

Starting in the early eighties, considerable efforts have been made to produce waste derived solid fuels – with little satisfaction due to insufficient qualities. Since then a lot of new techniques and processing machines have been developed, so we can use this formerly dumped material sustainably for heat and power generation as well as co-processing.

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Entrance of the SRF-production facility of REMONDIS, Ertstadt/Germany

REMONDIS

Production and use of Solid Recovered Fuels – developments and prospects

1 Initial situation

For many years decisive measures in the field of resource management have not only been determined by German and European environment political guidelines (e.g. “TA Siedlungsabfall¹” or “European Landfill Directive 1999/31/EC”) but have been driven by a growing shortage of energy reserves and resources. Getting access to resources is going to be a crucial matter not only for single economies but for all mankind. The ongoing problematic of ‘Food or Fuel’, the conflict of using cropland not only for growing crops but also for

¹ Technical Instructions for Utilisation, Handling and Disposal of Domestic Waste

growing energy plants clearly shows the priority of this issue of energy management. As a result, new ways of a resource efficient production, a more efficient generating of energy and an improved use of “waste as a resource” must be consistently pursued. The production and use of Solid Recovered Fuels (SRF) represent a sustainable alternative for waste that cannot be used for material recycling due to economic inefficiency.

As a consequence of both energy crises in 1973/74 and 1979/80, considerable efforts have been made to produce fuels from liquid and solid waste streams, amongst others in Germany, starting in the early eighties. These efforts regarding the first generation of secondary fuels turned out



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resources enhance efforts among the power plants and cement works by using alternative waste derived fuels. In particular the co-incineration of alternative fuels in coal fired power plants, cement and lime producing industries require a high quality standard which allows the replacement of fossil fuels without causing operative and technical constraints.

Thus, SRF are subject to stringent quality standards which may cause it to be quite similar to regular fuels regarding the most crucial characteristics. The ongoing development of appropriate recycling technologies enabled the breakthrough for secondary fuels. The quality requirements that have been agreed upon with customers often ask for an extensive and substantial treatment of the material.

In contrast, waste-to-energy plants that have particularly been built for using middle- and high-calorific waste fractions are generally modified with regard to incineration technology and equipment which allow lower quality standards and a less extensive treatment of the input material.

However, the parameters chlorine and calorific value as well as the particle size and the amount of disturbing material do have a great significance in all applications especially when aiming at a high availability and thermal substitution rate. These plants depend on agreed specifications and reliable quality levels.

2 Distinguishing between Solid Recovered Fuel (SRF) and Refuse Derived Fuels (RDF)

Due to a lack of common definitions of the terms, one first of all needs to explain its use in this context. In the meantime Solid Recovered Fuel (SRF) has been defined in compliance with CEN/TC 343 as a sub-category of waste derived solid fuels.

The terms Refuse Derived Fuels (RDF) is commonly used for waste derived solid fuels in differing coarser grain sizes and without any compliance to CEN/TC 343 and without a comprehensive quality assurance system.

While a sustainable co-processing of secondary fuels in the cement and lime producing industry as well as the use in power plants according to the regulations based on RAL-GZ 724 has been established over the past years, recent experience i.e. with corrosion shows that a permanent use of RDF in waste-to-energy plants may also profit from an established quality control of alternative fuels.

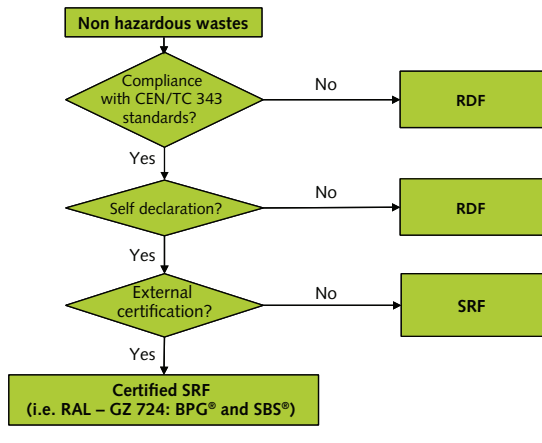
In the following, a closer look will be taken at the Solid Recovered Fuels called BPG® (Fuels from industrial/ commercial waste) and especially SBS® (Substitute fuel derived from municipal waste processing) which have been developed by REMONDIS and are both subject to quality assurance and protected by a trademark. These trademark rights were alienated to the German "Gütegemeinschaft Sekundärbrennstoffe und Recyclingholz e.V."

to be less than satisfactory due to insufficient qualities [1], [2]. Similar experiences have been made in several other European countries as well as in the US. Despite several attempts to use waste for the production of fuels its importance in this sector remained rather low compared to the established landfill disposal and incinerating waste with or without energy production.

The efforts towards resource efficiency were revived by two different impulses. Firstly, by the interest of industries which produce waste within their own industrial manufacturing processes. Secondly, the search for alternative fuels by cement and lime producing industries as well as the coal fired power plants; they were looking for homogeneous alternative fuels of guaranteed quality and sufficient availability.

Moreover, the demand for a decrease in climate-damaging emissions, as a result of the Kyoto Protocol and the establishment of a CO₂-certificate trade exchange, reinforces the need for alternative secondary fuels with a high share of biogenic materials. Rapidly growing costs for primary energy

1 How to distinguish between RDF and SRF



(BGS e.V. = Quality Assurance Association for Solid Recovered Fuels and Wood Recycling). The use of this trademark in accordance to the regulations is assured by the quality label RAL-GZ 724. The quality and assessment standards of the BGS e.V. also give a detailed description of approved input materials for the production of fuels.

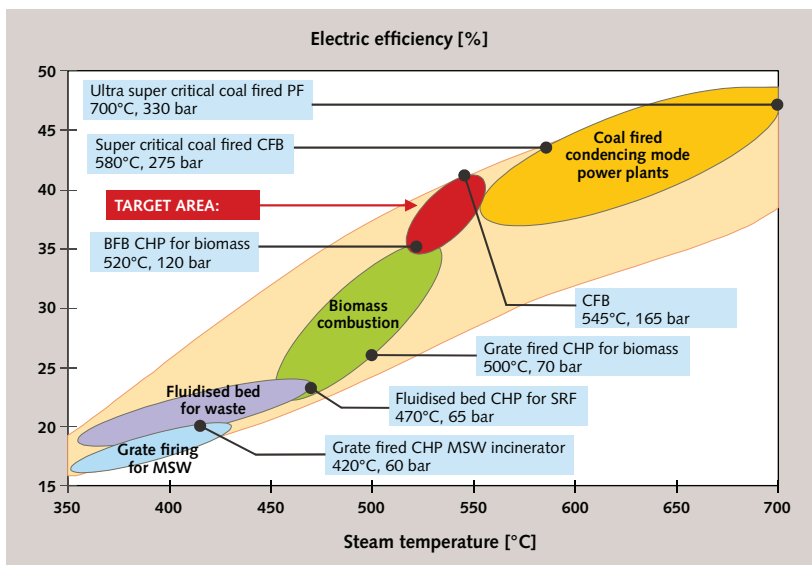
The production of SBS® mainly requires different high calorific fractions from solid waste as input material [3]. The upgrading of these fractions to SBS® is attained through an elaborated processing which allows its planned use as a substitute for coal or lignite. In the meantime modern kilns even use RDF in specially equipped calciners, resp. preheaters without such an extensive treatment as required for sinter zone burners [4].

3 Basic requirements for Solid Recovered Fuels

There are certain criteria that have to be fulfilled by SRF that do not depend on the firing system [5]. These criteria are:

- » Large, homogeneous amounts,
- » Reliable quality standards in terms of chemical, physical and fuel characteristics,
- » A long-term availability,

2 Target Area of the EU-Project RECOMBIO: red area



- » Product- and environment-neutrality during valorization,
- » Suitable for storage and conveying,
- » Acceptance (employees, authorities and public),
- » Economic efficiency

Therefore, it is necessary to influence or rather adjust especially the following parameter by making use of selected technologies:

- » Calorific value, chlorine, ashes and moisture content,
- » Particle shape, size and size distribution,
- » Flammability and combustion behaviour,
- » Share of disturbing material,
- » Heavy metals, for co-processing guidelines from the RAL-GZ 724 are taken into account.

Since co-incineration and waste-to-energy plants are aiming at high availability and efficiency rates, a consideration of the parameters calorific value and chlorine is of major importance.

4 Production of SRF at REMONDIS

The company has experience of producing alternative solid fuels since 1995. Due to different requirements regarding the quality of SRF, REMONDIS operates several types of SRF production plants on an international level. It is possible to combine these with mechanical-biological treatment plants or recovery plants for industrial waste. Determining a location and a specific type of plant heavily depends on the availability of wastes and markets for the products. Production plants provided with technology to reduce chlorine by Near-Infra-Red systems (NIR) are mainly located in regions with cement plants that show great sensitivity to chlorine or most of the power plants that work with high steam parameters and high availability rates.

Recovery plants that do not have technology to reduce chlorine mainly provide fuel for mono-incineration plants or power plants working with low steam parameters which means low electrical efficiency. Figure 2 illustrates the target area of the EU-Project RECOMBIO marked in red, which shows this matter quite clearly [6].

After having to close down several production plants for secondary fuels due to surplus capacities [7] REMONDIS now only operates plants in Germany that are able to reduce the chlorine content of SRF using NIR-technology in order to provide SRF of high quality. While the production of industrial waste derived SRF did not require a pre-sorting treatment [3], the production of SRF from municipal solid waste, bulky waste and blend industrial wastes similar to municipal waste comprises separation of high calorific fractions and a selective reduction especially of chlorine. In 2001 REMONDIS first implemented sensor-based sorting in order to

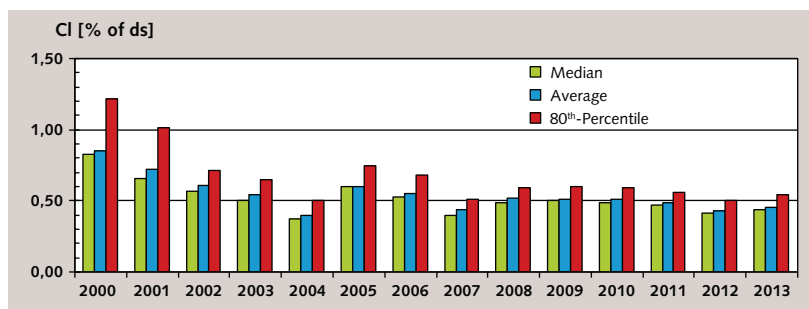
reduce chlorine and heavy metals in high calorific fractions [8].

Figure 3 shows a successful decrease and consistency of the parameter chlorine in SBS® as a result of an implementation of NIR-systems at the production site in Erfstadt. This also leads to new possibilities of an even more extensive decrease in heavy metals (such as Cd and Pb) that goes beyond the effects of using common technology for the extraction of iron /non-iron metals and of heavy parts [8]. Negative effects on the Cl-level resulting from the enforcement of the “Technical Instructions for Domestic Waste” in the second part of the year 2005 [9] as to be seen in Figure 3 were mastered as well in the course of the year 2006. It is quite remarkable that fuel produced in Erfstadt has become more homogeneous by now amongst other parameters with regard to the parameter chlorine than some types of coal, especially imported coal. The fuel being homogeneous to a great extent allows large amounts to be used even for highest TSR and in power plants working with high steam parameters. Along with the EU-Project RECOFUEL, positive effects on heavy metals and other parameters such as K, Na and Al were recorded [10].

The use of sensor based sorting ensures that quality criteria according to RAL-GZ 724 for SRF from high calorific fractions of municipal waste and customer requirements regarding reliable low amounts of chlorine of class 2 according to EN 15359 are being fulfilled [11]. And sensor-based sorting thus enabled a third generation of SRF (SBS®) to become well established in Germany.

The separation of high calorific fractions is followed by the actual production of secondary fuels according to certain quality criteria. The process of producing an SRF which is pneumatically injectable with a fluffy consistency and constitutes a completed and quality assured fuel is made up of multiple steps; two size reducing steps, two windshifters for separation of heavy parts (inerts and metals), several steps of iron/ non-iron-separation. The result is a fluffy SRF with the requested grain size (e.g. $d_{95} < 25$ mm) and a large surface. Fe- and non-Fe metals that have been separated from the product can be used for metal recycling. The residues from the separation of the high calorific fractions from municipal waste are dried in a biological process first and then burnt in waste-to-energy plants to produce heat, steam or power.

Due to a material splitting that is carried out consistently in Erfstadt it is also possible to separate certain fuel fractions for waste-to-energy plants. It has been common practice for years now to a significantly improve even the quality of separated fractions which are being used in municipal waste incineration in terms of homogeneity and thus efficiency compared to wastes that have not undergone any preprocess. It has been proven that



production sites like Erfstadt allow an optimized combination of co-incineration and waste incineration technology [12].

3 Development of Cl-concentrations in SBS® from Erfstadt

5 Quality assurance and standardization

5.1 REMONDIS activities

The successful use, acceptance and substantial production of SRF is based on a quality assurance chain; starting off with the waste collection, on to the production sites for Solid Recovered Fuels up to the control of incoming materials at the fuel receiving plants.

The quality assurance system which originated back in 1996 and has gradually been improved [3] by a standardized sampling, preparation and analysis process and is part of delivery and customer contracts within the industries, crucial for an authorized use as well as the quality verification by RAL and an essential element of authorizations that have already been granted.

5.2 National activities of the BGS:RAL-GZ 724

The “Gütegemeinschaft Sekundärbrennstoffe und Recyclingholz e.V.” (BGS) in Germany has developed nationwide standards with respect to quality criteria, resp. environmentally relevant parameters and biogenic content, quality levels and internal and external quality control systems of SRF [13], [14]. The activities of the BGS have been approved by RAL by 01.07.2001. Since then members of the BGS can request to obtain the RAL label RAL-GZ 724 (1) and since 2006 the RAL-GZ 724 (2) in order to certify their biogenic content of their SRF recipe.

The information on which the BGS e.V. based its determination of guiding values was confirmed through a long term project which had been initiated by the MUNLV-NRW² [15]. Even the approach of different forecasting tools confirmed Solid Recovered Fuels on the quality level of RAL can be used for co-processing according to German and European technical standards without any negative environmental effects. A side effect which is interesting to be mentioned is that studies on national

² Ministry for Protection of Environment, Nature, Agriculture and Consumer of the state of Northrhine-Westfalia/ Germany

Tab. 1 Classification system for Solid Recovered Fuels according to EN 15359: 2011 [10]

Classification characteristic	Statistical measure	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV)	Mean	MJ/kg (ar)	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3
Chlorine (Cl)	Mean	% (d)	≤ 0.2	≤ 0.6	≤ 1.0	≤ 1.5	≤ 3
Mercury (Hg)	Median 80 th percentile	mg/MJ (ar) mg/MJ (ar)	≤ 0.02	≤ 0.03	≤ 0.08	≤ 0.15	≤ 0.50
			≤ 0.04	≤ 0.06	≤ 0.16	≤ 0.30	≤ 1.00

[16] and international level [17], done before and after the activities of the MUNLV-NRW [18], [19], show that the actual emitted levels of mercury are significantly lower than calculated caused by the formation of HgCl₂, which is triggered by a sufficient availability of HCl during the co-processing of SRF [15], [20]. These reaction kinetical dynamics had already been described by [21] and have been applied i.e. for the technical optimization of flue gas cleaning systems in municipal waste incinerators.

Overall the BGS e.V. has given out 16 quality labels so far. Solid Recovered Fuels that have been certified through RAL play an essential role in permitting procedures, and the acceptance of SRF has been significantly improved. A sustainable contribution to the mitigation of climate relevant gases is being made.

Since its foundation of BGS e.V. the national and European standardisation activities of CEN/TC 343 were greatly supported. The REMONDIS SRF-production in Erfstadt was awarded the first nationwide RAL-GZ 724 on 22.05.2002.

5.3 International activities of CEN/TC 343 and the EU-Projects QUOVADIS, RECOFUEL and RECOMBIO

In order to launch a European standardization of fuels through CEN, financial support has been given to the project “NNE5/1999/533 Waste to Recovered Fuel” by the European Commission and the attending industry. These activities resulted in a foundation of the European standardization committee CEN/TC 343 “Solid Recovered Fuel”, in spring 2002. By the end of 2002 five committees took up their work. In 2011 it was completed with the publication of six technical reports and 25 standards [22]. For the broad international data base and its statistical evaluation on which the establishment of a European classification system was based refer to [23].

The following parameters are of dominant significance for the classification:

- » Calorific value: Technical and economic significance (“Parameter fuel economics”)
- » Chlorine: Impact on process engineering (“Parameter process engineering”)

- » Mercury: Ecological impact (“Parameter environment”)

Table 1 shows the different classes within the classification system. The result is a three-digit numerical code. The significance of all other parameters is to be incorporated along with bilateral specifications between producers and customers. EN 15359 also introduces normative parameters (i.e. all heavy metals according to the Waste Incineration Directive) thus covering additional environmental aspects.

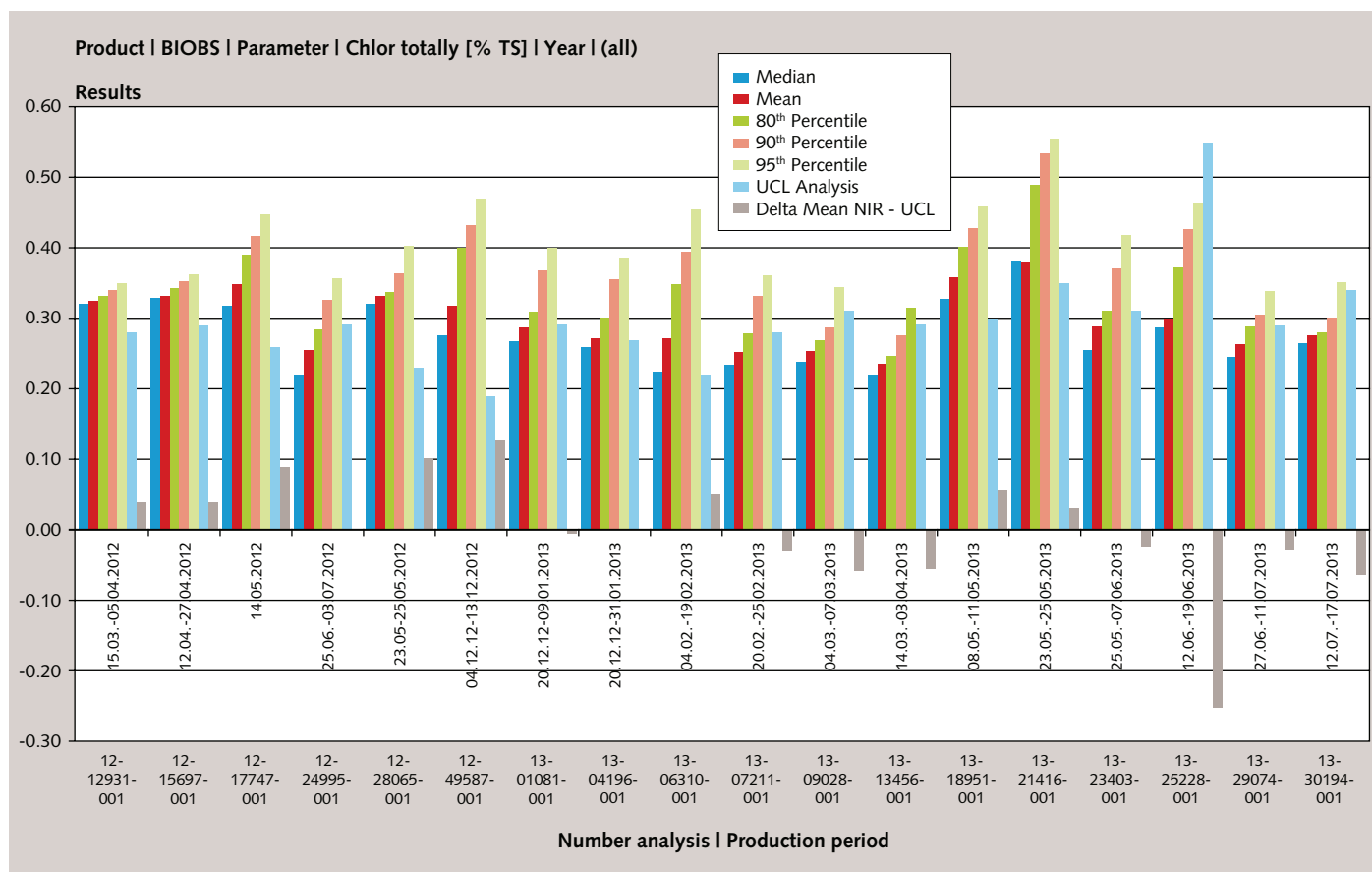
The EU-Project QUOVADIS to validate all major proposals for standardization initiated back in January 2005 and was completed at the end of 2007 [24]. For important reports on the results of the QUOVADIS-Project please refer to [25]. Activities have been practically accompanied by the European demonstration project RECOFUEL [26].

A close cooperation within the activities of the BGS e.V. and the CEN/TC 343 was ensured through a respective involvement of the quality assurance board and institutions and enterprises supporting the BGS e.V. for activities on an international level.

For instance it turned out to be less effective to base evaluations on single values even when applying comparable sampling as well as analyzing methods instead of taking a minimum amount of samples to ensure proper evaluations [23]. This circumstance was incorporated in the specifications according to EN 15359 which require a minimum of ten analyses in order to classify a fuel. Hence, it was picked up on the approach of the BGS e.V. on an international level to create an appropriate evaluation process that allows one to differ between statistical outliers and system errors (actual inadequate qualities).

Along with the EU-Project RECOMBIO which is being coordinated by REMONDIS an instrument for online-analysis developed by TiTech/TOMRA has been tested at the SRF-production site in Erfstadt.

This device delivers data in real time of the parameters chlorine, calorific value and water content. Measurements in the TAMARA of the KIT-



Karlsruhe which were done in order to compare analysis results from secondary fuels which were sampled according to EN 15442 [27] and HCl raw gas figures show that the NIR-Online-Analysis may become a promising part of the quality assurance system [28].

Figure 4 presents a comparison of the CI-results (several thousands of signals per lot) of the online-NIR-system implemented in Erftstadt compared to the laboratory results for 18 production lots of BIOBS (see table 3).

The calculated average of CI for all NIR-signals is 0.30%_{ds} compared to 0.30%_{ds} of all 18 laboratory results. So, for BIOBS a good comparability of both methods can be concluded. Online-measurement via NIR-technology is obviously promising and should be further developed i.e. for additional parameters. Figure 4 also demonstrates the good homogeneity of BIOBS.

5.4 Summary of quality assurance

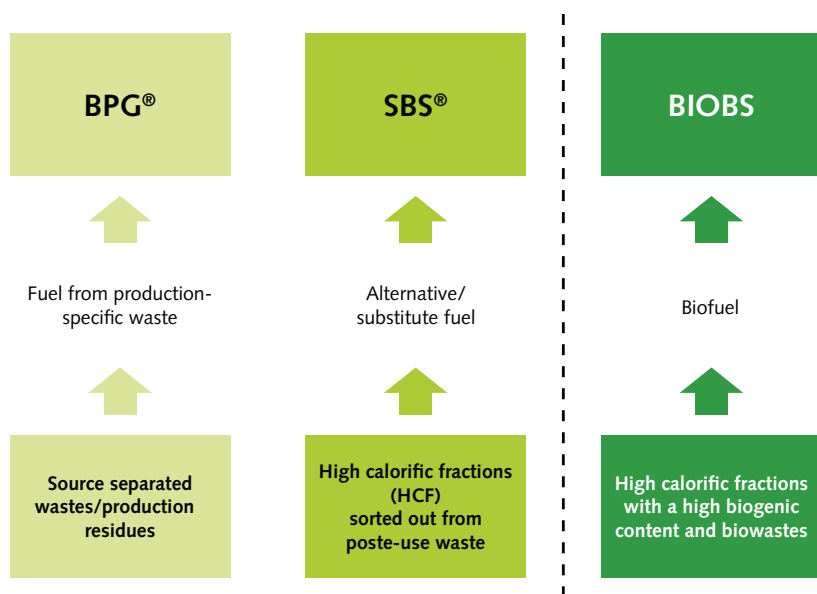
Table 2 presents all of the significant aspects of quality assurance for secondary fuels and compares the specifications according to RAL-GZ 724 to those stated in CEN/TC 343. It becomes obvious that regulations for RAL-GZ 724 provide stringent guided values and a mandatory external control as well as an external certification. This is still missing on the European level. On the other hand, CEN/TC 343 extensively describes the field of SRF. All fuels that do not consist of hazardous wastes and do not belong to biofuels can be classified and therefore be compared to one another. This is not possible for RAL-GZ 724 due to the focus on co-incineration.

It is of vital interest to processes aiming at high efficiency rates to rely on a credible quality assurance. In times of an increase in energy efficiency being the top priority of European

4 Comparison of statistical results of online NIR-analysis and laboratory values for Cl

Clarified aspects	RAL-GZ 724	CEN/TC 343
Input materials for production described?	EWC-numbers	EWC-groups
External supervision obligatory?	Yes	No
Kind of sampling?	Yes	Yes
Sample preparation?	Yes	Yes
Analytical standards?	Yes	Yes
Limit values?	Yes	No
Statistical evaluation?	Yes	Yes
Classification system for all fuels?	No	Yes
Certification/external supervision obligatory?	Yes	No

Tab. 2 Relevant aspects of quality assurance (according to [14] and [29])



5 Types of fuel qualities developed by Remondis

and national environment and energy policies, quality assurance is a central aspect, also for waste-to-energy plants. The question of international prospects for co-processing and mono-incineration in waste-to-energy plants decisively depends on the establishment of viable quality assurance systems.

For this purpose national and international activities on quality assurance for secondary fuels form a sound basis. They serve to improve the acceptance of Solid Recovered Fuels and to strengthen the content-related understanding between fuel producers and users for one another, for working QM-systems and for a useful fuel characterization.

Tab. 3 Comparison of lignite [32] to SBS®1 and BIOBS (mean values)

	Unit	Lignite from the Rhine, Mean (Berrenrath/Wachtberg)	SBS®1, Mean 2010–2013	SBS®2, Mean 2010–2013	BIOBS, Mean 2010–2013
Short analysis					
Net. Calorific Value	MJ/kg o.s.	10.1	13.2	18.2	11.9
H ₂ O	% o.s.	54	24.8	16.4	24.7
Ash	% o.s.	2.5	9.5	10.1	11.0
Chlorine	% o.s.	0.02	0.36	0.74	0.23
Volatile	% o.s.	23.5	53.5	60	52.7
Elementary analysis					
C	% o.s.	30.5	35.3	39.2	32.5
H	% o.s.	2.2	4.5	5.6	4.1
O	% o.s.	10.3	23.8	26.8	26.2
N	% o.s.	0.4	1.4	1.0	1.2
S	% o.s.	0.2	0.2	0.3	0.1
Additional parameters					
Biogenic C	% of TC	0	74.3	50	84.4
Chlorides	mg/kg d.s.	300	2005	1655	1575
Al	mg/kg d.s.	750	5550	5685	4700
K	mg/kg d.s.	215	2160	1610	3190
Na	mg/kg d.s.	1400	2665	2213	1420
Pb (50th. Percentile)	mg/kg d.s.	1	75	65	45
Zn (50th. Percentile)	mg/kg d.s.	3.5	275	350	210

6 Fuel qualities by REMONDIS

The REMONDIS GmbH produces different types of fuel qualities in various production sites based on regional requirements. The following types of fuels have particularly been developed at the production site in Erfstadt (Fig. 5). Today's production mainly focuses on providing municipal waste derived SRF (SBS®). This is also applies to other production sites.

Table 3 compares lignite (brown coal) to the quality of the two types of SRF which play an important role in substituting rhenish lignite and so far made up for 550 000 t of fuel. These SRF have been subject to a quality assurance according to RAL-GZ 724. The classification code 421 for both SBS®1 and BIOBS according to EN 15359 results in class 4 for calorific value, class 2 for chlorine and class 1 for Hg.

The energy related carbon content and thus of CO₂-emissions based on fuel characteristics (fossil and biogenic) turns out to be considerably lower for BPG®, SBS® and BIOBS compared to lignite and hard coal (Fig. 6). When only considering the fossil ratio, SRF's are superior even to natural gas. The renewable content in SRF and the use in high efficiency processes make a significant and growing contribution to the mitigation of CO₂-emissions [30] and [31].

Experiences in determining biogenic shares of secondary fuels according to EN 15440 [33] and in calculating respective factors of emissions show that secondary fuels based on high calorific fractions from municipal waste emit about 20–40 t CO₂/TJ. Thus, for instance substituting lignite with SBS®1 or BIOBS reduces CO₂ emissions about 1 t CO₂/t SRF.

Within the EU-project RECOMBIO environmental sustainability for both SRF demonstration cases in Finland and Germany has been demonstrated taking into account all 15 LCA categories [34].

7 Market for Solid Recovered Fuels

In Germany, co-incineration of SRF has become an essential link to the waste management. Figure 7 illustrates the growing significance of fuels from waste starting with its use in the German cement industry [35].

In 2013 substitution of fossil fuels by SRF in the German cement industry amounted to 62% [36]. With a level of 2.17 million t/a secondary fuels consisting of industrial waste and high calorific fractions have become an indispensable source of energy in this industry. Regarding the European SRF-market further development of recycling and SRF-activities will be strongly influenced by the

- » Existence and level of national landfill taxes,
- » Costs of primary energy and
- » Costs of CO₂-credits

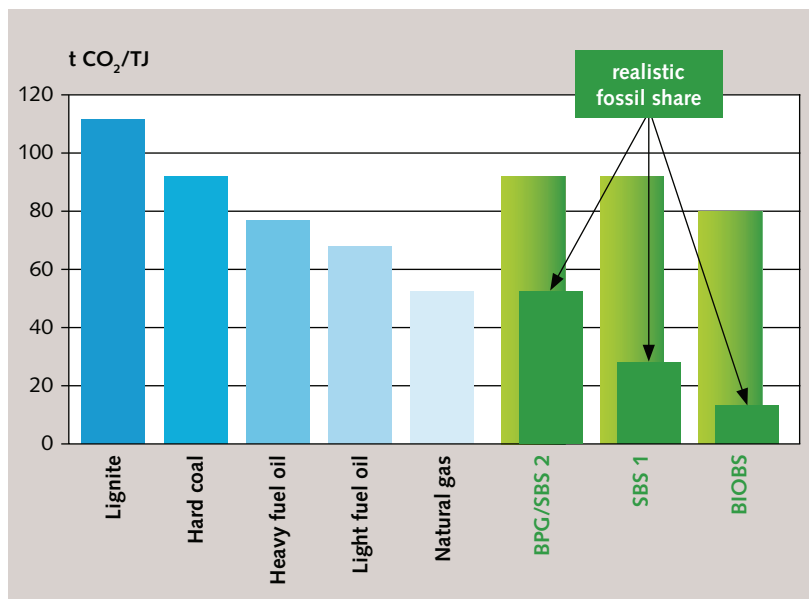
8 Outlook

In the interest of keeping up full capacity in capital-intensive waste incineration plants (e.g. in the Netherlands and Germany), it is of major importance to acquire waste from foreign countries where overcoming the age of landfill disposal hardly started or is being prepared through European cooperation. Together with the implementation of a stepwise increasing landfill-tax international cooperation is the decisive way to avoid excessive capacities of waste incineration plants with a high capital commitment are being installed in these countries as well.

This kind of cooperation is desperately needed in order to be able to implement the setting of direction by the European waste directive. As soon as waste incineration plants that are not working at full capacity endanger the aims of waste management policies among others the priority for recycling and a sustainable waste management. Once an investment in a plant has been made, the high capital commitment does not leave much room for actions afterwards. Then options are very limited due to fixed costs that constantly have to be covered. Even high prices for secondary materials can hardly overcome this situation.

Countries that are reorganizing their waste management concepts right now are strongly recommended to pursue a restrictive examination of the needed capacities of waste incineration plants in a more consistent way than happened in Germany where the dynamics of the resource and energy sector remained underestimated.

The technical prospects for the production and use of SRF have improved due to decades of profound experiences in the cement and power



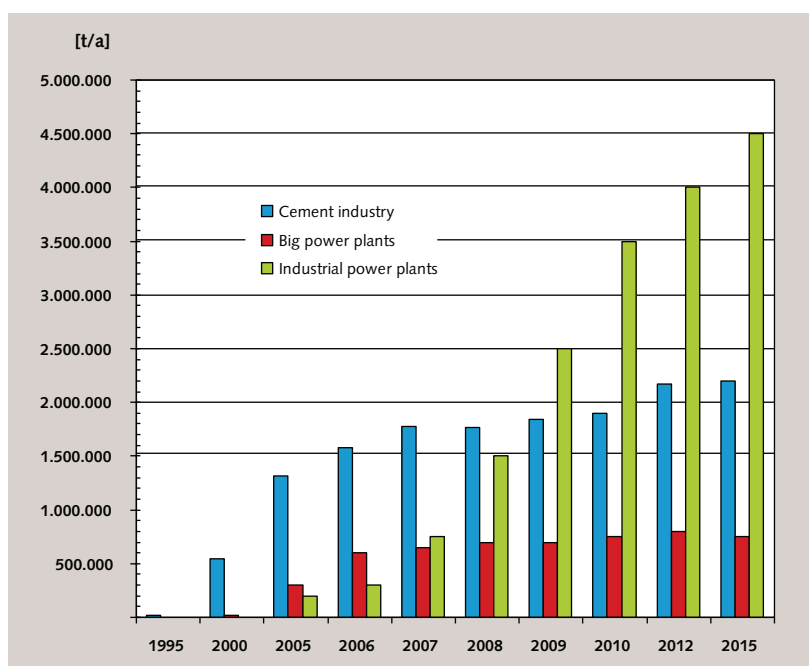
plant industries. Nowadays this applies even more because of a greater knowledge of the fuels and advanced calculation models which increasingly allow simulating the influence of especially homogenous quality certified secondary fuels [37] and therefore allow them to be evaluated or improved for use even faster.

Acknowledgement

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6 CO₂-emissions based on different types of fuel

7 Development of the amounts of SRF used in Germany, actualized version of [34]. Figure refers to fuel from industrial waste or high calorific fractions



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