yield amounts up to around 70 per cent of the sorting facility input on average. Here too, SRF of varying quality are produced. Other output streams are materials for recycling (e.g. paper, cardboard, carton, plastics, wood) and sorting residues for waste incineration.

The recovery paths for SRF from municipal and commercial waste are

- mono-combustion in SRF power plants
- combustion in waste incineration plants (together with residual waste)
- co-combustion in coal-fired power plants as well as
- co-combustion in cement plants.

Currently, 35 SRF power plants with a total capacity of 6.03 million tonnes per year are operated in Germany. The capacity for SRF from municipal and commercial waste amounts to 4.62 million tonnes per year. A further plant is under construction. The capacities of the plants show a wide range between 15,000 tonnes per year and 575,000 tonnes per year. The continuous energy use is an important aspect with regard to site selection for SRF power plants. Most plants are operated with combined heat and power generation. The heat is utilised in form of processing steam, local or district heating.

Part of the SRF is utilised in conventional waste incineration plants together with non pre-treated residual waste. A few of the newer plants were designed for a mixture of residual waste and fractions with enriched calorific value from the processing of municipal and commercial waste from the start.

In ten coal-fired power plants in Germany SRF from mixed municipal waste and production-specific commercial waste are co-combusted. Altogether, in 2010 about 800,000 tonnes of these SRF were used. As the operational experience shows, a set of problems may be posed by co-combustion, key factors are firing technique (burnout) and chlorine corrosion. The co-combustion in Germany is caught in an area of tension between different economic factors that have a significant influence on the usage of SRF: the increase in electricity supply from renewable energy sources and its impact on the operation regime of coal-fired power plants, the development of co-payments/prices for SRF as well as price trends of coal and CO₂ allowances. In the coming years up to 2014 a slight decline in the quantity of SRF used in co-combustions is expected.

In 2010, 54 cement plants were operating in Germany. The proportion of SRF from the total fuel energy input rose continuously in the past few years and lay at 61 per cent in 2010. As regards mass, the largest proportions were made up of fractions from industrial and commercial waste (in total around 1.6 million tonnes – including plastics, cellulose/paper/cardboard and other fractions) as well as processed fractions from municipal waste (287,000 tonnes).

The recoverers pose different demands towards the quality of SRF, which depends in particular on the recovery process (e.g. type and design of the reactor, residence time of the fuel, type of flue gas treatment) and if applicable on the type of the products or the residues produced (e.g. cement clinker, power plant ashes, granulate, FGD gypsum). Particularly high quality demands are posed in the co-combustion in coal-fired power plants and cement plants.

1. Production of SRF

SRF in Germany are mainly produced in:

- Mechanical(-biological) waste treatment plants and
- sorting facilities for industrial and commercial waste.

Mechanical(-biological) waste treatment

The generic term *Mechanical(-Biological) Treatment Plants – M(B)T plants* – in the following comprises those plants, in which household waste (in most cases with other waste like commercial waste, bulky waste, sorting waste) is treated by applying mechanical processing, mostly in combination with biological treatment.

In all plants, fractions with an enriched calorific value are separated from the waste, that are utilised as SRF.

The mechanical(-biological) waste treatment includes four different process concepts in which mechanical, biological and thermal process stages with different objectives are combined with each other [27]:

- Material Stream Separation,
- Mechanical-Biological Stabilization – with biological drying,
- Mechanical-Physical Stabilization – with thermal drying,
- Mechanical(-Biological) Pre-treatment prior to incineration.

At present, 61 mechanical(-biological) waste treatment plants with a total capacity of around 6.4 million tonnes per year are operated in Germany (cf. [2]). 42 of them are equipped with a biological treatment stage.

In mechanical(-biological) waste treatment plants the following main output streams are produced:

- SRF – the produced quantities vary substantially,
- combustible fractions, which do not meet SRF quality,
- value added materials (e.g. Fe scrap, NF scrap, wood fraction) and
- landfill fractions.

The quantitative partitioning of the waste input into different output streams particularly depends on the material composition of the waste input, the process concept and the objective and correspondent technical equipment of the M(B)T plant (e.g. production of high quality SRF, or: maximizing the SRF amount with simultaneous lowering of quality). The SRF yield varies within a wide range: the lower limit is between 20 and 30 wt %, the upper limit is up to 70 wt % in some cases.

Within the scope of a study the SRF production as well as the other value added materials and secondary waste streams from the mechanical(-biological) waste treatment plants in Germany were estimated. On the basis of a balance scheme the yearly mass flows of the different output streams were calculated (Figure 1). The methodical procedure applied, the assumptions, and data taken as a basis and the derived balance scheme are described in the study [25].

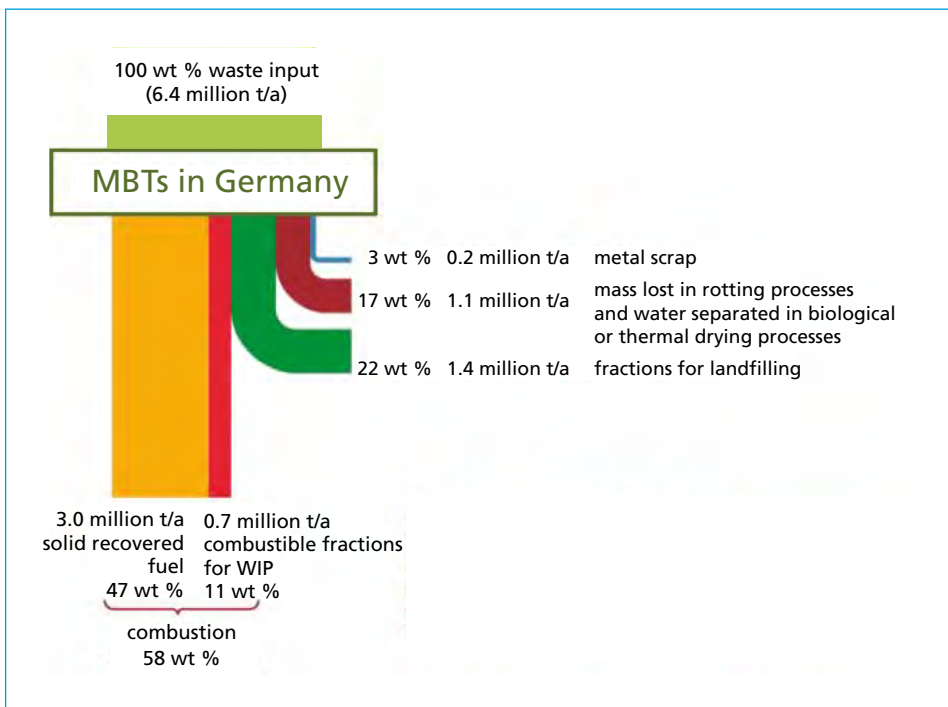


Figure 1: Mass balance of M(B)T plants throughout Germany (estimation)

Accordingly the total SRF production in German M(B)T plants amounts to about three million tonnes per year. Additionally about 0.7 million tonnes of combustible fractions (including extraneous materials) are recovered in waste incineration plants. Thus altogether nearly sixty per cent of the M(B)A input materials finally are incinerated – partly by mono-incineration in SRF power stations, partly by co-incineration in coal-fired power plants and cement plants and partly by conventional waste incineration. Beyond that, about 160,000 tonnes of Fe scrap and about 32,000 tonnes of NF scrap are separated annually for material recycling. Finally about 1.4 million tonnes per year of secondary waste from M(B)T plants remains for landfilling. The difference between the mentioned output streams and the waste input amounting to 6.4 million tonnes per year consists partly of mass lost in rotting processes and partly of water separated in biological or thermal drying processes (together about 1.1 million tonnes per year).¹

Processing of industrial and commercial waste

According to a report by the Prognos AG [19] about 6.6 million tonnes of waste from industry and commerce ends up in sorting facilities². Around 15 per cent of the input are separated as recycling material (e.g. paper, cardboard, carton, plastics, wood). A further 15 per cent are sorting residues for waste incineration plants. Up to around 70 per cent of the sorting facility input on average – that is up to around 4.6 million tonnes – are processed into SRF of varying qualities for mono or co-combustion³ (Figure 2).

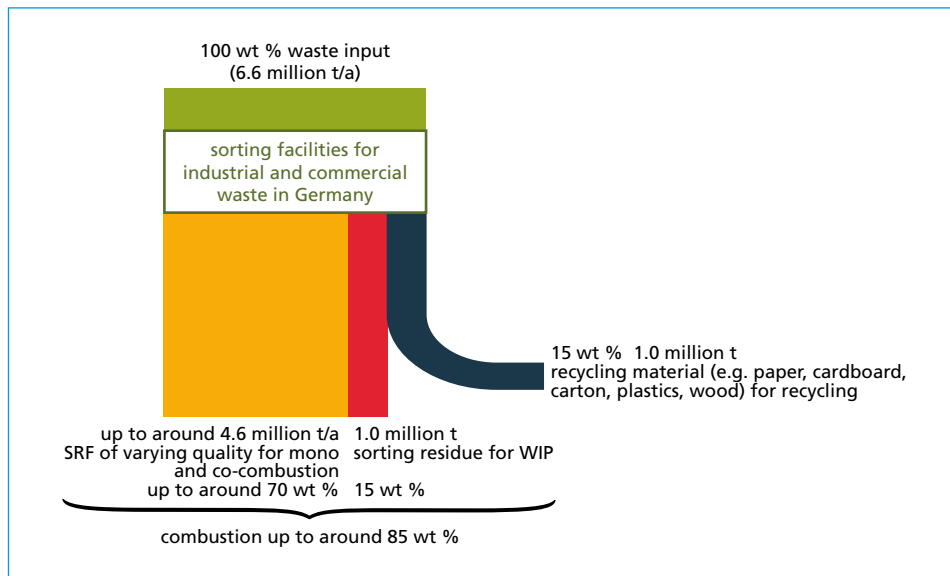


Figure 2: Mass balance of sorting facilities for industrial and commercial waste throughout Germany

Data source: Prognos AG: Der Abfallmarkt in Deutschland und Perspektiven bis 2020. Endbericht für den Naturschutzbund Deutschland e.V. (NABU), Berlin, Februar 2008

¹ The data above refer to the *capacities* of the mechanical(-biological) waste treatment plants in Germany. Due to the fact that not all plants are operating at full capacity, the actual throughputs and output quantities are somewhat lower.

² Further proportional parts of industrial and commercial waste are put towards waste incineration plants and mechanical(-biological) waste treatment plants. The given quantities are for the year 2008.

³ According to the Prognos report altogether about 6.9 million tonnes of SRF are produced in Germany (sum of SRF from mechanical-biological waste treatment plants and sorting facilities for industrial and commercial waste (base year 2008)).

2. Mono-combustion in SRF power plants

The following points are based on research [26], that has been continuously updated. Important information regarding SRF power plants in Germany is collected therein, inter alia in relation to the operator, energy user, further involved parties to the project, firing system, type of fuel, total rated thermal input and capacity.

As regards the capacity of SRF power plants there is a distinction between the total capacity – sum of all fuels – and the capacity for SRF from municipal and commercial waste. That way, a detailed overview of the capacities available for SRF from mechanical(-biological) waste treatment and from the processing of commercial waste is made possible.

The design calorific value and the calorific value of the materials used in the SRF power plants show a wide range of fluctuation. The total capacities are therefore given in relation to mass – tonnes per year – as well as in relation to energy – Gigajoule per year.

The current situation of the operation and construction of SRF power plants in Germany in August 2012 as regards the number of plants, the sum of the total rated thermal input, total capacity as well as capacity for SRF from municipal and commercial waste, are collated in Table 1. The plant locations and their capacities are shown in Table 2.

Table 1: Solid recovered fuel (SRF) power plants in Germany (as at August 2012)

Status	No. of plants	Total rated thermal input	Total capacity (Sum of all fuels)	Total capacity (Sum of all fuels)	Capacity for SRF from household and commercial waste
		MW	PJ/a	Mio. t/a	Mio. t/a
in operation	35	2,651	75.33	6.03	4.62
under construction	1	110	3.24	0.24	0.21
sum	36	2,761	78.57	6.27	4.83

Table 2: Solid recovered fuel (SRF) power plants in Germany – plant locations and capacities (as at August 2012)

Location	Commissioning	Firing system	Total capacity (Sum of all fuels) t/a	Capacity for SRF from household and commercial waste t/a
Amsdorf (ST) – 1. Linie	2004	grate	60,000	60,000
Amsdorf (ST) – 2. Linie	2009	grate	60,000	60,000
Andernach (RP)	2008	grate	on average 114,000 t/a SRF and max. 14,500 t/a production waste by the Rasselstein GmbH	114,000
Aßlar (HE)	1999	grate	15,000	15,000
Bernburg (ST)	2009	grate	400,000	400,000
Bitterfeld-Wolfen (ST)	2009	grate	100,000	100,000
Bremen-Blumenthal (HB)	2005	grate	60,000	60,000
Bremen-Hafen Mittelkalorikkraftwerk (HB)	2009	grate	226,000	226,000
Eisenhüttenstadt (BB)	2011	circulating fluidised bed	340,000	225,000

Table 2: Solid recovered fuel (SRF) power plants in Germany – plant locations and capacities (as at August 2012) – continued –

Location	Commissioning	Firing system	Total capacity (Sum of all fuels) t/a	Capacity for SRF from household and commercial waste t/a
Erfurt-Ost (TH)	2006	grate	64,000	64,000
Essen (NRW)	2010	stationary fluidised bed	26,500	26,500
Frankfurt/Höchst (HE)	2010	rotating fluidised bed	575,000 with 13.5 MJ/kg (layout); max. 675,000	575,000
Gersthofen/Augsburg (BY)	2009	grate	70,000	70,000
Gießen/Atzelbusch (HE)	2009	grate	25,000	25,000
Glückstadt (SH)	2009	circulating fluidised bed	254,000	135,000
Großräschen/Freienhufen (KW Sonne) (BB)	2007	grate	240,000	240,000
Hagenow (MV)	2009	grate	80,000	80,000
Heringen/Wintershall/Philippsthal (Werra) (HE)	2009	grate	270,000	270,000
Hürth-Knapsack (NRW)	2008	grate	240,000	240,000
Karlsruhe (BW)	2010	circulating fluidised bed	535,500	22,000 (planned operational point)
Korbach (HE)	2008	grate	75,000	75,000
Lünen (NRW)	1982/2005	circulating fluidised bed	up to 165,000 (dependent on calorific value)	20,000
Meuselwitz-Lucka (TH)	2005	grate	50,000	50,000
Minden (NRW)	2002	grate	35,000	35,000
Neumünster (SH)	2005	circulating fluidised bed	150,000	150,000
Premnitz (BB) (CFB)	2001/2005	circulating fluidised bed	100,000	100,000
Premnitz (BB) (grate)	2008	grate	150,000	150,000
Rostock (MV)	2009	grate	170,000	170,000
Rüdersdorf (BB)	2008	grate	226,000	226,000
Rudolstadt-Schwarza (TH)	2007	grate	60,000	15,000
Schwedt (BB)	2011	circulating fluidised bed	400,000	200,000
Spremberg (BB)	under construction	grate	240,000	210,000
Stavenhagen (MV)	2007	grate	90,000	90,000
Weener/Leer (NI)	2008	grate	140,000	120,000
Werdohl-Elverlingsen (NRW)	2002/2004	stationary fluidised bed	around 187,800 (fuel mix 2008)	4,600 (applied amount 2008)
Witzenhausen (HE)	2008	circulating fluidised bed	265,000	210,000

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Currently, 35 SRF power plants with a total capacity of 6.03 million tonnes per year are operated in Germany – this is equivalent to an energy-related capacity of 75.3 Petajoule per year (PJ/a) – and a total rated thermal input of around 2,650 Megawatt (MW). The capacity for SRF from municipal and commercial waste amounts to 4.62 million tonnes per year.

The plant in Spremberg/Schwarze Pumpe (240,000 t/a) is under construction. The start of the trial operation is planned from November/December 2012. The location of Stade-Bützfleth has had a halt in construction for around 2 years. The operator is insolvent. It is unclear whether an investor can be found who will finish off the construction process.

The capacities of the plants show a wide range between 15,000 tonnes per year and 575,000 tonnes per year. The largest plants are in Schwedt (400,000 tonnes per year), Bernburg (400,000 tonnes per year), Karlsruhe (535,500 tonnes per year) and Frankfurt/Höchst (575,000 tonnes per year). They are all designed as fluidised bed, apart from Bernburg (grate furnace, three lines).

Energy forms and use

The continuous energy use is an important aspect with regard to site selection for SRF power plants. The use of the heat has to be aspired for economical as well as for ecological reasons (energy efficiency).

SRF power plants serve

- partly as energy supply for a single plant or company, e.g. for paper factories, in the food and pharmaceutical industry as well as in the production of potash, soda, cement, tin plate and tyres,
- partly for the energy supply of an industrial or commercial estate, e.g. industrial and commercial estate Premnitz, industrial estate Frankfurt/Höchst, industrial estate Gersthofen, chemical estate Knapsack, chemical estate Bitterfeld-Wolfen as well as
- partly for public energy supply, e.g. for public utilities, examples are Erfurt, Neumünster and Großräschen.

Hybrid forms – made up for example from the energy supply of an industrial and commercial estate on the one hand and the public electricity and district heating supply on the other hand (e.g. Premnitz) – are possible too.

Most plants are operated with combined heat and power generation with the heat being used in form of process steam, local or district heating. District heating production on its own is the exception: only the plant in Gießen passes the gained energy solely back into the district heating network of the public utilities of Gießen. There are few SRF power plants solely with electricity production (e.g. Rüdersdorf, Meuselwitz-Lucka), where no heating consumer could be found nearby.

In many plants solely SRF from processing of household and commercial waste are combusted. In SRF power plants located at production sites production-specific wastes from the neighbouring industrial plants are also partly combusted. Most frequently this combination of energy supply and waste recovery was used at the sites of paper mills.

With regard to the firing system in SRF power plants grate firing dominates (with a proportion of around 70 per cent in relation to the number of plants) – followed by circulating fluidised bed firing.

Grate firing has lower demands towards the depth of material processing of the SRF. It offers the highest process security but reaches a slightly lower energy yield at the same time. The investment is normally lower for a grate firing plant than for a plant with circulating fluidised bed – with the same capacity.

For the circulating fluidised bed, the demands towards the SRF quality and therefore towards the depth of material processing are higher. Because of the fluidisation of bed material and fuel, the energy consumption is initially higher, over all however the energy efficiency is higher in comparison to grate firing. A major strength of the circulating fluidised bed is its flexibility in relation to the broad range of calorific values and the spectrum of usable fuels: for example it is possible to co-combust very moist sludge with low calorific value. (compare [31])

3. Combustion in incineration plants for residual waste

SRF from mechanical(-biological) waste treatment are partially utilised in conventional residual waste incineration plants too. The SRF are mixed with the residual waste in the bunker and co-combusted with it. Some new plants were however designed for a mixture of untreated residual waste and fractions with an enriched calorific value from the processing of municipal and commercial waste from the start. This category includes for example the waste incineration plants Hannover-Lahe and Salzbergen.

The technical characteristics of residual waste incineration plants will not be discussed further here. Instead the reader is directed to the available literature (e.g. [29, 22, 4]).

4. Co-combustion in coal-fired power plants

Presently, in ten coal-fired power plants in Germany SRF from mixed municipal waste and production-specific commercial waste are co-combusted (Table 3) and experiments have been conducted at other locations. Altogether, in 2010 about 800,000 tonnes of these SRF were used. In the coming years up to 2014, a slight decline in the quantity of materials used in co-combustions is expected.

Trends in co-combustion

The co-combustion of SRF from mixed municipal waste and production-specific commercial waste in Germany is caught in an area of tension between different factors that have a significant influence on the current usage of SRF and related plans of power plant operators.

On one hand, the increase in electricity supply from renewable energy sources has had a noticeable impact on the operation regime of coal-fired power plants. In a number of black coal units, contrary to previous plans, the co-combustion could not be extended or even had to be significantly restricted or completely terminated due to reduced operating hours.

In addition, various economic incentives affect the power plant operators in their decisions regarding the SRF usage and the choice of SRF types and quantities.

- **Development of co-payments or prices for SRF:** In recent years the SRF market has undergone a great change, especially through the great expansion of capacity at SRF power plants. As a result, the co-payments for SRF from mixed municipal waste and from production-specific commercial waste decreased significantly. In some cases, depending on the quality of these fuels, (e.g. particle size, chlorine content, renewable carbon content) even *prices* have to be *paid*.

- Price trends in coal:** The price of coal is a significant cost factor for black coal-fired power plants. According to figures by the Federal Office of Economics and Export Control (BAFA), the price for power plant black coal (coal from third countries free at the German border) in 2011 was at 107 EUR/t of coal equivalent (tce) on average and therefore significantly higher than in the past fifteen years – apart from the maximum so far in 2008.
- Price trends of CO₂ allowances:** Depending on the renewable carbon content in SRF, the power plant operators may economize on CO₂ allowances. From 2013 no more free CO₂ allowances for electricity production will be allocated and the energy industry will have to buy them all by auction. However the emission trade is characterised by a surplus of certificates on the market at present. The price of the certificates has sunk significantly since their introduction and ranges between 7 and 8 EUR/t CO₂ – originally 30 EUR were envisaged [33]. The economic crisis, sinking productivity and the promotion of the Renewable Energy Sources Act are cited as reasons. In order to stop the price fall, the Commission is planning to delay the output of further CO₂ certificates from 2013 and increase their price by way of this artificial shortening of supply.

Table 3: Power plants with continuous co-combustion (as at March/April 2011)

Location	Operator	Type of coal	Firing system	Boiler	Start of continuous co-combustion
Jänschwalde	Vattenfall	Brown coal	Dry pulverized coal firing	Plants Y1 + Y2 (8 of 12 boilers)	Y1: 02/2005 Y2: 07/2005
Schwarze Pumpe	Vattenfall	Brown coal	Dry pulverized coal firing	Both boilers	08/2007
Werne/ Gersteinwerk	RWE	Black coal	Dry pulverized coal firing	Unit K (only boiler)	2004/2005
Berrenrath/Ville	RWE	Brown coal	CFB firing	Both boilers	01/2007
Veltheim/Porta Westfalica	GK Veltheim (E.ON/SWB)	Black coal	Slag tap firing	Unit 3 (1 of 2 boilers)	01/2007
Pforzheim	Heizkraftwerk Pforzheim GmbH	Black coal	CFB firing	Only boiler	11/2009
Flensburg	Stadtwerke Flensburg	Black coal	CFB firing	boiler 9+10+11 (3 of 5 boilers)	boiler 11: 2007 boiler 9: 06/2008 boiler 10: 10/2008
Duisburg	Stadtwerke Duisburg	Black coal	CFB firing	Unit I (1 of 2 boilers)	01/2009
Osnabrück	Ahlstrom (paper factory)	Brown coal and black coal	CFB firing	Only boiler	1993
Oberkirch	Koehler (paper factory)	Black coal	CFB firing	Only boiler	SRF-P: 2004 SRF-M: 2006

CFB: circulating fluidised bed

Biofuels

Aside from the usage of SRF with biogenic content, the co-combustion of pure renewable biofuels has become more important in coal-fired power plants. In Table 4 coal-fired power plants are listed, where biofuels are co-combusted or where it is planned. Examples of co-combusted biofuels are: waste wood of A1 and A2 classes, fresh wood, for example from maintenance works, green waste as well as coffee grounds and spelt. Different *exotic* biofuels, such as rice husks or olive pits have also been taken into consideration by some operators; however from the economic point of view their co-combustion does not pay off (yet).

Table 4: Co-combustion of biofuels in coal-fired power plants – examples (as at 2011)

Power plant	Type of biofuel	Status
Berrenrath	Waste wood	Continuous operation
Bremen/industrial port	Spelt, coffee grounds	Continuous operation
Duisburg	Fresh wood, waste wood (A1)	Planning
Flensburg	Waste wood chips, fresh wood chips	Continuous operation
Moorburg/Hamburg*	Biomass	Use is examined
Offenbach	Wood pellets (A1) wood chips (A1)	Continuous operation Permit for continuous operation striven
Wachtberg/Frechen	Fresh wood, green waste, waste wood (A1 and A2)	Test operation, application for continuous operation planned
Wedel	Biomass pellets	Tests

* New-build power plant, commissioning planned for 2012

In June 2012, different environmental organisations and organisations in the German wood industry made a joint declaration saying that they are in opposition of the movement by some energy companies that promotes the co-combustion of wood type biomass in coal power plants. They demand, that wood should be used resource efficient, combined with high value added. Considering that the energy political goals towards the further development of biomass utilisation will still be implemented, according to EU studies there will be a *massive shortfall in the supply of wood* in Western Europe. An additional demand for wood by conventional coal-fired power plants would make the situation worse and increase pressure on the forests [1].

Operational experience – problems

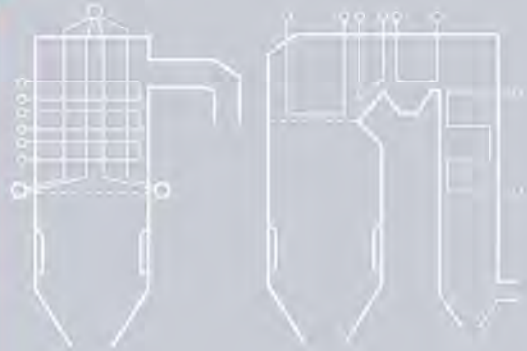
As the operational experience shows, a set of problems may be posed by co-combustion:

- Incomplete burnout (e.g. [16, 8])
- Chlorine corrosion (e.g. [6, 24])
- HCl emission – Retrofitting of emission control requirements at CFB plants (e.g. [35])
- Fouling and slagging of the boiler heating surfaces (e.g. [17, 3])
- Increased chloride load of the flue gas desulphurisation and FGD products (e.g. [13, 20])
- Problems with discharging, conveying and dosing (e.g. [10])
- Mechanical problems due to metallic contaminants (e.g. [21, 23])
- Chemical and thermal problems due to aluminum in CFB boilers (e.g. [23])
- Erosion of boiler (e.g. [20, 5])
- Exceeding the capacity of the ash discharge systems.

Some of them can cause massive disruption of plant operations, others are possible permanent limiting factors and finally there are problems that can be managed by optimisation of SRF quality and/or adjustment in some plant components. Thus, there are two key factors that determine technical and operational success or failure of the co-combustion project: the firing technique and corrosion. Different types of power plants offer various favourable conditions for the co-combustion regarding these two factors in dependency to the firing system and type of coal.

Ersatzbrennstoffe in Kohlekraftwerken

Mitverbrennung von Ersatzbrennstoffen in Kohlekraftwerken



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Im Bereich der Kohlekraftwerke bestehen grundsätzlich Potentiale zum Ausbau der Mitverbrennungskapazitäten für Ersatzbrennstoffe und zugleich hohe wirtschaftliche Anreize durch Einsparung von Brennstoffkosten sowie Zuzahlungen der Ersatzbrennstofflieferanten.

Um Ersatzbrennstoffe aus Siedlungsabfällen herzustellen, ist ein enormer aufbereitungstechnischer Aufwand erforderlich. Die Berichte der Kraftwerksbetreiber über Nichteinhaltungen der Spezifikationen machen deutlich, dass hier zum Teil noch erheblicher Optimierungsbedarf besteht.

Zielsetzung dieser Arbeit ist die Untersuchung der Eignung von Ersatzbrennstoffen aus der mechanisch(-biologischen) Abfallbehandlung zur Mitverbrennung in Kohlekraftwerken aus verfahrenstechnischer, ökologischer und wirtschaftlicher Sicht sowie die Identifizierung der wesentlichen Einflussfaktoren und Optimierungsmöglichkeiten.

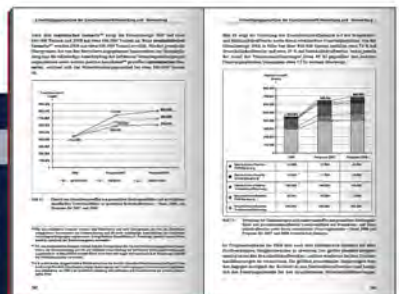
Hierzu wird zunächst der Stand der mechanisch(-biologischen) Abfallbehandlung in Deutschland hinsichtlich Anzahl, Kapazität und technischer Ausstattung der Anlagen dargestellt. Daran schließt sich eine detaillierte systemtechnische Analyse der Anlagen im Hinblick auf die Verfahrenskonzepte, verfahrenstechnischen Konfigurationen sowie die erzeugten Outputströme und deren Verbleib an.

Im zweiten Teil der Arbeit werden die bislang durchgeführten und derzeit vorbereiteten Projekte zur Mitverbrennung von Ersatzbrennstoffen aus aufbereiteten Siedlungs- und Gewerbeabfällen in deutschen Kohlekraftwerken auf der Grundlage einer Literaturrecherche und der Befragung der Kraftwerksbetreiber untersucht.

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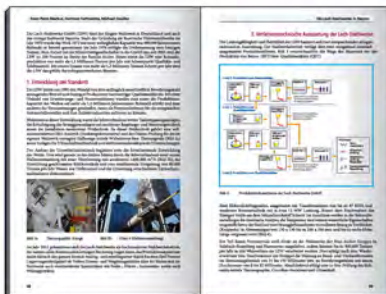
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With regard to the environmental compatibility of co-combustion especially the following has to be examined:

- accumulation of heavy metals in power plant by-products and the impact on their environmental compatibility and usability (e.g. [3, 14]) as well as
- the emissions particularly of volatile heavy metals into the atmosphere (e.g. [34, 11, 30]).

For a detailed report about the mentioned problem areas, the reader is pointed to the earlier examination [25].

5. Co-combustion in cement plants

The co-combustion potential in the cement industry has been used to an increasing extent in the past few years. The production of cement clinkers is an example for combined energetic and material waste utilisation in *one* process. The ash of the SRF remains in the product and becomes a part of the cement.

In 2010, 54 cement plants were operating in Germany. Cement clinker is produced in Germany mainly by way of the dry process in rotary kilns with cyclone preheater. Rotary kilns with grate preheaters have less importance, shaft furnaces are practically irrelevant with a proportion of only around one per cent of the capacity. [32]

Secondary raw materials

During the production of Portland cement secondary raw materials are increasingly used which – just like the natural raw materials – have silicium, aluminium, iron and/or calcium oxide as their main components. Secondary raw materials include for example lime sludge from drinking and waste water processing (Ca), waste sands from foundries (Si), steel mill dust and mill scale (Fe) as well as granulated blast furnace slags and fly ashes (Si-Al-Ca). The demand for sulfate carriers, that aid the control of processing characteristics of cement, is partially covered by gypsum from flue gas desulphurisation plants. [32]

Substitute fuels

Clinker burning is a highly energy intensive process. The conventional fuel for the cement industry – mainly coal – has been partially substituted with petroleum coke. It is the solid mineral oil fraction that is produced during the processing of crude oil and consists mainly of carbon.

By now, substitute fuels are used to a considerable extent too. Their proportion in the total fuel energy input rose continuously in the past few years and was at 61 per cent in 2010. The largest mass proportions fell into

- fractions of industrial and commercial waste: in total around 1.6 million tonnes – including plastics, pulp/paper/cardboard and other fractions,
- mixed fractions of municipal waste: 287,000 tonnes,
- sewage sludge: 276,000 tonnes,
- tyres: 253,000 tonnes,
- meat and bone meal and animal fat: 182,000 tonnes.

Lower proportions include other substitute fuel types such as oil mud, organic distillation residues, solvents, waste oil and waste wood.

Figure 3 shows the development of input masses of the various substitute fuel types since 2001. Their calorific values show a great variation range with average values between 4 MJ/kg e.g. for sewage sludge and 28 MJ/kg for waste oil and tyres. [32]

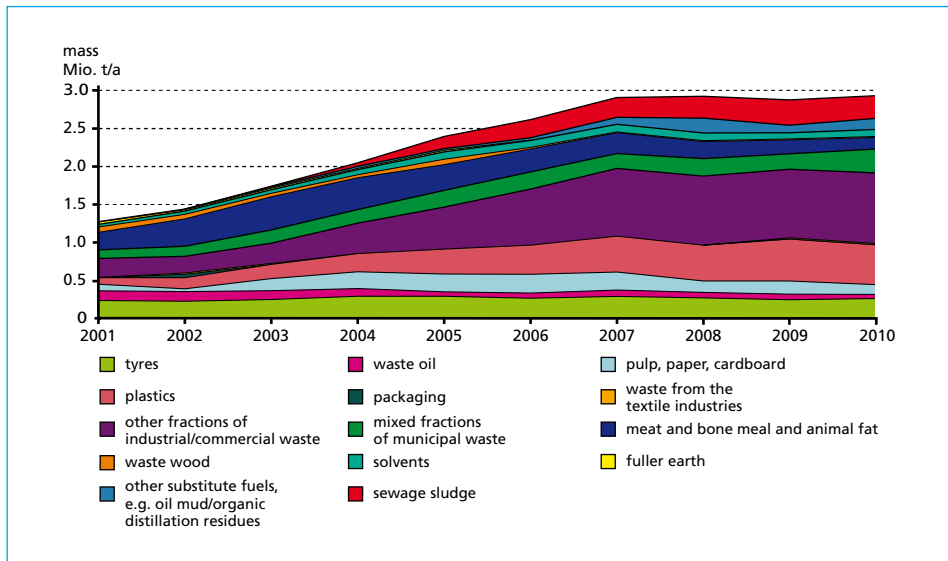


Figure 3: Use of substitute fuels in the German cement industry

Data source: Verein Deutscher Zementwerke e.V. (VDZ): Umweltdaten der deutschen Zementindustrie 2001 bis 2010. Düsseldorf, 2002 bis 2011

Different concepts for SRF utilisation in cement plants are described for example by Hoffmann and Kragting [9], Pomberger [18], Mauschwitz und Hackl [12].

The cement plant Rüdersdorf is a special case. SRF are gasified here in a circulating fluidised bed. The low calorific gas is used as fuel in the calcinator firing. The ash from the circulating fluidised bed is ground down, mixed with raw meal and bound into the clinker in the rotary furnace [7].

For the co-combustion in cement plants, the operators also have high demands towards the SRF quality [15].

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