Preparation of Refuse-Derived Fuels (RDF) for use in the Cement Industry in Turkey

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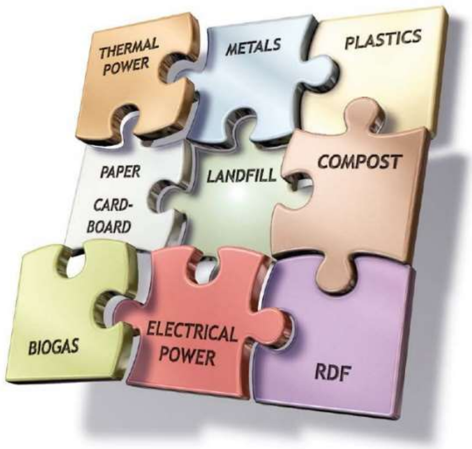
Contents

Abbreviation list

BImSchV	German Immission Control Act
BGS e.V.	Gütegemeinschaft Sekundärbrennstoffe und Recyclingholz e. V. (= German Quality Assurance Association for Solid Recovered Fuels and Recycled Wood)
BREF	Reference Documents on Best Available Technologies
CATY	Communiqué(s) on waste fuels, added fuels and alternative raw materials published in Turkey
CEN/TC	European Committee for Standardization/Technical Committee
CFRP	Carbon fiber-reinforced plastics
CO_2	Carbondioxide
°C	degree Celsius
DM	Dry matter
EU	European Union
EN	European Standard
EPR	Extended producer responsibility
HCl	Hydrogen chloride, hydrochloric acid
HF	Hydrogen fluoride
kg	Kilogram
kJ	Kilojoule
MBT	Mechnical biological treatment facility
MJ	Megajoule
MSW	Mixed (municipal) solid waste
MoEU	Ministry of Environment and Urbanisation of the Republic of Turkey
NIR	Near-infrared (spectroscopic method)
NOx	Nitrogen oxide
PCB	Polychlorinated biphenyl
PVC	Polyvinyl chloride
RDF	Refuse-derived fuels
RTO	Regenerative thermal oxidizer
SO_2	Sulphur dioxide
TOC	Total organic carbon
VDI	Verein Deutscher Ingenieure e.V. (= The Association of German Engineers)
☞	To obtain more details on this subject, you may avail of the *link* or *chapter reference* provided hereafter

1 Introduction

As a substitute for fossil fuels, secondary fuels made from waste (abbreviated RDF) are an important component for climate-friendly energy generation and to save resources and protect the environment. Market and usage of RDF are likewise indispensable for the endeavor of modern waste management to enable high-quality recycling, achieve the highest possible utilization of residues and to safely eliminate dangerous substances.



The cement industry is an energy-intensive industry with energy typically accounting for around one third of the production costs, the share of capital investment excluded. Various fuels can be used to provide the heat required for the process. Whilst at the beginning of this century the most commonly used fuels were petcoke and coal (together >75%) this has been changing drastically over the past twenty years in that alternative fuel materials gained significantly in importance.

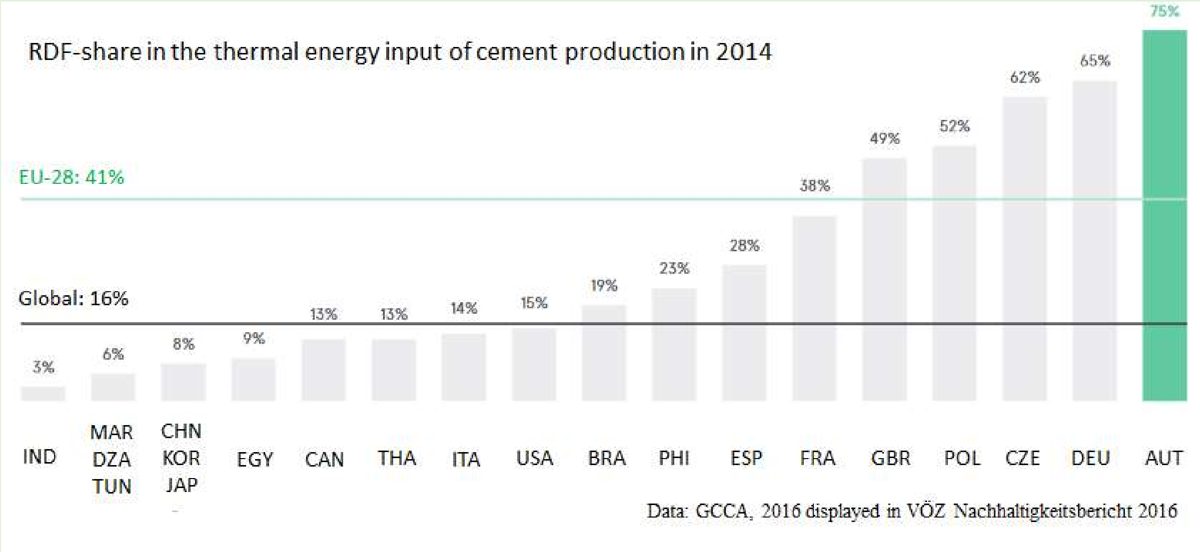
The process of using fuels in cement kilns to generate the needed energy is marked by very high flame temperatures and relatively long residence times of the material and combustion gases in the heated zones. Raw material is heated up to over 1400°C in the sintering zone and cement clinker is generated at 2000°C flame heat. Flue gas remains between 3–5 seconds in zones at 1600–2000°C temperature whilst the thermal and chemical conversion of solid particles happens in a much longer interval. These are favorable conditions for using refuse which is delivering the necessary energy content as part of the fuel and at the same time gets safely destroyed this way.

Also specific to this process and the material conversion taking place is that neither under technical nor environmental considerations special adaptions in the firing technology must be made. Even mineral particles and ashes that would normally form combustion residues become components of the process of cement generation and are therefore recovered substantially when co-incinerating suitable waste components at cement works.

Refuse-derived fuels are an important component for establishing a modern and functional waste management

That waste materials are kind of permanently created, locally available resource and that the fuels made from them show price advantages versus conventional fossil fuels provide the cement industry further arguments for their use. Not less important for this industry is the better environmental balance which may result from replacing standard fuels with RDF in cement processes. In addition to getting the possible biogenic content of the RDF credited as climate-neutral, effectively reduced CO_2-emissions from the combustion of certain plastic components also play a role.

Refuse-derived fuels consequently become more and more popular in this industry segment, and as a result, their use is already common practice in many regions. Austria, as an example, reports the utilization of certain RDF amounts meanwhile for all cement plants whereas from other countries, including ☞ *Germany*, is known that this occurs at a varying but very significant order of magnitude.



Examples from the international practice

The German Association of Cement Works (VDZ) puts the share alternative and secondary fuels take in Germany in total fuel energy consumption at 67.5 percent for the year 2018. This is a further 2.5 percentage points compared to the record value from the previous year. The industry used 3.601 million tons of alternative fuels in absolute terms, which also marks a record high. Compared to other countries this is a remarkable high level, well above the average achieved globally and in the EU.

Source: EUWID Recycling, 13.09.2019

For Turkey, a comparable situation of interests can be assumed. In addition to a powerful cement industry that operates nowadays in the country under conditions similar to the rest of the world in terms of markets and technical requirements, there are also material flows and ambitions in the field of waste management that are comparable to those of the EU countries.

Even though some examples for RDF use by the local industry including cement plants and approaches to spur such concepts already exist in Turkey, the relevant technologies, markets and structures in the form of processing and quality assurance mechanisms are not that advanced yet in the country. Further development steps and an increase in knowledge capacity must be initiated here. This guidance has been created and geared with the intent to aid this process. It does not include the initial generation of the waste, collection activities or the process of cement production.

Refuse-derived fuels now have a range of applications that extends far beyond the cement industry. The above-mentioned process peculiarities and the resulting special features in the processing and feedstocks make refuse-derived fuels intended for use in this particular segment the focus of this guidance. However, another special document that gives similar attention and support to the other application areas is highly recommended.

2 Application Framework

Turkey has been a fast emerging economy in past decades with significant population growth and a tremendous trend of urbanization having essential impact. The expansion of economic activities and consumption is causing large amounts of waste to be generated, especially in the densely populated urban areas. The total municipal and commercial waste (MSW) quantity collected in the country today is estimated to range somewhere in between 30-33 million tons per annum. Whilst most of this waste is still landfilled, efforts to increase the waste sorting capacities are already underway and a single-digit number of MBT plants with a total annual throughput resulting in the treatment of nearly one million ton of mixed non-hazardous waste meanwhile operate in the country.

The Turkish government's National Action Plan for Waste Management 2016 to 2023 foresees the capacity for mechanical-biological treatment to be increased to 11% and that of thermal treatment to 8%, based on the MSW total volume. However, the low calorific value characteristic for the mixed waste collected in Turkish municipalities is generally problematic to have it directly combusted for energy generation. Converting waste into RDF involves specific processes (☞ *chapter 7*) to cope with this issue.

A government regulation on waste incineration from 2010 and amended in April 2017 stipulates that only hazardous waste can be send to regular waste incineration plants. Conversely, using waste has been completely opened for the cement industry for that the plants could avail of this option to meet their own demand for process energy. Also the requirements for facilities using waste mono fractions for energy recovery were lowered.

A special communiqué on waste fuels, added fuels and alternative raw materials ("Atıktan Türetilmiş Yakıt, Ek Yakıt ve Alternatif Hammadde Tebliğinin", refered to in this document as CATY)[1] provides the relevant legal basis for the production and usage of RDFs in Turkey. Among others it contains general principles for the preparation and use of RDFs (e.g. restrictions in regard to substances providing the feedstock for RDF generation, limit values for heavy metal content in RDF input, quality criteria RDF products must be able to meet) as well as requirements for plant technical design, operations and permitting. Reference to corresponding stipulations will be made in the respective chapters of this guidance (☞ *chapters 4, 5, 9*).

In Turkey a legislative basis and first practical examples for RDF use are available

As per the latest available statistics about licensed plants in the country, there exists 44 units of RDF preparation facilities[2] with an installed overall capacity of approximately 1 million tons per year. About one third of the 54 Turkish cement factories so far possess of a license for using alternative fuels from waste. From 2007, when the use of such fuel products reached less than 50 thousand tons in this industry segement, it went up to 760 thousand tons within a period of ten years.

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1 first published in official gazette no. 29036 on 20 June 2014 and amended on 13 April 2017 as per official gazette no. 30037

2 with some of the biggest being for example located in Kocaeli, Istanbul, Izmir, Ankara, Adana, Bolu, Bursa, Denizli, Düzce, Eskişehir, Hatay, Kahramanmaraş, Manisa, Sakarya, Ordu, Tekirdağ and Kontamine (☞ *plant promotional video*)

The Aslan Çimento plant in Kocaeli is a pioneer and continues to be one of the main players in the use of RDF. Here one of the highest substitution rates for conventional fuel is achieved in Turkish cement production[3]. Aslan Çimento's example has since been followed by other plants, such as the cement producers Cimsa and Akçansa (Sabanci Holding).

On average, the thermal substitution rate attained by the use of RDFs in the Turkish cement industry is still quite low, however. According to the Turkish Cement Manufacturers 'Association it has grown by less than 5 percentage points over the past ten years and is still not reaching a level higher than 6-7% today[4]. Compared to the cement industry in the Czech Republic, Germany and Austria, where RDFs provide far more than two third of the thermal output, there is still considerable potential for increase in Turkey. The lacking availablity of locally produced RDFs of sufficiently high quality is obviously one central reason for that kind of unexploited reserve.

Using RDFs could help Turkey to save up to 20 % of the GHG-emissions its waste sector produces
(Turkish Statistical Institute, 2017).

This is all the more disadvantageous since it has been calculated that incinerating MSW instead of coal could help the country to reduce CO_2-emissions at a scale of 3-7 million tons per year. Including avoided landfill gas emissions, it could even be a quantity in the range of 20-50 million tons[5]. Among other things, this underlines that a focused guidance geared to enhancing generation and supply of RDFs in Turkey is of particular relevance.

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[3] in 2015 a 30% substitution of conventional fuel was envisaged

[4] https://www.turkcimento.org.tr/tr/alternatif_yakit_ve_hammaddeler

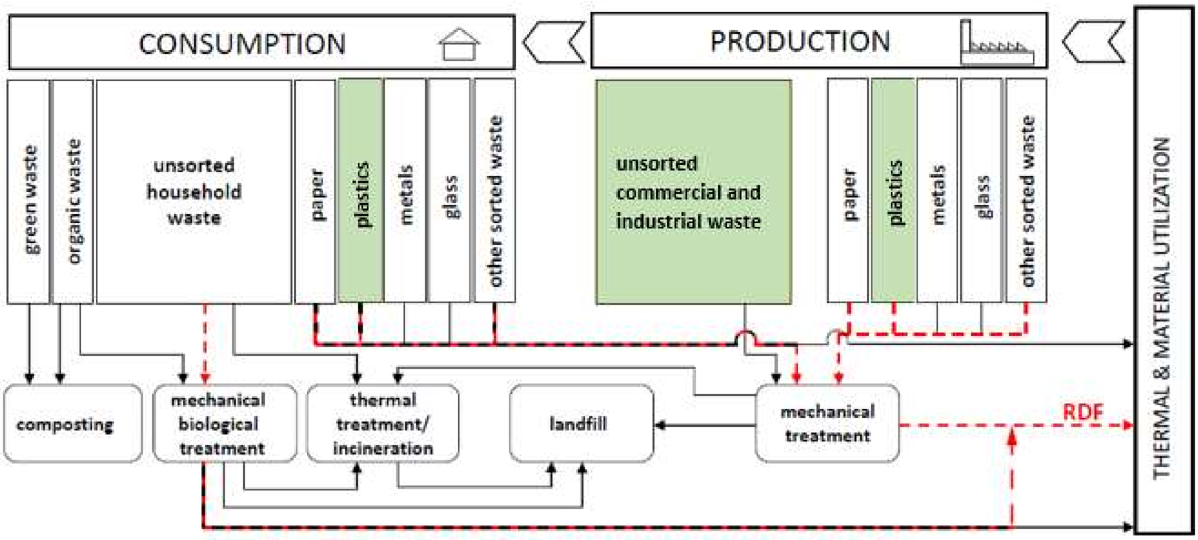
[5] Beysin Tekinel, 2017

3 Current and potential sources for RDF production

Available information suggest that the number of cement-producing plants in Turkey using RDF for covering parts of their thermal energy need is rising, albeit at rather low speed (☞ *chapter 2*). Where indeed use is made of the option to run the production with waste as fuel material, an intake of high-calorific production residues and specific industry and commercial wastes is so far noted. Above all, this still comprises waste oil and used tires. These materials accounted for about two thirds of the alternative fuel use in the Turkish cement industry already in 2008.

High-calorific production residues give the primary source of RDFs for the cement industry

High-calorific waste components stemming from industrial and commercial activities traditionally give the preferred input for RDFs used by the international cement industry or for their production by waste processors (Figure 1). It is considered a striking advantage that suitable material is generated and can be collected from these sources in form of rather clean and homogenous waste fractions in consistently large quantities. This results in a lower demand for sorting, cleaning and processing to obtain the wanted supply.



(modified after Pasuki, 2011)

Figure 1: Scheme for the most common routes of waste disposal and to obtain the feedstock for RDF used in cement kilns

Examples from the international practice

High-calorific waste components from industrial and commercial sources contributed 55% of the RDF utilized in cement kilns in Germany in 2018, dried sludge from municipal sewage treatment gave another 18% of the overall RDF input. The share plastics material take in this type of fuel is making significant growth while conversely a decline in the proportion of waste tires has occurred in past years (Table 2). Source: EUWID Recycling, 13.09.2019

Due to the process characteristics in cement production (☞ *chapters 1, 5*) this sector can deal quite well with a much larger range of waste materials used or processed as RDFs, however. A look on the spectrum of RDFs used by the world's leading cement manufacturers illustrates this impressively. At the same time can be seen that the preferences for RDF materials vary considerably (Table 1).

Table 1: RDF utilization of world's leading cement manufacturers

RDF materials	Cement producer [figures in %] Holcim	Cemex	Heidelberg	Italcementi	Lafarge
Waste oil	5.0	-	3.7	8.5	22.1
Solvent and other liquid waste	11.0	-	4.7	21.9	-
Waste tires	10.0	16.0	11.6	14.9	19.7
Impregnated sawdust	6.0	-	-	-	-
Waste plastic	9.0	-	26.4	4.7	33.1
Industrial and mixed (municipal) solid waste	-	65.0	-	13.8	-
Industrial waste and other fossil fuels	30.0	-	-	-	-
Meat-and-bone meal	2.0	4.0	6.1	15.7	-
Agricultural residues	9.0	10.0	4.2	11.1	-
Wood chips and other waste biomass	15.0	5.0	24.5	-	25.1
Sewage sludge (dried)	2.0	-	4.2	1.7	-
Other specially prepared RDF	-	-	-	7.8	-
Other refuse	-	-	14.6	-	-

Source: Rahman

On the one hand side this must be attributed to differences in plant design, the spectrum of produce and the plant's permitting status, thus a plant-specific individuality of the demand.

Having certain flexibility on the other hand leads the cement industry and RDF processors to also take a relatively strong orientation on the market supply and price situation for waste materials when deciding on the selection and mix of waste components used as RDF. Policy developments and geostrategic constellations may have quite considerable influence on this. The materials used as RDF input especially in the cement industry experience changes or undergo a faster replacement or exchange one for another also as a result of politically motivated decisions or economic measures.

Examples from the international practice

The ban imposed in 2001 on using meat and bone meal in the European fodder industry was quickly followed by an increase in the use of this material as a fuel in cement production. Also the politically desired reduction in applying sewage sludge as a soil improver in agriculture in some countries led to an increase in the use of sewage sludge as RDF in cement kilns. Nowadays import restrictions imposed in many regions on plastic waste are having the effect of an increasing use of these wastes for fuel production.

Table 2: RDF materials used by the German cement industry, 2019

RDF materials	1,000 t	MJ/kg	% of total energy consumption
Waste tires	175	28	5.1
Waste oil	70	29	2.1
Pulp & paper/cardboard waste	79	5	0.4
Waste plastics	806	24	20.2
Wastes from textile industry	6	31	0.2
Other industrial and commercial waste	1,151	21	25.2
Meat-and-bone meal, other animal fats	164	18	3.1
Mixed fractions of municipal waste	370	18	6.9
Waste wood	1	15	0.1
Solvents	129	26	3.5
Sewage sludge	703	2	1.5
Others	140	5	0.7
Total RDF use in the cement sector	3,794		68.9

Source: VDZ

Which fuel materials and how much of them will be used by different industry segments is hence determined by both, the supply and demand side of the market. Still it remains a priority for the cement industry that the RDFs must fit to the processes and not impair the quality of the produce. **It cannot be expected therefore that cement plants take any RDF which is theoretically suitable for their branch. For each case, the particular features of the manufacturing process and technical installations must be taken into account and individual specifications for RDF concluded accordingly.**

The feedstock materials which are used or processed as RDFs for the cement industry principally can be grouped into

- process residues from industrial production and commercial activities (commercial origin)
- components of municipal waste (municipal origin).

Waste materials of commercial origin for the most part are characterized by a quite stable homogeneity (purity) and high heating values. The need for these materials to be further processed in order to meet the cement industries' fuel requirements is generally rather low (☞ *Table 3*).

Most prominent waste materials from these sources with a high suitability for RDF include pulp, paper, plastics, packaging or *waste from the textile industry*. Processed fractions from the said industrial and commercial waste are also referred to as ***fluff or blowable RDF***.

Likewise a source of homogenous material fractions of high-calorific value with the potential for RDFs is the processing of waste quantities recovered under extended producer responsibility (EPR) schemes. Quite a substantial portion of the RDFs eventually taken by the cement industry is obtained in European countries via this route. *Sorting and processing* the respective material fractions for recycling leaves *residues* and unrecyclable amounts behind which in many cases suit as an RDF input. Twelve EPR organizations have been given a license by the Ministry of Environment and Urbanisation (MoEU) in Turkey, each responsible for specific types of waste such as tires, batteries, packaging, plastic and paper. Their assignment and mandate should very likely include activities from which materials suitable for the production of RDFs arise.

Carbon fiber-reinforced plastics (CFRP) which are nowadays used as a metal replacement in aerospace technology, vehicle construction and for the rotor blades of wind turbines are considered a potentially new material source for RDF for the cement industry. For the disposal of the CFRP waste and in particular for recovering the fibers for recycling without quality losses, no technical process has yet been realized at large scale. Preparing and using the material in other incinerating facilities is expensive and difficult. One ton of rotor blade material replaces around 600 kg of coal in cement kilns. The resins contained in the rotor blades have good fuel properties. The ash that accumulates is completely used as a material in the clinker burning process and becomes part of the clinker. The silicon from the glass fiber replaces the natural sand normally used as a corrective substance in the raw material mixture.

Sludge and treatment leftovers (e.g. rejects, pulper rags, screenings) which accrue in the paper industry and during sewage treatment make an exception of the industrial production and commercial residues with high-calorific value in that these are rich in moisture making a safe and purposeful disposal (and the payments for this service) more attractive to the cement industry than the heating value. A certain effect of mineral substitution in the raw material mixture is also taking place here, however.

Table 3: Median values from waste analyses for typical RDF feedstock materials in Germany

PARAMETER	**02 01 04** Waste plastics	**03 03 07** Reject	**03 03 08** Sorting rests from paper recycling	**04 02 09** Composite material waste	**04 02 21** Unprocessed textile fibres	**15 01 06** Mixed packaging	**19 12 01** paper and cardboard	**19 12 04** plastic and rubber	**Range**	**19 12 08** textiles	**17 02 03** Plastic from demolition waste
Heating value [MJ/kg]	*31.5*	14.0	15.7	20.9	19.1	*20.3*	18.6	36.48	14.0-31.0	*26.6*	27.4
Water content [%]	*30.0*	40.0	4.01	1.61	4.45	*4.80*		0.5	0.60-40.0	*7.90*	1.3
Ash content [%]	*2.10*	5.88	7.63		2.48			4.2	2.48-16.2	*20.8*	6.3
Chlorine [%]	*0.18*	0.76	0.05	0.11	0.04	*0.08*	0.20	1.00	0.04-0.76	*0.05*	0.25
Fluorine [mg/kg]	*550*	36.1	26.3					25.00	26.3-600	*20.0*	27.5
Sulphur [%]	*0.02*	0.05	0.06	0.03	*0.05*	*0.10*	0.40	0.04	0.03-0.40	*0.11*	0.05
Cadmium [mg/kg]	*0.28*	0.30	0.05	0.30	0.30	*0.10*	0.50	4.63	0.05-2.94	*1.29*	0.54
Thallium [mg/kg]	*0.38*	0.21	0.12	0.49	*0.10*	*0.95*	1.00	*0.12*	0.12-1.00	*0.18*	0.69
Mercury [mg/kg]	*0.38*	0.11	0.02	0.10	0.02	*0.14*	0.15	*0.15*	0.02-0.20	*0.28*	0.25
Antimony [mg/kg]	*0.73*	2.60	0.96	0.98	1.67	*1.48*	3.00	**46.77**	0.96-22.4	*9.21*	6.42
Arsenic [mg/kg]	*0.70*	0.51	0.48	0.69	*1.60*	*0.76*	3.00	0.12	0.48-3.00	***9.21***	0.69
Lead [mg/kg]	*9.09*	9.48	2.40	0.98	*2.87*	*5.71*	2.00	63.69	0.98-40.5	*8.29*	5.98
Chromium [mg/kg]	*21.3*	6.09	2.50	5.61	*3.40*	*6.19*	1.00	*24.38*	1.00-19.2	***258***	5.48
Cobalt [mg/kg]	*4.20*	1.09	0.24	0.52	*2.03*	*5.71*	1.00	1.84	0.24-2.21	*4.61*	2.99
Copper [mg/kg]	*4.55*	22.5	6.28	1.79	*8.70*	*8.09*	5.10	*109.5*	1.79-42.8	*23.9*	14.07
Manganese [mg/kg]	*0.70*	20.9	0.67	2.49	***71.0***	*6.19*	3.80	***15.23***	0.67-20.9	*17.5*	20.25
Nickel [mg/kg]	*5.60*	5.21	1.92	1.33	***41.3***	*1.90*	2.00	5.37	0.99-5.21	*8.84*	2.60
Vanadium [mg/kg]	*0.70*	1.05	0.48	0.47		*1.43*	2.00	1.44	0.47-3.48	*0.92*	2.57
Tin [mg/kg]	*0.70*	8.49	*0.38*	0.59		*2.38*	3.00	26.37	0.59-8.49	*9.21*	
Beryllium [mg/kg]	***0.70***	0.09	*0.02*	0.05	*0.24*	***0.52***	0.20	*0.12*	0.05-0.99	*0.46*	0.10
Selenium [mg/kg]	*0.70*	0.51	*0.29*	1.18		*0.95*	3.00	*0.05*	0.30-3.00	***9.21***	5.43
Tellurium [mg/kg]	*0.70*	0.30	*0.48*	0.49		*0.95*	2.00	*0.02*	0.15-1.94	***9.21***	0.53

Source: MUNLV-NRW

Municipal waste and its content of components with energetic value is generally less homogenous in composition and a more intensified treatment generally needed to derive a fuel material acceptable to the cement industry (☞ *Table 8*).

Treatments in this case must not necessarily be geared towards the fuel production in the first place. MBTs whose primary objective is to get the waste volume reduced and biodegradable content stabilized before landfilling, do operate concepts and processes in which suitable material can explicitly be won and/or converted for the purpose of RDF (☞ chapter 7).

MBTs are a suitable gateway to get municipal waste volumes reduced and RDF material won

Separating components of higher heating value and/or drying the waste mix make up optional parts of the treatment procedure and lead to material streams of sufficient calorific value. With a view to the conditions in Turkey that is of particular relevance as the yet insufficient separation of materials at source causes Turkish MSW to be generally of high moisture content. Especially the lacking source separation efforts for kitchen and food waste effects an intermixing of the wet portion with other components in the waste thus resulting in a high overall moisture content and relatively low heating value (Table 4).

Table 4: Waste characteristics of Turkish MSW as established during studies in different cities and years

Location	Moisture content %	Lower heating value Range (kJ/kg)	Lower heating value Average (kJ/kg)	Data source / Reference
İstanbul	62.4	5,260 – 9,510	6,000	Yildiz et al., 2013
Denizli	65.3	n.a.	5,150	Ağdağ, 2009
İzmir	46.5 – 57.2	6,000 – 7,000 (industrial sources) 3,500 – 5,500 (urban sources)	< 6,000	Dolgen et al., 2005

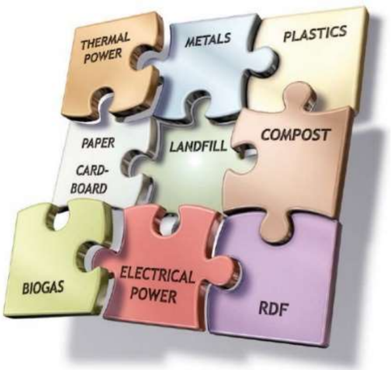
Source: Beysin Tekinel, 2017

Due to the quality features of RDF from mixed municipal waste that lag behind other substitute fuels, they are generally only considered for a rather limited part of the total fuel input in cement kilns (☞ *Table 8*). Other fuels of lower calorific value such as sewage sludge or even bleaching earth and foundry sands are clearly competing with them.

The attractiveness of the treatment route of MBTs and the RDFs it can deliver lies for cement producers first of all in very competitive prices for the fuel material or even extra payments they can obtain for incinerating substances that otherwise must be elsewhere disposed.

Multiple cases of using RDFs instead of coal in cement works show that up to 0.7 ton of fossil CO_2 emissions can be avoided per ton of such alternative fuel used.

It should be highlighted though, that RDF production and usage must always take a complementary function in a concept aimed at closing the loops and achieve circularity in the economic system. This is why **the hierarchy of waste management options considers this practice a form of other recovery** which should neither obstruct a recycling nor be given a priority over it.



However, RDFs offer an option for the ecologically sensible use of such waste materials for which there are no longer any technically and economically feasible recycling options available. This possibility creates recycling operators in many cases the conditions for economically viable activities and hence enables them to engage in recycling at all.

4 Quality requirements and standards for RDF to cement kilns

One of the most important aspects in producing RDFs and to get them marketed to the cement industry is that the requirements in terms of fuel quality and stability in the supply of this industry segment are reliably being met. These requirements are explained on the one hand by the particularities of the process and the technology for cement production, on the other hand by the operational, environmental and product standards to be adhered with. A decent understanding for this entire complex is needed in order to comprehend these requirements and build up a trusted partnership with the cement industry on delivering RDFs.

In the cement industry, the mineral components limestone, sand and clay as well as iron are burned into clinker. The ratio of calcium to silicon to aluminum to iron is about 30 : 10 : 2 : 1. Large energy amounts are needed for this. Producing the clinker in a dry process kiln with multi-stage suspension preheating and pre-calcination is considered as best available technique from the energy point of view in the EU's BREF for this industry. It mentions an associated heat balance value of about 3000 MJ per ton clinker for this technique. There exist different options and stages where the fuel material is fed into the process and directly mixes with the raw material mixture.

Depending on where and how this happens, the fuel consistency matters and the spectrum of required particle size therefore varies correspondingly. Fuels including RDFs are used to heat the rotary kiln and the calcinatory, or in the primary and secondary firing stage of the process. RDF material of larger particle size (>30 – 150 mm) is generally suitable at the calcinatory, whereas the firing in the rotary kiln is normally performed with particles smaller 30 mm.

Further it is of relevance that via the solid fuels used to cover the energy demand also silicates etc. are introduced into the process. This shifts the spectrum of the mineral components being used, which in turn has to be compensated for by changing the initial recipe of the mineral components. This means that it is of crucial importance for the cement industry to be sure on the mineral content of the fuels it uses. Of course, only substitute fuels can be used for which the above described ratio of the mineral components can be ensured (☞ Figure 2).

Recycling beverage containers (such as Tetra Pak) by means of dissolving pulper for the recovery of paper fibres causes for example a residual material comprising the coating and barrier films made of plastics and aluminium. This mixture not only suits as RDF due to a high-calorific value but is quite ideal in its compostion to match with the process stoichiometry and material recipe. When fluff is burned in the clinker burning process, around 13% of non-combustible components are produced, which accumulate as ash - consisting of calcium, silicon, iron, aluminum, magnesium and other oxides - and these are completely incorporated and bound in the clinker.

Chemical properties of RDF fluff Chemical properties of waste tires Chemical properties of dried sewage sludge

Source: VDZ gGmbH

Figure 2: Analyses of the material composition of alternative fuels used in the cement industry

In addition, the very high temperatures needed for the clinker burning process must be taken into account. Among others this means that also alkali chlorides become volatile. Since these cause considerable technical problems in addition to emission problems, both the input of alkalis and chlorine via the RDF material are to be limited.

Chlorine content indeed is a highly sensitive issue for cement kilns using RDF since chlorine weakens the cement. The cement industry is well aware of potential liability issues for its cement products and hence must have control over these risks. To ensure smooth processes the RDF must also meet certain requirements as far as sulfur content is concerned.

Product quality and emission protection require that the entry of heavy metals via the RDF into the process must be minimized as well.

Concentrations of heavy metals are present in the different material entering the cement production process and therefore an accumulation effect must be considered. Eventually there is a transfer of such concentrations towards the direction of the two principal process outputs, the finished cement clinker and the flue gas taking place (Figure 3).

For the most part the heavy metals are hereby incorporated into the cement clinker chemically and mineralogically (Table 5).

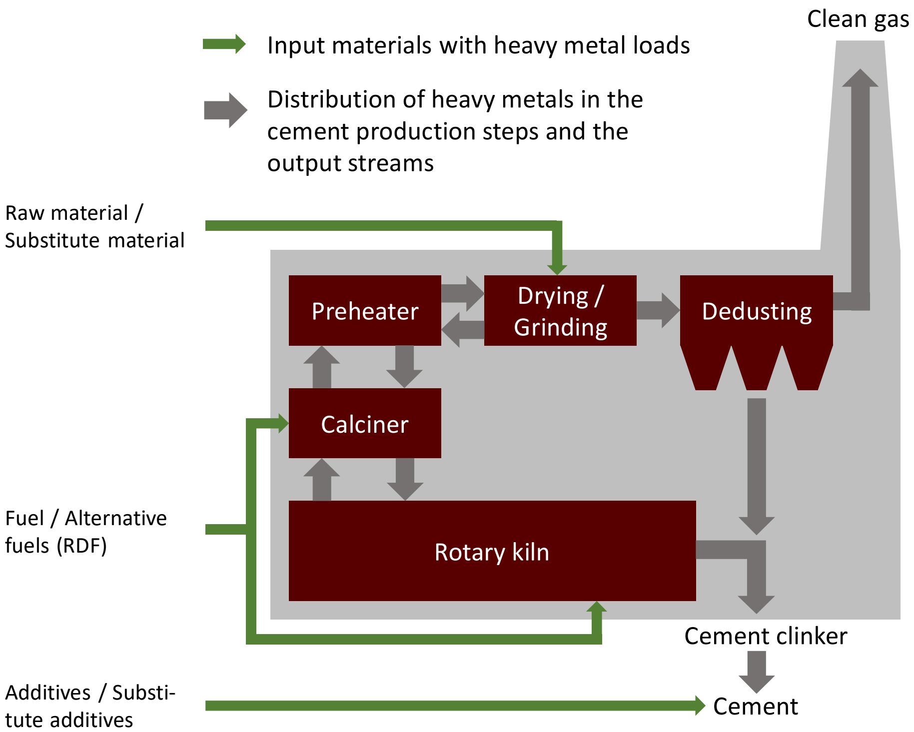


Figure 3: Heavy metal distribution in cement production

Table 5: Discharge of introduced heavy metals from cement production

	TRANSFER FACTORS (EMISSION FACTORS) FOR CEMENT PLANTS	
PARAMETER	Cement clinker (%)	Clean gas (%)
Cadmium	**99.83**	**0.17**
Thallium	**98.7**	**1.3**
Mercury	**60.0**	**40.0**
Antimony	**99.97**	**0.03**
Arsenic	**99.977**	**0.023**
Lead	**99.95**	**0.05**
Chromium	**99.988**	**0.012**
Cobalt	**99.981**	**0.019**
Copper	**99.9907**	**0.0093**
Manganese	**99.982**	**0.018**
Nickel	**99.97**	**0.03**
Vanadium	**99.948**	**0.052**
Tin	**99.926**	**0.074**

Source: MUNLV-NRW

The very high temperatures needed can only be reliably achieved, at least in primary firing, with fuels having a calorific value above 20 MJ/kg. Cement works from a process engineering point of view hence have a clear preference for fuels that are above this calorific value threshold. Ultimately, the high process temperatures also limit the entry of water into the process. After all, every ton of water that is introduced into the process via the fuel must be evaporated and heated to over 2000 °C and then cooled again without any significant gain in energy. Low water contents are therefore another desirable feature RDFs should fulfill.

The criteria describing the suitability of substitute fuels including RDF for use in the cement industry and therewith setting the main quality parameters derive from the general process requirements as depicted above. In summary these are:

- Heating value
- Mineral/ash content
- Chlorine content
- Heavy metal content
- Presence of other disturbing components/elements
- Particle size
- Moisture content.

In this spectrum of relevant parameters, the cement industry and, more specifically, each RDF receiving plant has a certain leeway and therefore slightly different requirements of what is acceptable with regard to the individual situation and process conditions. A certain variability and value range as the suitable or desired qualities of the fuels and RDF are concerned reflect this (☞ *Table 6 and Table 8*).

RDF with higher chlorine content is for example less problematic where cement plants operate a so-called chlorine by-pass. RDFs with calorific values well below 20 MJ/kg are usually limited to use in secondary firing. However, if another, very energy-rich fuel is used in the primary firing area, such calorific value is again not required.

Examples from the practice do show that with the appropriate RDF a cement plant can cover up to 100% of its demand in process heat (Table 7).

Table 6: Example for specifications used by a processor of RDF for the cement industry

PARAMETER	
Grain size	**0-25 mm**
Calorific value	**24 MJ/kg**
Density	**200-350 kg/m³**
Moisture	**max. 20 %**
Ash content	**max.20 %**
Chlorine content	**max. 9 %**
Sulfur content	**max. 5 %**
Lead content	**max. 0.2 %**
Mercury	**max. 2 mg/kg**

Source: Presentation by RDF producer firm Becker

Table 7: Example from a German cement plant which covers 100% of its demand in process heat with RDFs

Kiln capacity	**3,700 t clinker/day**
RDF utilization	**up to 100 % of the required heat**
Fluff input in the rotary kiln and calcination process	**max. 27 t/h**
Solvents input solely in the rotary kiln process	of which max. 4 t/h solvents
Input sewage sludge solely in the calcination process	**max. 10 t/h**

Source: Presentation Dyckerhoff GmbH Lengerich plant

Table 8: Median values from waste analyses on different types RDF obtained from MSW

PARAMETER	**19 12 10** RDF	**19 12 10 dry stabilate**	**19 12 10** high-calorific fraction (municipal waste)
Heating value [MJ/kg]	14.40	15.2	16.70
Water content [%]	30.10	03.0	8.80
Ash content [%]	8.90		13.80
Chlorine [%]	0.27	0.49	0.80
Fluorine [mg/kg]	39.84		0.02
Sulphur [%]	0.10		0.10
Cadmium [mg/kg]	0.64	1.22	2.10
Thallium [mg/kg]	0.12	0.22	0.18
Mercury [mg/kg]	0.12	0.31	0.28
Antimony [mg/kg]	7.02	5.07	20.41
Arsenic [mg/kg]	0.24	0.45	0.48
Lead [mg/kg]	25.02	**148**	131.60
Chromium [mg/kg]	29.36	**57.7**	82.73
Cobalt [mg/kg]	2.66	1.14	4.23
Copper [mg/kg]	111.84	166	**480.96**
Manganese [mg/kg]	37.05	192	105.00
Nickel [mg/kg]	8.32	19.2	14.19
Vanadium [mg/kg]	2.94	4.59	5.19
Tin [mg/kg]	5.04	15.7	16.64
Beryllium [mg/kg]	0.07	0.44	0.09
Selenium [mg/kg]	0.59	2.23	0.46
Tellurium [mg/kg]	0.35		0.18

Source MUNLV-NRW

The characteristics of RDFs have for long been described in many different ways and this practice still exists to fit for a single producer and buyer arrangement. To opening RDF a larger market, a common language had to be developed. This common language is actually what EN 15359 and all the other European Standards of CEN/TC 343 are about. CEN/TC343 has chosen to use the net calorific value, chlorine and mercury concentrations to quickly describe and group the RDFs present on the market (☞ *Table 9*). The set of these three properties gives an immediate and rather reliable impression of the overall RDF quality and RDF users can quickly assess type, value and environmental quality of the fuel product.

With this as one part, EN 15359 provides for methods of specification and classification of RDFs. The standard does in no way regulate all issues about RDFs, however. In particular, EN 15359 does not regulate which RDF may be used in which type of incineration, and it is not meant to setting limit values for contaminants. EN 15359 is not also a tool to establish the end of waste status for RDF.

Processing RDFs should however take orientation on the parameter range of this standard in order to be successful in producing a fuel material which is largely acceptable for the cement industry.

Table 9: Classification system for RFD according to DIN EN 15359:2012-01

Classes	Calorific value MJ/kg (mean)	Chlorine % (mean)	Mercury mg/MJ (median)	Mercury mg/MJ (80th percentile)
1	≥ 25	≤ 0.2	≤ 0.02	≤ 0.04
2	≥ 20	≤ 0.6	≤ 0.03	≤ 0.06
3	≥ 15	≤ 1.0	≤ 0.08	≤ 0.16
4	≥ 10	≤ 1.5	≤ 0.15	≤ 0.30
5	≥ 3	≤ 3.0	≤ 0.50	≤ 1.00

Source: EN 15359 *(displayed at https://fdocuments.in/document/which-future-for-the-srf-market.html)*

A list of the RDF properties to be met by processors in Turkey is contained in the currently enforced communiqué on waste fuels, added fuels and alternative raw materials (further referred to in this document under the abbreviation 'CATY'). It does prescribe a general minimum standard for RDFs allowed for use in Turkey (Table 10). However, in comparing that standard to the RDF quality usually requested by the cement industry certain differences can yet be noted (☞ *Table 11, Table 12, Table 15, and chapter 9*). To what extent technical reasons may explain these differences remains thus far unclear and should become subject of a thorough review and discussion process of all involved actors.

Table 10: RDF minimum standard in Turkey

PARAMETER	Limit values set
Calorific value	>2,500 kcal/kg
Grain size	<50 mm*
Moisture	<35 %
Chlorine content	<1 %
Mercury	<330 µg/MJ*
Total heavy metal content	<2,500 mg/MJ
PCB	<50 ppm
Solvent content	<15

* where evidence on appropriate technical installations is provided higher limits might be approved by the authority

Source: CATY, Annex 2, Table 4

5

Environmentally-sound management of RDF

Processing and using RDFs involves numerous challenges that must be appropriately addressed in order to minimize potential risks and harm. The quality requirements for the fuel product referred to in chapter 4 do have meaning not just from a technical but also environmental point of view. There are several more aspects that eventually require attention in a generally sound RDF concept, however.

RDF production stage

Facilities in which waste is accepted, stored and processed into RDF must be given the status of waste treatment facilities. All processes can lead to risks for the environment and human health. This concerns possible dangers that emanate from the waste itself or that can arise in the course of its handling (storage, treatment, processing, transport).

Some of the waste supplying a suitable substitute fuel or RDF for the cement industry, such as waste oil or solvents, are directly classified as dangerous waste and must therefore be managed with the appropriate precautions.

In the case of mixed municipal waste, organic components and thus a possible contamination by germs, spores, infectious bodies or decay products play a role. Here it is good practice for pre-treatment of malodourous waste to occur as soon as possible after receipt. Waste should be processed on a first-in first-out basis, with a robust system in place to demonstrate this.

In the biological processes of MBT, volatile substances, gases and reactive substances are also released, which have to be retained by filters or rendered harmless. For the latter purpose, regenerative thermal oxidizer (RTO) are, for example, used in these installations. A decrease of these dangers in the potential RDF output occurs only after the material passed the biological treatment and stabilization processes (in particular drying).

Instead, the pollution and distribution of dusts is now more prominent. In general, the generation of RDF is associated with the creation of dust, primarily due to the shredding and possible drying steps. The dust concentrations can be harmful to health but also cause explosion hazards.

The focus of RDF production on waste components with a high-calorific value goes hand in hand with an overall risk of ignition and fire. This concerns the processing but also the stages of material storage in particular.

Not least because of the processing, noise emissions also play a role. These are basically caused from the machines and technical devices used (☞ *chapter 7*).

Considering the mentioned impacts, plants producing RDF should be subject to approval processes and environmental regulations. In the EU this is ensured by means of emission protection regulations, in Germany e.g. by the Technical Instructions on Noise (TA-Lärm), Technical Instructions on Air Quality Control (TA-Luft) and Emissions Protection Ordinances (BImSchV), whereby the 30th BImSchV applies on MBT.

An important protective mechanism that many systems use in addition to filters is the creation of a negative air pressure in the storage and processing halls, which minimizes the escape of odors and dust to the outside. Furthermore, noise protection measures are applied, e.g. by encapsulating the machines and technical devices in place.

RDF in most of the cases must be stored prior to onward transportation, or at multiple stages within the supply chain. Storage may be required in order to accumulate sufficient quantities of RDF before a shipment can occur. The storage of RDF should be put under an appropriate environmental permitting procedure and the material then must be stored

- in accordance with the permit conditions,
- not outside of permitted areas,
- not in excess of permitted capacity, or for periods in excess of those set out in the permit (☞ *chapter 8*).

For reducing the potential for nuisance and smell, to keep the material in a state compliant to the specifications set out in the contract with the off-taker, and for enabling a further easy handling and storage it is of advantage that the finished RDF is wrapped or containerized. It is especially important to protect the RDF in storage from the effects of weather. Installations closed off from the outside are a preferable solution. Storage halls for RDF often have separate bunkers in which different types of fuel material (e.g. shredded old tires, processed municipal waste fractions) are stored and later combined to obtain the actually wanted fuel mixture and quality.

Further aspects of key importance in the duty of care during RDF production comprise:

- RDF input material and RDF products should be stored protected from the weather on an impermeable surface with sealable drainage to minimize the risk of leachate seeping into the ground and leading to contamination of the soil or water body;
- RDF production facilities should have a robust fire prevention plan in place;
- Producers and transporters of RDF material and products must declare the waste accurately to ensure it is handled in an appropriate manner and
- undertake appropriate measures preventing the escape of waste, particularly in relation to careful transportation of wrapped bales of RDF to prevent damage to the wrapping.
- RDF must only be transported by registered waste carriers.

RDF usage

Cement producing plants, in contrast to waste incineration plants, are usually not planned and designed as waste treatment processes. The usage of the RDF follows the procedural conditions of the respective cement production process. In order to destroy organic pollutants, sufficient temperatures and residence times of the gases in the furnace must be maintained. In addition, there must be a high retention capacity for particle-bound heavy metals.

The specific operational features render the clinker burning process fundamentally suitable for the environmentally friendly energetic and material recycling of waste. Following features (as contained in the German VDI guideline 2094 for the emission reduction in cement works) are most relevant here:

- Firing material temperatures of around 1,450 °C and maximum gas temperatures in the rotary kiln (primary combustion) of 2000 °C.
- Oxidizing gas atmosphere in the rotary kiln with residence times of gases in the rotary kiln of around 8 seconds at temperatures >1,200 °C.
- Firing material temperatures in the secondary furnace or calciner of 850 °C with residence times of the gases in the secondary furnace of more than 2 seconds at temperatures >850 °C.
- Short residence time of the exhaust gases in the temperature range of the new formation (de novo synthesis) of dioxins and furans.
- Sorption of gaseous components such as HF, HCl, SO_2 on alkaline reactants.
- Destruction of organic pollutants through high temperatures with sufficiently long residence times.
- Uniform burnout conditions due to the high heat capacity of the rotary kiln even with load fluctuations.
- High retention capacity for particle-bound heavy metals and chemical-mineralogical integration of trace elements in the clinker.
- Complete use of the fuel ashes as a component of the clinker, therefore simultaneous material and energetic utilization regardless of the calorific value.

Careful operations that include the limitation of critical substance inputs into the process are nevertheless indispensable to safeguarding the full effect of these factors, the environmental quality of the end product and an appropriate control of emissions.

To make heavy metals in particular subject to a constant monitoring and to restrict them accordingly, and especially within the frame of delivery agreements, cannot be overemphasized therefore.

Long-standing practical experience and the transfer factors (☞ *chapter 4*, *Table 5)* do provide valid orientation which load of critical substances is to be regarded as uncritical with regard to the applicable regulations for air pollution control and product quality. On that basis some practical values for the restriction of heavy metals can be given for the example of Germany (☞ *Table 11*). The maximum values displayed correspond to the restriction of the German Immission Control Act (BImSchV). The values apply to RDF with a calorific value of 20,000 kJ/kg respectively 16,000 kJ/kg for urban solid waste. Inhomogeneities in the material may justify a transgression in individual cases to be acceptable, this applies, for example, to the element content of copper.

Table 11: Practical and maximum values of heavy metals in RDF for cement production

PARAMETER	HEAVY METAL REFERENCE VALUES (mg/kg DM)	
	Practical value	Maximum value
Cadmium	4	9
Thallium	1	2
Mercury	0.6	1.2
Antimony	50	120
Arsenic	5	13
Lead	70-190	200-400
Chromium	40-125	120-250
Cobalt	6	12
Copper	120-350	300-700
Manganese	50-250	100-500
Nickel	50	100
Vanadium	10	25
Tin	30	70

Source: MUNLV-NRW

In the context of RDF production in Turkey, this issue is regulated by a similar definition of heavy metal parameters as well as by an additional listing of further substance restrictions and material properties in the annexes to the CATY (Table 12).

Table 12: General substance restrictions on materials to be used for RDF in Turkey

PARAMETER	Limit values set
Halogenated organic compounds	max. 1% by weight
Persistent organic pollutants (such as PCB)	max. 50 mg / kg
Solvent content (PAHs or VOCs)	< 15%
Flash point	> 55°C
Waste from highly active or biologically active substances	generally excluded

Source: CATY, Annex 1, Table 1

To make sure a high protection level of the environment and human health and prevent at the same time that waste materials and fuels products of insufficient quality are shipped to plants operating at lower environmental standards, stringent operating conditions, technical requirements and limiting values for emission must be defined and maintained for the incinerating industry including plants using RDF.

The successor regulation of the former waste incineration directive, Directive 2010/75/EU (☞ *Directive on industrial emissions and for integrated pollution prevention and control*) specifies the conditions for combusting fuels in industrial plants and the emission limits to be complied with in the EU. The co-incineration of substitute fuels in the cement industry is treated separately in this regulation. Emission limits relating to RDF use in the cement industry have been set here for total dust, HCl, HF, NOx, SO_2 and TOC for which these are applying as daily average values (in continuous measurement series), and for heavy metals as well as dioxins and furans where these are defined as average values over specified sampling periods.

However, **clearly defined RDF quality and respecting a certain limit in total fuel consumption for firing RDF are the prerequisites for an efficient, sustainable and eco-friendly co-incineration at cement and lime works**.

6 Organization of quality assurance for RDF

A constantly high product quality in RDF production is beneficial for both RDF processor and offtaker. For the processing companies, this opens up a broader market potential and reliable outlets of the produce, thus setting the basis for sustainable investments and a robust business. Operators of the cement plant on the other hand obtain security for an efficient and harmless co-incineration due to the proven calorific value and established substance values, and for a long-term, cost-effective supply concept for the fuel they need. Where the producers undertake a qualified processing and monitoring of RDF production they are recognized as particularly quality aware market partners and are thus able to win a competitive edge.

Quality management and assurance measures along the whole supply and utilization chain therefore form crucial and increasingly important elements in the RDF market. The concept of quality assurance comprises a larger series of activities which the various actors should undertake at the different stages of the process (Table 13).

Table 13: Quality assurance concept along the RDF supply and utilization chain

Process stage	Core actions	Supplementary measures
Place of waste generation	• Sorted collection of the waste materials • Avoidance of impurities • Agreement on composition of waste materials and permissible qualities • Documentation of the outgoing quantities	• Instructions to the waste generator on the do's and don'ts • Regular visual inspections of the waste generator and offtakers feedback on whether performance is in a desirable range
Entrance of waste processing plant	• Visual control • Regular sampling and analysis of waste input materials • Retain samples for cross-checking and dispute resolution • Documentation of incoming and processed quantities	• Certification of the processing plant (e.g. DIN EN ISO 9002) • Certification of the processor as a competent specialized waste management company
Exit of waste processing plant	• Regular sampling and analyses of outgoing materials • Retain samples • Documentation of outgoing quantities	
Offtaker (Cement plant)	• Regular sampling and analyses of the incoming RDF • Retain samples • Documentation of incoming quantities	• Regular sampling and analyses of the input materials by an external auditor

Source: Braun, H., Lafarge, Centre Technique Europe Centrale GmbH, 2002

A transparent and well-communicated regime of proper sampling, material analyses and declaration respectively documentation is at the core of such a quality assurance mechanism. The necessary trustworthiness and reliability of such a mechanism is brought about by the recurring application of complementary and mutually confirming procedures. In particular these are based on constant internal sampling and analysis as well as frequent external analysis of samples and sampling by an external appraiser at regular intervals. Evaluation and documentation of the results complete the quality assurance (Figure 4). Creating a special body in form of a quality assurance association or commission has proven itself as a supporting framework for communication, monitoring and the balancing of interests and not at last to ensure scientific and methodological competence within the procedure.

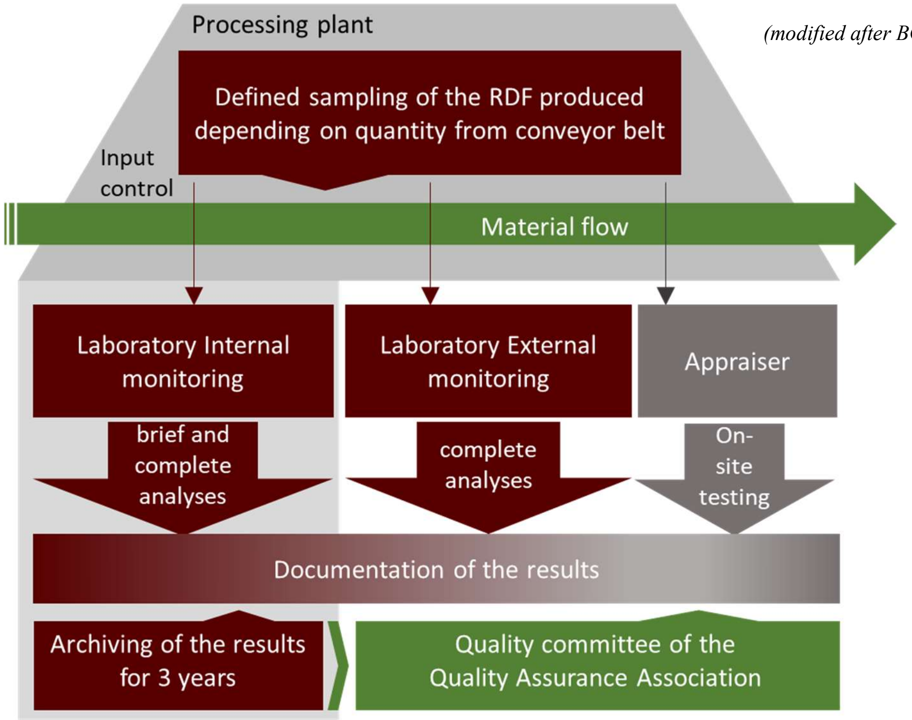


Figure 4: The concept of quality assurance (as applied in Germany)

Introducing (or applying) quality marks is one possible way to not just prove that proper quality assurance has been carried out but to influence also the application of procedures and control criteria that can guarantee the highest possible level of product quality and operational safety. Such quality marks can also be essential for awarding the RDF an end-of-waste status.

Quality marks identify products and services that are based on stringent quality criteria and are therefore well above the minimum standards. On this basis, a quality mark will be awarded by an independent organization, such as can be the quality assurance association. It is then regularly checked upon fulfilment of all relevant criteria and observance of the target values set by this organization and/or in corresponding regulations.

All the quality mark requirements are based on one another, so it can refered to this as a closed system. Within this, quality assurance takes place as a combination of internal monitoring by the RDF producers and third-party monitoring by an accredited auditor and test laboratory. The various elements of the procedure follow a defined sequential order.

Table 14: Key elements for organizing a RDF quality assurance

Elements of Quality Assurance	
• **Input control/verification**	Initial assurance of the defined quality and waste types. Waste type must be compliant with the quality and test specifications.
• **Sampling**	Continuous monitoring of the material flow in production according to a defined scheme, with manual or automatic sampling
• **Sample preparation and analysis**	Clear requirements for the extraction, preparation and analysis of the samples in the test laboratory
• **Quality criteria**	Compliance with the ambitious heavy metal guide values and the procedural and fuel-related parameters
• **Data evaluation**	Statistical evaluation of the analysis results and preparation of a test report by the Quality Assurance Association

In Germany, the Quality Assurance Association for Solid Recovered Fuels and Recycled Wood (Gütegemeinschaft Sekundärbrennstoffe und Recyclingholz e. V. - BGS) has defined and succesfully introduced such a quality assurance mechanism for RDFs.

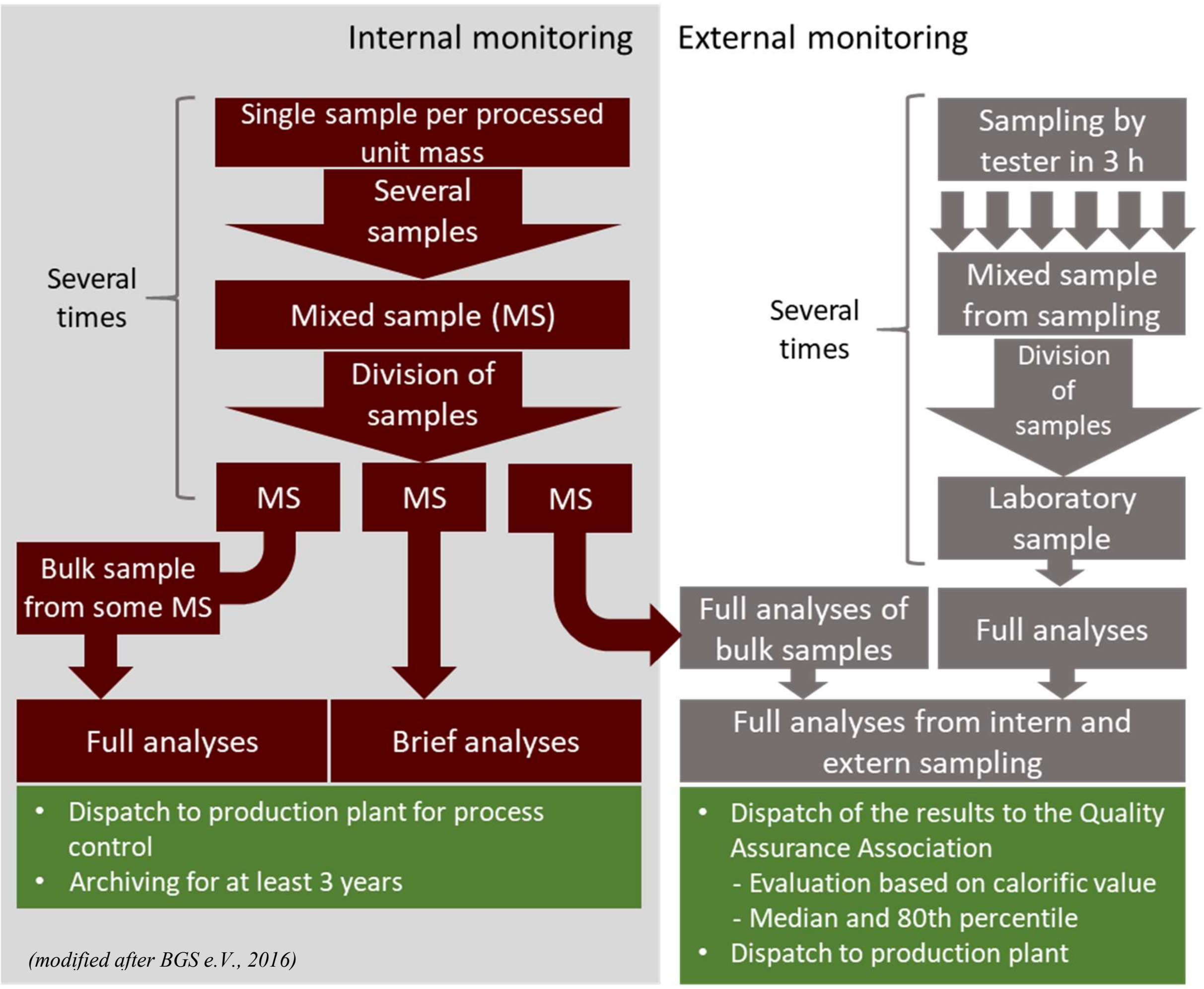


Figure 5: Monitoring structure applied for the quality assurance of RDFs (by the German Quality Assurance Association)

Precisely specified sampling and analysis operations in terms of type and number come between the receiving inspection and the attestation of quality. This allows both internal and third-party monitoring to be carried out using established quality criteria, thereby guaranteeing an independent and reliable end result.

The largest part of the quality control is undertaken by the RDF producer. According to the processed mass, samples must be taken continuously and analyzed in brief. At defined intervals, severals samples have to be merged to a bulk sample in order to carry out more extensive analyses. These internal results are helpful to manage the production process in a way that meets the quality criteria for RDFs. The external part of the monitoring comprises the full analyses of internal taken samples in the same number and quantity of the internal full analyses. A few times a year, an external appraiser visits the processing plant for reliable and represantative sampling of the material flow and division of samples. From this, laboratory samples are taken for full external analyses. The results of extern analyses are dispatched to the RDF producer and the Quality Assurance Association for evaluation and control (☞ *Figure 5*).

Based on this procedure, the German Quality Assurance Association-BGS has succeeded in establishing high standards for RDFs with the implementation of the RAL Quality Mark 724 in Germany.

In order to obtain this quality mark that distinguishes an individual RDF from competitors, stricter requirements are set for the quality and heavy metal content of approved RDFs. The limit values for heavy metals of the German RAL Quality Mark 724 for solid recovered fuels (Table 15) complement for example the RDF quality classification system established through CEN/TC 343 and CEN-EN 15359 (☞ *Table 9*).

Table 15: Heavy metal values of the German Quality Mark RAL-GZ 724 for solid recovered fuels

	HEAVY METAL REFERENCE VALUES (mg/MJ)	
PARAMETER	Median	80^{th} percentile value
Arsenic	**0.31**	**0.81**
Cadmium	**0.25**	**0.56**
Cobalt	**0.38**	**0.75**
Chromium	**7.8**	**16**
Mercury	**0.038**	**0.075**
Manganese	**16**	**31**
Nickel	**5.0**	**10**
Lead	**12**	**25**
Antimony	**3.1**	**7.5**
Tin	**1.9**	**4.4**
Thallium	**0.063**	**0.13**
Vanadium	**0.63**	**1.6**

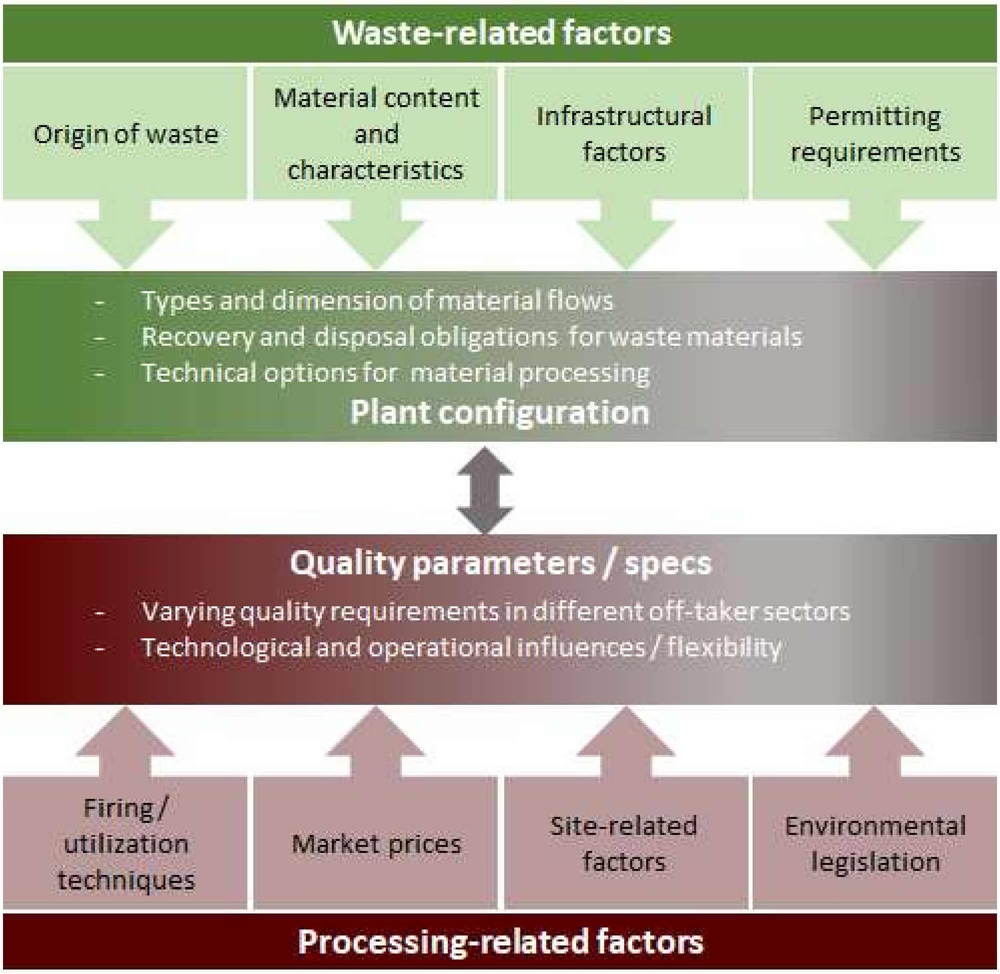
Source: BGS e.V.

The parameters calorific value, water content, ashes and chlorine must also be analysed and documented during the quality assurance regime. The contracting parties establish these procedure-specific parameters bilaterally. The copper parameter must also be analysed and documented.

Differences that in certain cases may be found in regulations and standards can be explained with country-specific political, technical and market situations though these indicate as well the need for harmonization that still exists globally and between the countries. At the same time, however, it is also important to consider the complemetarity of standards and to understand them as instruments that can be adopted to help good practice and more ambitious goals achieve a breakthrough.

7 Overview on technical options to prepare RDF for the cement industry

The technical options and technologies, i.e. process configurations and intensity that ultimately suit for RDF production are essentially determined by the to be processed waste and goals of processing, with the latter eventually also involving fuel specifications set from off-takers such as the cement industry. MBT, for example, is not actually meant to be a RDF production technology but provides an option for doing this. However, there are numerous more waste-specific and market-specific aspects that eventually influence the adopted process design, including for example environmental protection and permitting obligations both waste processors and RDF off-takers have to comply with (Figure 6).



Source: compiled with information from various source

Figure 6: Influences on RDF production and processing arrangements

It follows from the essential requirements that fuels in the cement industry must fulfill that most waste streams have to undergo mechanical processing before they can be used as RDFs. The objective of this treatment is to produce a material mixture with defined properties (☞ *Chapter 4*).

Producing RDFs follows very individual ways, there is no one-fits-all procedure

Substance content, calorific value and particle size are hereby particularly relevant (Table 16). These aspects essentially determine the RDF's final applicability and the processes associated with their generation and use.

Table 16: Key aspects in processing waste to RDF

Focus	Relevance for
Material composition	• Energy content (aim of up-concentration) • Substances with potentially negative impact on cement quality and emission situation (aim of limitation) • Overall material balance of production process (RDF added contributions and conversion products) • Ignition point
Calorific value	• Substitutable energy amount or additional energy input • Process entry point • Temperature stability and flame shape
Particle size	• Dosing • Process entry point • Uniformity, duration, and completeness of burnout

Components of the processing chain

Processing waste into RDFs, in general, may involve various process components and techniques of which the following can be considered the most relevant and applicable ones (Table 17, ☞ *Annex 2*).

Table 17: Principal techniques applied in RDF-processing and their purposes

	Purposes and aims
Comminution	• Ensures the sortability of the material components • Gives a certain homogeneity/uniformity of the material mixture • Leads to the desired particle size and controllability (for dosing) • Improves the storage and transport economy
Sorting / separation	• Generates the desired material composition / streams • Eliminates or minimizes unwanted material components • Increases or sets heating value to the desired level
Drying	• Increases or sets heating value to the desired level • Improves the storage and transport economy

Central in the RDF preparation process are sorting and separation steps facilitated by the different chemical and physical properties and behavior of the raw material components (☞ *Figure 7*). RDF processing goals and quality requirements are largely realized by the targeted use and the combination of sorting and separation techniques.

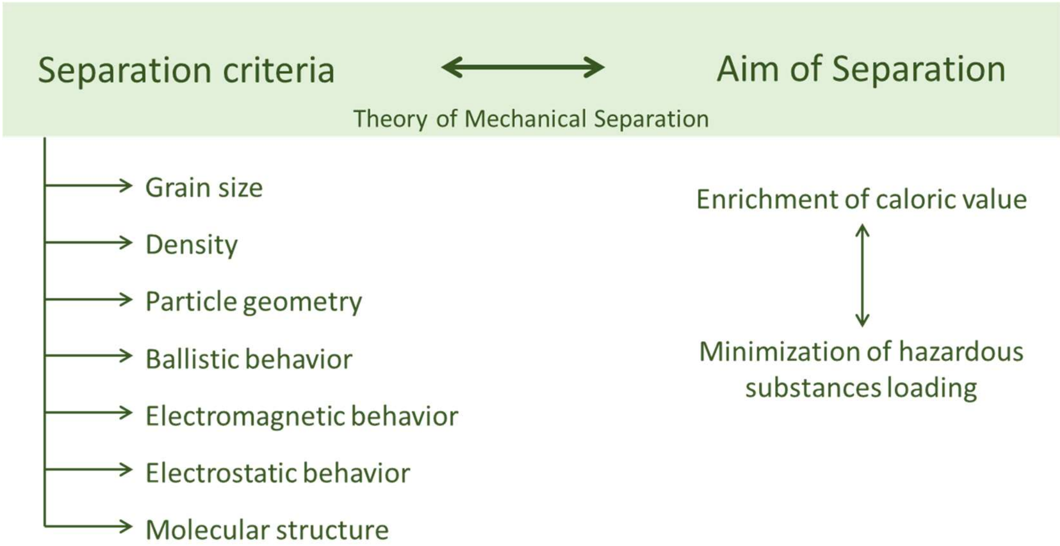


Figure 7: Principal criteria and aims adopted for mechanical sorting/separation of RDF input

Apart from the requirement specification for RDFs, the waste input determines predominantly which techniques and steps have to be applied for processing and to what extent. In the below overview are displayed the technical steps and component combinations usually needed and applied to process those waste streams that are most suitable for RDF in the cement industry (Table 18).

Table 18: Required processing steps for different waste streams

Waste input	Processing components / techniques					
	Comminution	Sieving / sizing	Sifting / classifier	Metal separation	Optical sorting / classification	Drying
Waste oil and Solvents	-	-	-	-	-	-
Waste tires	possibly	-	-	-	-	-
Sewage Sludge	possibly	-	-	-	-	×
Meat and bone meal	×	-	-	-	-	×
Sorting residues	×	×	possibly	×	possibly	possibly
Commercial waste	×	×	×	×	×	possibly
Mixed municipal waste	×	×	×	×	×	×

Source: compiled with information from various source

The greater the inhomogeneity and the spectrum of different material components in the waste input for RDF production, the more complex and extensive are the processing and separation steps required.

Role of processing components in RDF production

Material reception

Operations for RDF production (or in any waste treatment plant) begin in the receiving area, where delivered waste is weighed and registered. Visual inspection and accompanying documents must ensure compliance with the waste acceptance criteria. In most cases, the waste is afterwards stored in a bunker until it is processed. In this step, coarse disturbing materials (including metal parts) can already be sorted out by hand, with an excavator or a polyp grabber.

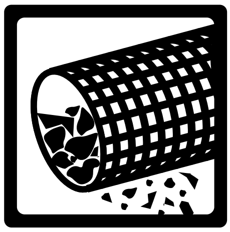
Comminution

As preparation for the further processing, coarse or mixed materials are pre-shredded and waste bags get torn opened at the same time. During pre-shredding it must be ensured that the waste remains in a sufficiently large size so that further sorting in subsequent steps is possible. For this reason, a not too small particle size is created. Usually, the particles should be pre-shredded to a size of > 300 mm.

Later on, in the treatment process, additional shredding steps ensure the grain size wanted for the final RDF material. This may result in the so-called "fluff" or blowable quality, that is preferred by cement plants due to its good dosing properties. A small particle size enables the RDF to be fed in easily controllable quantities into the incineration process. It likewise guarantees ignition and complete burnout of the RDF in the manner wanted. The expenses for preparation rise the finer the RDF has to be. Depending on the entry point in the cement process (☞ *Figure 3*), the following differences usually apply to the grain size specifications:

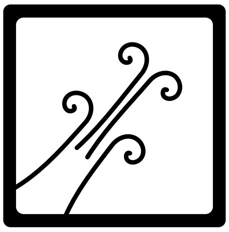
- Rotary kiln: < 20 mm
- Calciner: < 80 mm

Sieving / sizing



In the case of mixed waste materials, sieving follows the first shredding step. Sieving is no material specific separation but rather a size-specific separation, which is why sieving has hardly any significant influence on the discharge of undesirable components and contaminant carriers (☞ *Figure 8*). Nevertheless, a sieving step after shredding separates fines such as sand and inerts as well as brittle materials like organics and glass. Hence, sieving is useful to separate abrasive particles, which increases the service life of downstream processing and shredding units. In addition, insufficiently pre-shredded material can be returned. Generally, sieving generates a high rate of RDF-compatible component output, such as paper, plastic films, textiles etc.

Sifting / classifier



When using sifting techniques, the main objective is to separate material components according to their suitability for the RDF. For example, unwanted material components can be discharged and/or material flows with desirable properties (e.g. components with a higher calorific value content) can be separated. The separation of light, fragmentary material components with a high-calorific value, such as foils, plastic particles and paper, is in the focus of RDF production (positive sorting). Heavy fractions, such as stones, shoes and hard plastics with a lower calorific value but a higher pollutant content can also be sorted out (negative sorting). Density and ballistic properties are thus used by the employed separation devices.

Using different sifting and sieving methods and devices is done with the aim to influence RDF yield on the one hand and reduce polluting or harmful substances from mixed waste material streams on the other hand. Each method has its own merits and advantages here (Figure 8).

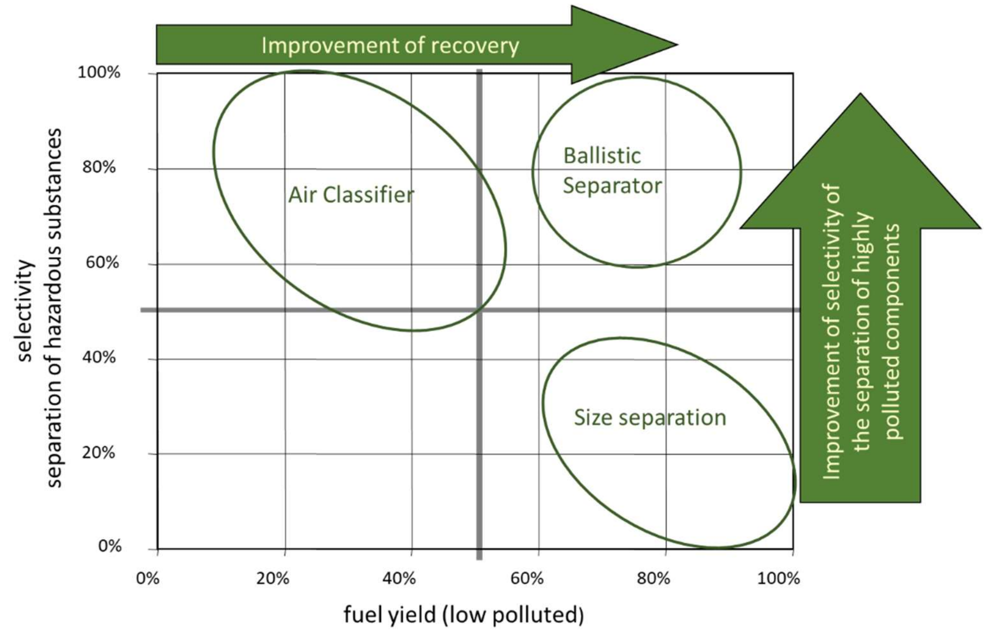
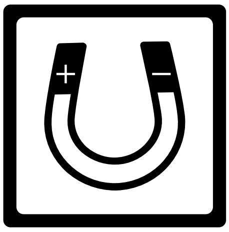
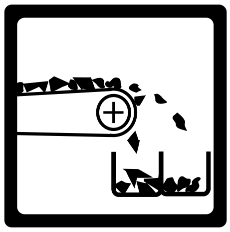


Figure 8: RDF-related performance of sifting and sieving techniques

Metal separation



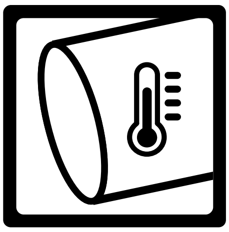
As inert materials, metals are unsuitable for energy use, but have a value for the scrap recycling industry. In addition, the separation of metal-containing particles also removes relevant proportions of heavy metals from the material flow. Where metals can be expected in the waste input, magnetic separators for the ferrous metals and eddy-current separators for other non-ferrous metals, such as copper, zinc, are applied.



Optical sorting / classification

Chlorine and sulfur in the RDF cause that alkali chlorides are formed during incineration which, if not absorbed by the clinker, enter the gas phase and condense at lower temperatures. Resulting crust formation and cyclone clogging impact on the operation performance. For this reason, the chlorine content must already be limited in the RDF material selection and processing. Optical or optoelectronic techniques (such as NIR) allow specific material detection and thus also for those components in the material flow with increased undesirable substance concentrations (e.g. PVC, leather). These components are separated after detection from the material flow. This is especially important where mixed waste or plastic waste is processed into RDF.

Drying



Material drying can be necessary in order reach a desired calorific value and/or to lower transport burdens and energy losses due to high water contents. The calorific value and moisture content are important factors determining the price of RDFs. Compared to situations in which the cement works themselves carry out final processing steps (e.g. final crushing, further drying or moist feed), the revenue situation shifts in favour of the processors where they can offer the RDF with the ideal characteristics for the cement plants. Which scenario is finally chosen is determined by the local market situation and agreements made in advance by the market partners.

Other optional components

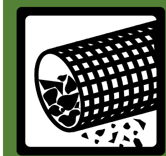
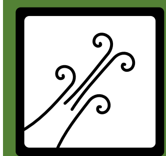
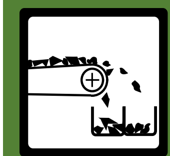
Depending on how the target quality parameters can be achieved in the previous preparation steps, manual sorting can be integrated to ensure the final quality of the RDF.

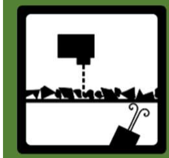
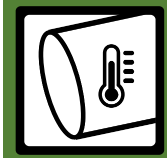
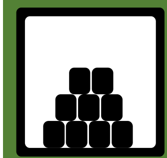
An automated NIR control to record the material composition at the input can be employed to adjust the further processing steps, likewise practiced is NIR-supported quality monitoring on the RDF output. Especially this option is expected to be increasingly used in the future. However, manual sorting may also work as a replacement where expensive optical or opto-electronical devices are not affordable.

Other possible processing steps to obtain final RDF properties as required by the cement industry include blending of material with different calorific values and pelletizing. However, cement plants use generally only soft pellets or fluff.

Whether the final comminution or drying is carried out at the RDF producer or directly in the cement plant depends on the prize for purchasing the fully prepared RDF, and on the mechanical equipment that the cement plant or RDF producer have at their disposal, respectively.

Commonly applied equipment (☞ *Annex 2*)

Component	Equipment types	Typical characteristics
	**Pre-shredding** • Rotary shears • Rotor shredders **Secondary shredding** • Granulator • Impact mill • Hammer mill	• Usually low-speed rotors Single-shaft or twin-shaft shredders, depending on the supplier • High-speed rotors
	• Drum sieve • Shaking screen • Star screen	• Screen designs (e.g. length, perforation) influence performance Good accessibility and ease of repair to remove clogging and blockage should make up criteria too
	• Air classifier/wind sifter • Ballistic separator	• For separating heavy and lightweight fraction. Lightweight material is ejected from the material by means of a strong air flow. • Consists of separately rotating paddles which allow a material stream to be separated into 2-3 fractions: body-like, heavy components roll downwards, flat and light particles are discharged upwards by rotation. If perforated paddles are used, a third fraction can be screened.
 	• (Electro) overbelt magnet separator • Magnetic drums • Eddy current separator • Induction sorting	• Sort out ferrous metals • Sort out non-ferrous metals

Component	Equipment types	Typical characteristics
	• Near infrared spectroscopy (NIR) • Manual sorting	• Detection of multiple materials is possible but especially relevant to separate PVC and reduce chlorine content in RDFs this way • Final quality control or separation of pollutants or materials for other purposes (e.g. various types of plastic, paper/cardboard for recycling)
	• Drying drum • Belt dryer • Rotting box in MBT	• Flue gases, waste heat or solar energy can be used, residual water content of 10 % possible • Drying can take place before or as part of producing RDFs; e.g. - Heating in the rotting boxes due to biological activities - Thermal drying in mechanical-physical stabilization facilities (MPS) - Heat generation during pelleting (often used for stabilized, pre-dried municipal waste)
 	• Silos, bunker or boxes depending on fuel conditions • Bale storage for RDF compressed into bales and wrapped in a waterproof manner	• to lessen degradation effects in quality and facilitate easy discharge loose RDF is often stirred and loosened while in storage (using compressed air or mixer aggregates) • ☞ *chapter 5*
	• Container trucks • Railroad wagon	• with hydraulically driven moving floor conveyor technology or suction nozzle for loose RDF (fluff) • wrapped bales are only crushed to the required grain size in the cement plant

Typical RDF processing chains

RDF production is characterized by various treatment techniques (process components) applied to varying degrees and their targeted, sequential combination depending on the input material and the need for preparing it in order to met the fuel specifications. Basically, the more demanding the specifications and diverse and inhomogeneous the waste input are, the more complex are the components arrangements for RDF-production. These can range from a rather simple, one component processing to very extensive and sophisticated treatment chains.

Processing RDF can range from rather simple to technically sophisticated concepts

Descriptions for process configurations of increasing complexity are found hereunder, starting from rather simple processing examples for less complicated waste materials up to waste inputs of challenging nature and the more complex processing chains needed for these.

Waste oil and solvents

Separately collected waste oils and solvents must be analyzed primarily for their pollutant content (e.g. PCB content) and calorific value. Feeding and dosing in the cement process is carried out in the same way as for crude oil as a primary fuel. Hence, no further treatment is necessary as long as the respective waste oil or solvent meets the specifications.

Waste tires

Used tires in general represent a relatively uniform waste material stream with sufficiently high-calorific value and defined size. Cement plants often are able to handle tire casings without pre-treatment. The tires can be fed piece by piece into the rotary kiln after a general check (size, wheel rim removed). Shredding the tire casings into chips can be an alternative. If the tires are not shredded, their use in cement plants is normally limited to certain sizes (max. diameter of 1.2-1.3 m).

Sewage sludge

For using sewage sludge as an RDF, thermal or solar-assisted drying up to a dry matter content of at least 40 % is indispensable after mechanical dewatering. In some cases the mechanically dewatered sewage sludge is dried as part of the process in cement plants. The high phosphorus content limits the input quantity they can use to a maximum of 20 % or less depending on the further fuel mixture. Cement plants must ensure that the phosphate content in the clinker does not exceed 1 % which would reduce the cement's strength.

Meat and bone meal

When processing slaughterhouse waste, hygienic requirements must be adhered. After pre-shredding, the carcasses and slaughterhouse waste used for producing animal meal RDF must be thermally sterilized. Closed systems are to be provided in all process steps. Processing facility and the cement plant must have the appropriate design and installations for meat-and-bone meal and fat in place, especially to avoid clogging. Grain size, fat and water content are the decisive parameter for delivery and storage processes and the conveying of meat and bone meal RDF to the burner. Therefore the sterilized meat pulp is mechanically dehydrated, degreased and further comminuted. The phosphate content increases with increasing bone proportion and meat and bone meal also contains relevant chlorine content. Therefore, the input quantity of meat and bone meal as fuel in cement plants is limited.

The input composition and requirements at the RDF-using plants essentially determine how RDF is processed

Commercial waste

Depending on the calorific value and composition of the material fractions of commercial waste, different processes can be considered for RDF production. If the composition is relatively uniform and the material has a high-calorific value, simple and short process chains can be sufficient (Figure 9). The process shown is conceivable for the processing of waste from the packaging industry as well as from the production of plastics, hygiene products, carpets or textiles.

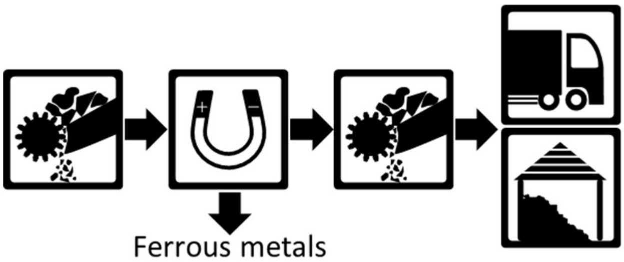


Figure 9: Exemplary processing of specific process waste

In case of a more complex commingled commercial waste, for example plastic fractions from mixed construction waste or bulky waste, processing must involve more steps (☞ *Figure 10*). Diverse commercial waste streams as well as the high-caloric fraction from MBT plants with no separate mechanical treatment (☞ *chapter 3* or *Mixed municipal solid waste* section below) can be sources of suitable input for the RDF processing scheme shown. A higher degree of separation can be achieved by a multi-stage metal separation, which reduces the heavy metal content at once, since metal scrap is one of the main causes of heavy metal pollution in substitute fuels.

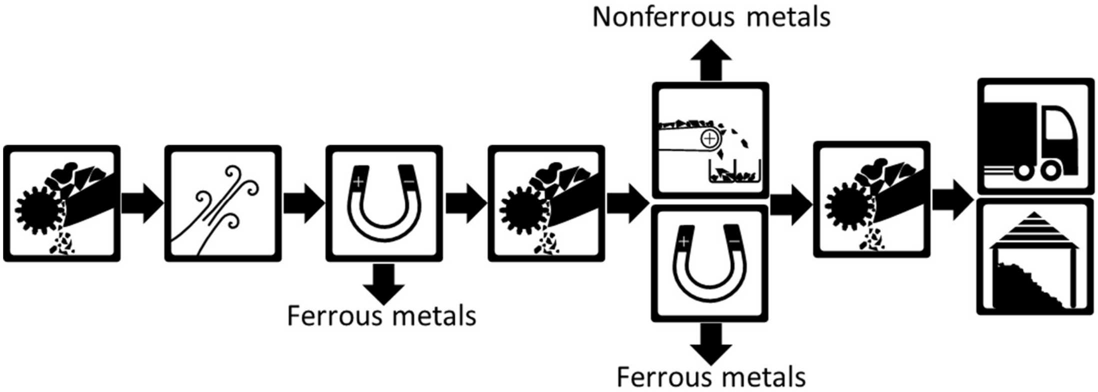


Figure 10: Exemplary processing of roughly pretreated, high-caloric waste or commercial waste

However, the individual waste composition and associated contaminant loads may just as easily require more complex arrangements for the RDF processing. Thus reference is to be made here also to the following process explanations for sorting residues.

Sorting residues

Recycling materials -as per the waste hierchy- has a higher priority than using those in waste to-energy processes. Generally this applies to all waste, including of course the commercial waste fractions referred to above. However, unsortable, unrecyclable and polluted components are separated during sorting processes and form a leftover waste. Similarly there are residues generated in the recycling process itself, such as rejects in paper and beverage container recycling, or the melt filter cake, composite and non-compliant polymers discharged whilst producing secondary plastic granule. All these leftovers contain combustible components but also pollutants at varying degree.

Processing them to RDF for the cement industry therefore requires different arrangements and intensities. These can be simple like just drying and shredding (e.g. for paper rejects, non-process compliant polymers) but also rather complex (e.g. for mixed leftover from sorting packaging, a high-calorific component mixture diverted at an MBT).

The chlorine content of such process residues can be high (e.g. up to 2 % for the last two mentioned examples), employing optoelectronical sorting (NIR) therefore be of decisive influence and a must have to reach the required RDF quality.

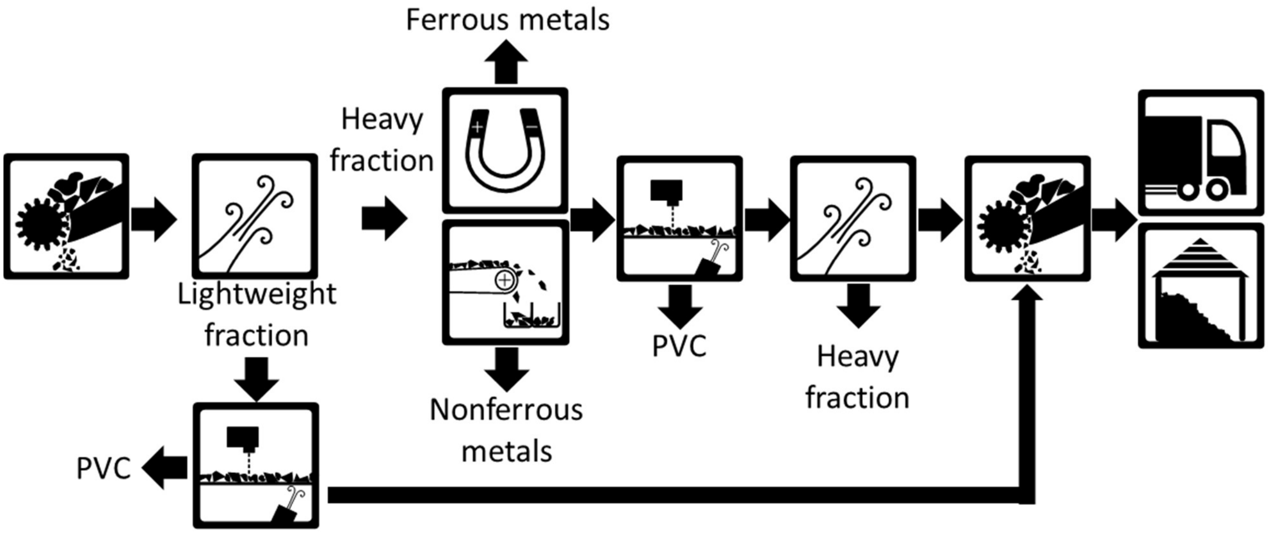


Figure 11: Exemplary processing of sorting residues from packaging recycling

Mixed municipal solid waste

Mixed municipal waste belongs to the most challenging input streams from which RDF can be won. It contains many different materials, including a high content of moist organic material, recyclables and inert materials. The fraction of light-weight materials, which is generally rich in calorific value, consists of plastics, paper and cardboard, rubber, wood and textiles. Diverting it from the input is one strategy of MBT to obtain a suitable RDF material and to reduce the quantities which are to be landfilled.

Generally, however, drying is essential for the municipal waste mix which has a water content of between 25 and 45 % and thus a not very good heating value. Untreated municipal waste has a calorific value of 8-11 MJ/kg, whilst the calorific value of processed and dried municipal waste RDF is about 15-20 MJ/kg.

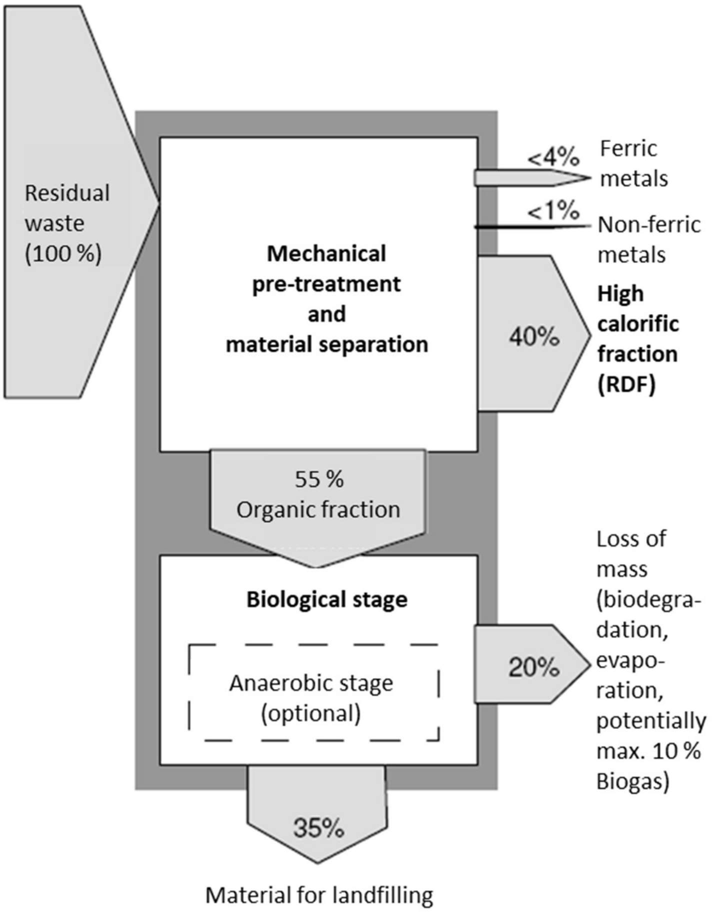


Figure 12: MBT splitting approach

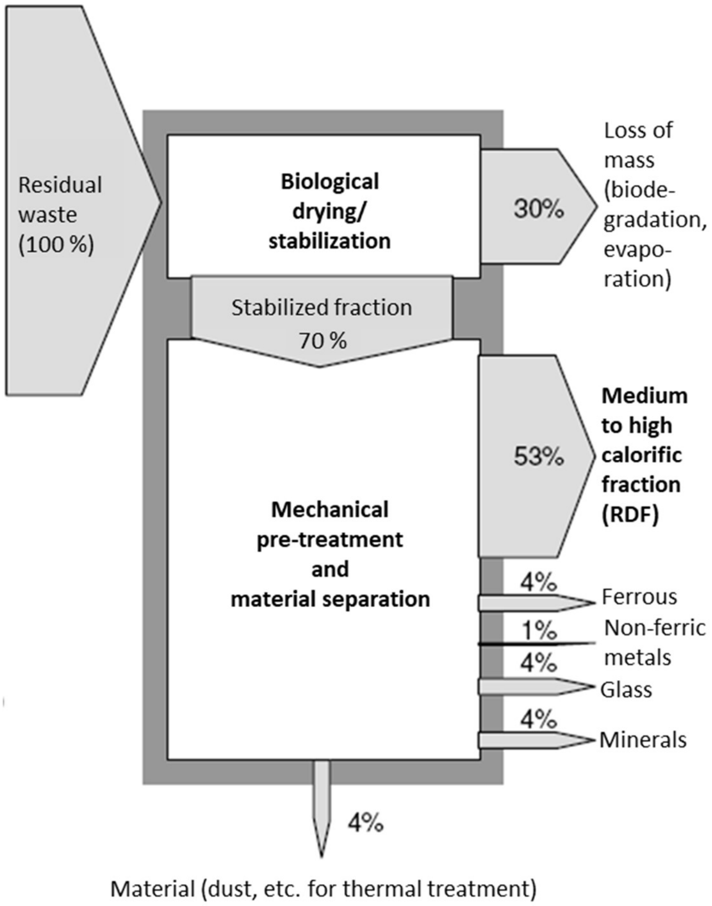


Figure 13a: Dry Stabilization Treatment

In a mechanical-biological treatment of municipal waste, two basic strategies can be followed to obtain a material which can be further processed into RDF for cement plants. One strategy is the splitting of material flows (Figure 12), the other is the concept of dry stabilization.(Figure 13a)

MBT with splitting diverts material of sufficient calorific value in the initial mechanical step away from the plant input whereas the moist, organic-rich rest is fed into a separate biological treatment. The separation of the two material streams is basically done by sieving with drum screens. The high-calorific material mix is forwarded to RDF production where the further processing is of the same sort like described above for input obtained from mixed commercial waste fractions and/or sorting residues.

Alternatively, the biological rotting applied on the entire mixed waste input in the dry stabilization process serves to dry the complete material by way of microbiological activities. This rotting is performed in closed container boxes or tunnels (Figure). More simple and time-consuming but of the same effect are rotting techniques that work with the waste put under a special semipermeable membrane (Figure). The dried, stabilized waste can be afterwards mechanically processed into RDF.

Figure 13b: Biological rotting in closed container boxes

Figure 13c: Biological rotting under a semipermeable membrane

An example for the possible processing chain that applies on the RDF material won in MBT is shown in Figure 14. Nowadays at least one additional optical sorting step using NIR is often installed for the separation of PVC, for the sorting of further material flows or for input control in modern RDF plants.

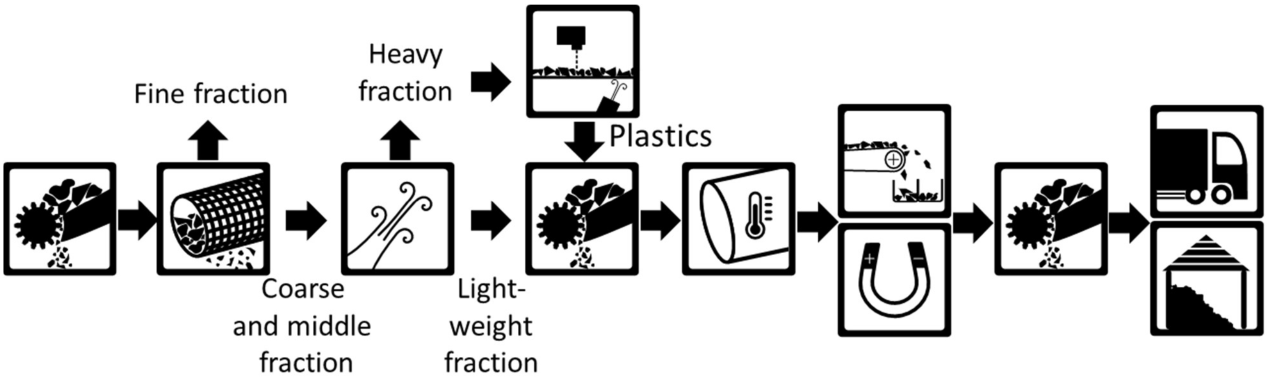


Figure 14: Exemplary processing of mixed municipal waste

In the case of municipal solid waste, the RDF output is sometimes less than 50 %, as the MSW contains a large proportion of organic material. In contrast, with a material input of specific commercial and production waste or sorting residues in RDF production, output rates of over 90 % can be generated.

8

Options for RDFs not in the demand and/or not complying to specifications

Under a good and farsighted management concept it should not become normal that RDF is produced for which the market has no demand or no capacities for usage. There can nevertheless be situations where capacities are temporarily not available or where the RDF quality produced does not suffice the needs of the users. Such gaps can be bridged by appropriate concepts and measures.

Situation encountered	Recommended action
• **no demand or temporarily lacking capacities on the side of RDF off taker**	• Interim storage of RDF • Material is offered/shipped to alternative users
• **RDF does not meet required quality**	• Material is reprocessed until complying to specifications • Material is offered/shipped to alternative users or taken to disposal

Storage

RDF storage should -from initial production to final treatment- not exceed a total cumulative period longer than 3 months. If there are additional preventative measures put in place to reduce any adverse impacts of longer storage this period can be extended up to 6 months. Storage should exceed 6 months from the date of production only under a specific agreement. Since RDF may be stored at multiple points through the supply chain, cumulative storage times should be monitored. A date marking of the RDF bales can provide an appropriate instrument for this.

Two main aspects are of particular importance for RDF storage:

► ***Keeping the material dry***
(for example through roofed dry bearing or waterproof wrapping)
Such a protective measure helps preventing a degradation of the RDF, seeping of leachate and fly or vermin infestation. Bales must be regularly inspected and storage times should be reduced if the RDF begins to show signs of degradation. Where RDF is being stored an assessment should be made of any risks the material may present to its surroundings. Action should be taken to minimize those risks and operators of the storage have to consider additional measures of protection and risk mitigation, if necessary.

► ***Prevention of spontaneous ignition and fire protection***

Special attention has to be paid to fire protection measures because these are absolutely necessary for the storage of most substitute fuels. For this reason, prior risk analyses of the RDFs to be stored are important. Possible fire protection measures include partition walls and fire breaks, the installation of infrared cameras, automatic fire detectors, sprinkler systems or other fire extinguishing equipment.

Reprocessing

Deficient quality or non-compliance with the user requirements on RDF first of all pose a contractual issue that the two parties RDF producer/supplier and the receiving cement plant must settle bilaterally. In the general practice this is ruled by stipulations in the contract respective bilateral agreement which has been concluded between the parties on the RDF supply. Usually is foreseen that if an RDF must be rejected due to deficient quality, it has to go back to the processor in order to be preprocessed until the agreed parameters are being met. It can also be an option that the cement plant accepts certain amounts of a substandard RDF but can claim a financial compensation or discount in the price. The RDF of non-compliant quality must then be used from the cement plant in such a manner that no negative effects arise from that for the process, product quality and the environment. Using only small quantities from the defective RDF batch together with a better-quality RDF or primary fuel can be a way to ensure this. However, the deviations from the quality norm in this case should not be too big, concern only smaller quantities and be temporary in nature only.

Alternative use

Where the quality problem is a permanent one, other alternatives must be found for the RDF. The energetic utilization is theoretically possible in all plants with an adequate firing system and emission abatement/control in place. Practically they must hold a permission for the usage of RDF, however. Generally this offers following options respectively utilization pathways for RDFs (Figure 15).

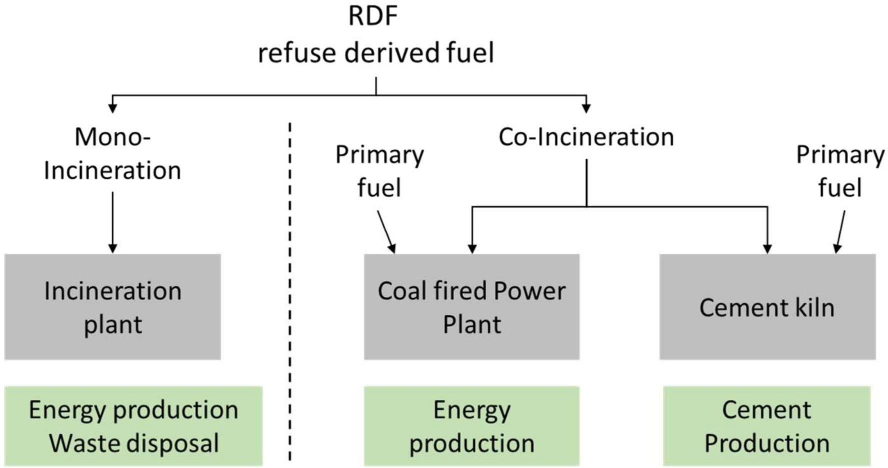


Figure 15: Utilization pathways of RDFs

The capacities and abilities to handle RDF vary across these potential pathways, however (☞ *Table 19*). Where the RDF cannot met the requirements of local cement plants, the main alternative routes are provided by:

- Dedicated mono-incinerating waste-to-energy facilities (RDF-power stations),
- Co-incinerating power plants,
- Waste mass-burn incinerators.

Table 19: Relevance of fuel characteristics for RDF use in the different incineration segments

Parameter	Cement plants	Power plants	RDF-power stations
Calorific value	++	+ to 0	- (with upper limit)
Chlorine content	++ to +	++	+
Grain size	+	++	0 to -
Impurities	+	++	0 to -
Ash content	+	+	+
Moisture	+	+	0
Heavy metal concentration	++	++	0 to -
Disposal prices	(quality-dependent)	- to 0	+ to ++

Requirements: ++ very high, + high, 0 medium, - low Source: Eckardt, 2005

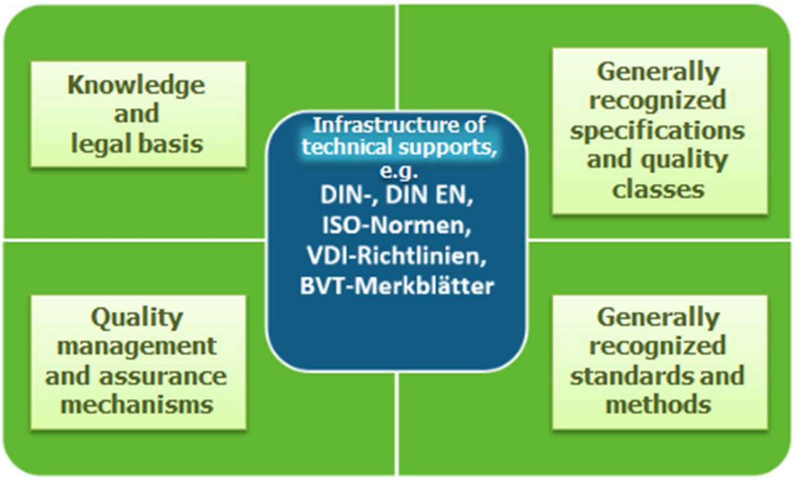
RDF-power stations include flue gas cleaning systems that are specifically adjusted to the RDF input and the critical components it may contain. These incinerators are furnished with refractory liners and combustion chambers able to deal with the material specifics such as certain extremes in calorific and ignition properties or critical substances content and reaction products. These kind power stations are usually set up to generate the energy for large industrial facilities from the residues and waste these facilities produce, and therewith serve a specific RDF market. Although such plants may have the technical possibilities to use a RDF not acceptable for the cement industry, their vacant capacities to absorb additional amounts are often very limited. Building RDF-power stations for fuels for which it is difficult or too expensive to find markets otherwise is not quite uncommon.

Contrary to this, existing *power plants* are designed for a certain unifom fossil fuel. For most cases this is coal and the feeding, boiler and exhaust gas system is specifially adjusted to the properties of this specific fuel. However, power stations that use partly RFDs can save fossil fuels, costs and CO_2-emissions, but need a permission and possibly an extension of the technical equipment. Authorities may grant the plants such permission subject to an upper limit in total fuel consumption set for co-firing RDF. These limits must be set so that there is no increase in the emission levels of gaseous pollutants (including acid gases, dioxins, furans, etc.). Power stations also define criteria for the acceptable RDF quality to fulfill the emission protection standards and to protect the plant components.

Waste mass-burn incinerators are capable and permitted to deal with diverse waste materials, including RDFs. They must operate flue gas cleaning systems able to handle waste with harmful content, aside from being under the obligation to assure a given high oven temperature and retention time. Due to the high calorific-value of RDFs, waste mass-burn incinerators use RDFs only in limited quantity and in mixture with other waste. Using RDF for and in waste mass-burn incinerators hence is a reasonable route only if no other usage option is available, i.e. an emergency exemption. Waste mass-burn incinerators do have the task to ensure a safe disposal and reduction of waste for which there is not other recovery possible. Much of the effort and energy contained in a RDF get lost this way, moreover that capacities of the facility for other waste are being blocked.

9 Recommendations for improving RDF status and utilization in Turkey

Comparing the practice of RDF production and usage , including the available institutional, legislative and technical-methodological basis and experience in relation to the cement industry in many European countries with that in Turkey, reveals that Turkey still has a huge potential of catching up. This extends to practically all fields of action pertaining to the RDF subject but mainly those visualized hereunder.



The informal exchange carried out both by the domestic actors among themselves and with international specialist as well as business partners is an important instrument for making progress. In general, communication between the potential contracting parties (waste disposal companies, waste processors / RDF producers, RDF offtaker) and with the responsible authorities forms an essential pillar in the process of developing viable RDF concepts and the necessary confidence basis.

Aim in this process must be to identify adequate quantities of RDF-suitable materials and products, and to enable targeted investments and contracts as well as practical and enforceable regulations that promote RDF quality and the environmentally friendly application of RDFs. It is along this route that RDFs can be established as a standard supply on the fuel market and complementary component in the national waste management system.

Apparently, a need for technical discussion among others exists with a view to the provisions and specifications as thus far contained in the Turkish CATY. In particular, insofar as the focus is initially kept on the cement industry as principal user of RDFs in Turkey, it certainly makes sense to review, readjust or even repeal certain regulations.

One issue such discussion may have to touch upon concerns the precautionary and permissible parameters for RDF input materials and products. In a comparison of the established reference values, the Turkish provisions show some debatable differences, for instance compared to the German ones (Table 20).

Table 20: Relevance of heavy metal parameters in the material control for RDF

Element	**Control parameters [and limit values set] to guarantee RDF safety**			
	Turkey *[mg/kg input material]*		**Germany** *[Median mg/MJ]*	
Lead	✕	*[<600]*	✕	*[12]*
Cadmium	✕	*[<10]*	✕	*[0.25]*
Chromium	✕	*[<400]*	✕	*[7.8]*
Nickel	✕	*[<300]*	✕	*[5.0]*
Tin	✕	*[<4000]*	✕	*[1.9]*
Copper	✕	*[<500]*	✕	*analysed/documented only*
Mercury	✕	*[<0.33 mg/MJ (RDF)]*	✕	*[0.038]*
Cobalt			✕	*[0.38]*
Manganese			✕	*[16]*
Thallium			✕	*[0.063]*
Vanadium			✕	*[0.63]*
Arsenic			✕	*[0.31]*
Antimony			✕	*[3.1]*
Total heavy metals	✕	*[<2500 mg/MJ (RDF)]*		
Total solvents	✕	*[<15 % (RDF)]*		
PCB	✕	*[<50 (RDF)]*		

Source: compiled with information from CATY and MUNLV-NRW

If one takes the sum parameter for total heavy metals as an example, among other things can be noted that the default value of the CATY is significantly above the comparative values from the approval procedures for German cement plants. A comparative value from German practice that can be cited for this purpose limits the permissible content of eleven heavy metals in the RDF used to 700 mg/kg in the maximum. As far as the environmental safety of RDF is concerned, no compromise or concession should be made by setting the leeway for critical pollutants too broad, starting with the selection or approval of waste materials for this purpose and their subsequent treatment.

The creation of confidence in the (RDF) products offered on the market is a crucially important prerequisite to generate demand for them. It gets built up and strengthened by giving producers the opportunity to take the technical measures appropriate to them for being able to provide safe and high-quality fuels in an economically sustainable manner and by establishing a credibly enforceable yet also strictly implemented control system at the same time.

Hence a further issue worth the discussion are the specifications which the RDF-related regulations and/or other legal rules in Turkey apparently prescribe for facility design and equipment. The CATY in Annex 2, Table 3 contains, for example, a list of equipment considered obligatory for a proper process of RDF production and handling. It names the components drum screen, coarse and fine shredder, metal separators and sifters as being the technical requisites necessary for all main input sources. Bag opener, drying devices and moving chutes are mentioned as optional components.

The practical value of such overview in a technical regulation appears rather limited. This is all the more true as there exists no one-fits-all scheme or RDF preparation process that can be generalized for producing RDF for the cement industry. ☞ *Chapter 7* clearly points out the reasons for that.

Instead of being part of regulatory documents it seems more effective to develop technical aids on RDF management techniques. In particular, targeted training and the transfer of practical experience would have to ensure that all actors involved in the subject are well informed about the principal aspects this subject comprises. In addition to the necessity to achieve a more transparent situation for RDF in Turkey in general, there is a particular need for boosting the knowledge on the processing options for waste and RDFs in the overall and for creating greater awareness of sensitivity towards the critical parameters and other issues this involves. It is hoped and intended that this guidance can provide one of the entrance points and a first practical aid for that.

Economic actors and plant operators base their commitment to RDF primarily on entrepreneurial considerations and their assessment of the operating environment (location, market, etc.) and their own performance capabilities. Therefore, the decisions on how the preparation of RDF can be realized in terms of processes and equipment and how the necessary quality parameters can be ensured must also be left to them. These cannot and should not be basically anticipated or even defacto replaced by administrative acts, which, however, partly corresponds with the orientation of the legal acts (e.g. CATY) and regulatory practice that still can be found in Turkey to date. It must be the responsibility of the authorities to specify not the path but rather the safety and environmental standards to be complied with, to strictly monitor compliance with these standards, and to sanction violations.

Certain provisions (of the CATY) which currently seem to impose rather sweeping restrictions on the entrepreneurial planning in the RDF field, distance regulations were for example mentioned, may have to be addressed via other supervisory and legal mechanisms (e.g. building/operating permits, construction audits, fire protection/OHS norms/certifications, etc.) and should in any case become subject of assessment procedures and solutions based on the respective location. This would also better reflect common international practice.

The freedom to accept waste materials of various types and to utilize or convert them into products does not need to be restricted insofar as proof can be provided that this is done in a proper, harmless and environmentally compatible manner. Permit applications, operating records and product certificates are the means by which such evidence can be demanded and produced. However, this must be contrasted with technical assessment competence, a mix of adhoc and routine controls, and the agreement on certain standards in order to ensure actual enforcement and equal standards in the evaluation and treatment of the various actors and processes.

Within this complex, a number of weaknesses and shortfalls can be assumed, which Turkey must continue to work and act upon.

10 References and useful aids

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11 Annexes

Annex 1: RDF processing facilities supplying the cement industry – Selection of Reference Examples

Facility short name	**GRE Ersatzbrennstoffe GmbH + Co. KG Ennigerloh** *(Germany)*	
EWC codes accepted at the plant	See below	
Input material for RDF production	**020104, 030101, 030105, 030307, 030308, 040209, 040210, 040215, 040221, 040222, 070213, 070299, 080112, 080313, 080318, 080410, 090108, 120105, 120113, 150101, 150102, 150103, 150105, 150106, 170201, 170203, 170604, 170904, 191204, 191212, 200101, 200139**	Certificate
	plastics from pre-sorted packaging grades 350-x, 352, 355, 360 or 365	Certificate
RDF production capacity	approx. 100,000 tpa input and 40,000 tpa output for cement ind.	
Further details	*Main process features:* pre-shredding, shredding, NIR optical sorting, Fe-separation, non-Fe separation, fine shredding, size separation, Fe-separation	
Membership in BGS - German Quality Assurance Associat.	Yes *(status checked 03/2021)*	

Facility short name	**ECOWEST Sekundärbrennstoffgesellschaft Ennigerloh mbH** *(Germany)*	
EWC codes accepted at the plant	https://www.ecowest.de/fileadmin/Media/Ecowest/Downloads/PDF/Zertifikate/EfbV-Zertifikat_ECOWEST_2021.pdf	
Input material for RDF production	**See certificate pages 4-10**	Certificate
	plastics from pre-sorted packaging, among others DSD sorting grades 350, 352, 328-5	Certificate
RDF production capacity	approx. 150,000 tpa input	Process brochure
Further details	RDF production since 2002, concept also integrates the associated biological treatment facility with stabilized medium-calorific RDF output, Major parts of the RDF produce goes to cement industry	
Membership in BGS - German Quality Assurance Associat.	Yes *(since 2006)*	

Facility short name	**ELM Ersatzbrennstoff GmbH & Co.KG Heidenheim-Mergelstetten ELM group** *(Germany)*	
EWC codes accepted at the plant	See below	
Input material for RDF production	**020104, 030101, 030105, 030307, 030308, 040209, 040221, 040222, 070213, 080410, 090107, 090108, 120105, 150101, 150102, 150103, 150105, 150106, 150109, 150203, 160119, 170201, 170203, 190905, 191201, 191204, 191207, 191208, 191212, 200101, 200110, 200111, 200139, 200301;**	Certificate
	plastics from pre-sorted packaging grades 310-3, 328-3, 350, 351-1, 351-2, 352, 361	Certificate
RDF production capacity	approx. 300,000 tpa (at the five different sites of ELM group in total)	
Further details	ELM group produces RDF in five quality classes (4 high, 1 medium calorific value), supplied among others to SCHWENK Zement plants	
Membership in BGS - German Quality Assurance Associat.	Yes, as affiliate firm of the ELM group *(status checked 03/2021)*	

Facility short name	**CALREC Ersatzbrennstoffaufbereitung GmbH & Co. KG Harburg, ELM group** *(Germany)*	
EWC codes accepted at the plant	**020103, 020104, 020107, 030101, 030105, 030301, 030307, 030308, 030310, 030399, 040108, 040209, 040221, 040222, 070213, 080410, 090108, 120105, 120113, 150101, 150102, 150103, 150105, 150106, 150109, 150203, 160119, 170201, 170203, 190501, 190502, 190905, 191201, 191204, 191207, 191208, 191212, 200101, 200110, 200111, 200138, 200139**	Certificate
Input material for RDF production	**plastics from pre-sorted packaging grades 350, 6.31 KEG2, residues of DSD sorting grades 830, 831**	Certificate
	waste mono-fractions from production facilities	Certificate
RDF production capacity	*Main process features:* pre-shredding, Fe-separation, size separation, fine shredding, classifying	
Further details	produces RDF for and at the location of the Märker Zement plant	
Membership in BGS - German Quality Assurance Associat.	Yes, as affiliate firm of the ELM group *(status checked 03/2021)*	

Facility short name	**Albbrennstoff GmbH Allmendingen, ELM group** *(Germany)*	
EWC codes accepted at the plant	See below	
Input material for RDF production	**020104, 030101, 030105, 030307, 030308, 040209, 040221, 040222, 070213, 080410, 090107, 090108, 120105, 150101, 150102, 150103, 150105, 150106, 150109, 150203, 160119, 170201, 170203, 170904, 190905, 191201, 191204, 191207, 191208, 191212, 200101, 200110, 200111, 200139, 200301, 200307**	Certificate
RDF production capacity	permit for 180,000 tpa	Photo image
Further details	erected in 2014 to produce RDF for and at the location of the local plant of SCHWENK Zement	
Membership in BGS - German Quality Assurance Associat.	Yes, as affiliate firm of the ELM group *(status checked 03/2021)*	

Facility short name	**Reiner Wertstoff Recycling GmbH Tussenhausen** *(Germany)*	
EWC codes accepted at the plant	https://www.reiner-wertstoff.de/images/pdf/Entsorgungsfachbetriebszertifikat_2019_1.pdf	
Input material for RDF production	**020104, 020110, 030105, 030307, 030308, 040209, 040221, 040222, 070213, 080318, 101103, 101112, 120101, 120102, 120103, 120104, 120105, 120113, 150101, 150102, 150103, 150104, 150105, 150106, 150107, 150109, 160117, 160118, 160119, 160120, 160210*, 160213*, 160214, 160216, 170101, 170102, 170103, 170107, 170201, 170202, 170203, 170204*, 170401, 170402, 170403, 170404, 170405, 170406, 170407, 170411, 170504, 70904, 191201, 191202, 191203, 191204, 191205, 191207, 191208, 191212, 200136, 200137*, 200138, 200139, 200140, 200301, 200302, 200307, 200399**	See the above Certificate pages 9 - 12
of which only shredded for RDF	**040209, 120105, 150101, 150102, 150105**	
for RDF conditioned to cement ind. needs	**combustible commercial and production waste, in particular those originating from plastics processing, cellulose industry and sorting operations (sorting residues), sewage sludge, bulky waste and municipal collected waste of high-calorific value**	
RDF production capacity	100,000 tpa total throughput (input/output quantities of RDF process unknown)	
Further details	45.000m² total operating area; total staff record: 20	
Membership in BGS - German Quality Assurance Associat.	No *(status checked 03/2021)*	

Facility short name	**Schenker Industrie- und Städtereinigungs GmbH, Hohenkammer** *(Germany)*	
EWC codes accepted at the plant	http://www.schenker-umwelt.de/wp-content/uploads/2020/11/Entsorgungsfachbetrieb_2020-22.pdf	
Input material for RDF production	**030305, 030307, 030308, 040221,040222, 070213, 120105, 160103, 160119, 160122, 160214, 160216, 160306, 170203, 100603, 170604*, 170904, 190210, 190805, 191004, 191006, 191208, 191211*, 191212, 200101, 200108, 200110, 200111, 200136, 200201, 200302, 200307**	See rows marked 'EBH' in the Certificate
RDF production capacity	no information available	
Further details	*Main process features:* sorting, shredding 105.000m² total operating area; staff record: 60 (in 2017)	
Membership in BGS	No *(status checked 03/2021)*	

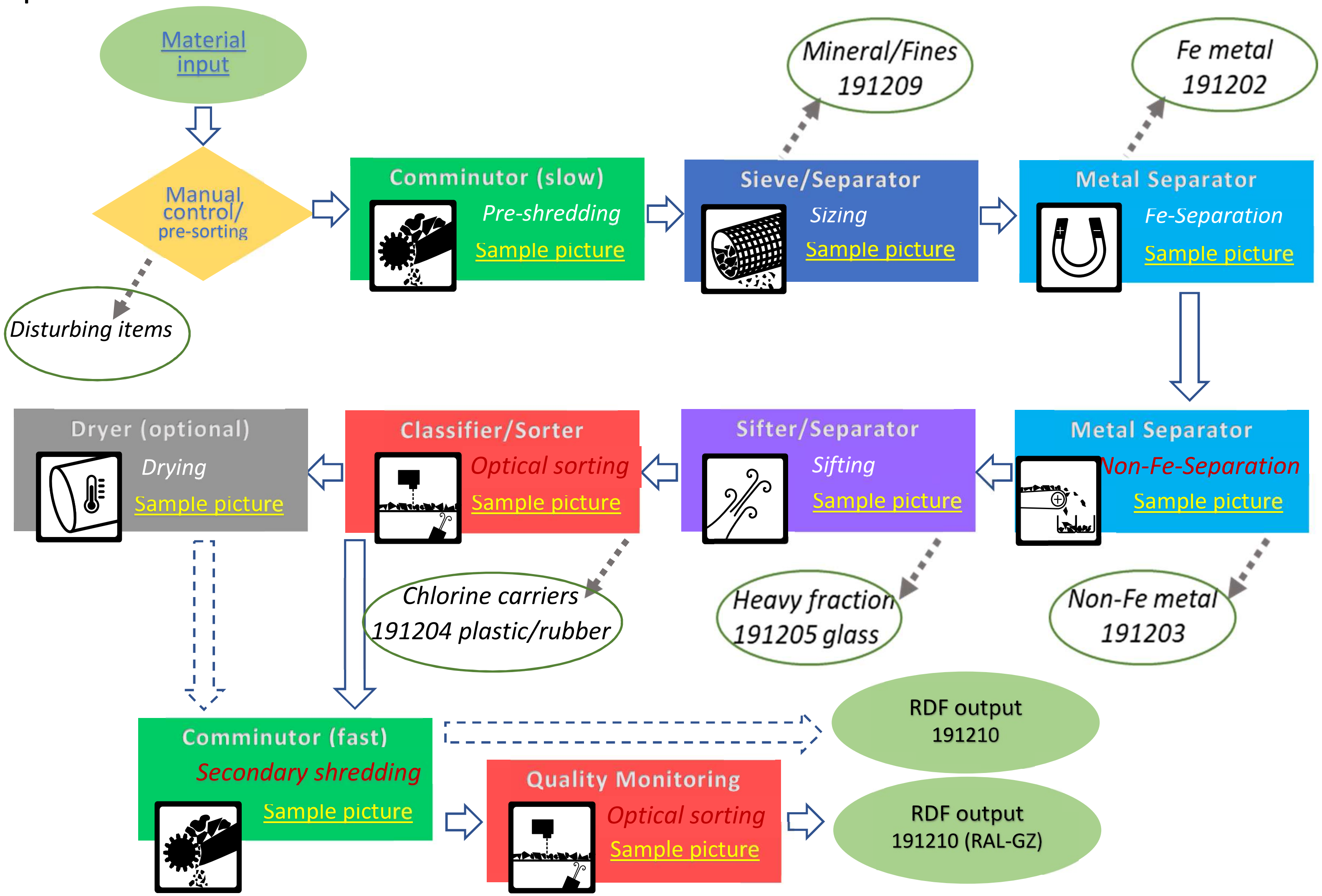
Facility short name	**RCERO Ljubljana** *(Slovenia)*	
EWC codes accepted at the plant	See below	
Input material for RDF production	**020107, 170201, 200108, 200138, 200201, 200301, 200302, 200307**	Input data
RDF production capacity	approx. 175,000 tpa throughput (in 2012), RDF output class A (for cement industry): 17,000 tpa RDF output class B (other WtE plants): 43,000 tpa	Mass flow
Further details	started operating in 2016, main technology provider STRABAG Umweltanlagen GmbH (Dresden, Germany)	Photo image
Quality Assurance	NIR optical sorters for PVC removal from RDF class A	

Facility short name	**Zakład Zagospodarowania Odpadów Sp. z o.o. (MBT) Marszów** *(Poland)*	
EWC codes accepted at the plant	municipal solid waste and commercial and industrial waste from 22 municipalities with approx. 200 000 inhabitants, detailed waste codes not available	
Input material for RDF production	CLO (compost-like material) which is the output of stabilized waste from the biological treatment stage of the MBT	RDF process and mass flow
RDF production capacity	approx. 72,000 tpa throughput, of which CLO input to RDF processing is 50% and RDF output 12,000 tpa	Plant data
Further details	Started operating in 2015, produces RDF output in two qualities, main technology provider Eggersmann group (Germany)	
Quality Assurance	no information available, read about quality parameters here	

Facility short name	**MUEG Mitteldeutsche Umwelt- und Entsorgung GmbH Beuna** *(Germany)*	
EWC codes accepted at the plant	https://mueg.de/fileadmin/user_upload/efb_zertifikat_komprimiert.pdf	
Input material for RDF production	**030104*, 030105, 030301, 030305, 030307, 030309, 030310, 030311, 040210, 040214*, 040215, 040216*, 040217, 040219*, 040220, 040221, 040222, 050103*, 050105*, 050106*, 050107*, 050108*, 050109*, 050110, 050112*, 050114, 050115*, 050116, 050117, 050601*, 050603*, 050699** (pyrolysis coke only), **060899** (filter cakes and polluted glycol only)**, 061303, 070101*, 070104*, 070108*, 070201*, 070208*, 070213, 070214*, 070199/070299/070399/070699** (excluding dangerous reaction and distillation residues)**, 070308*, 070608*, 080111*, 080112, 080113*, 080114, 080201, 080409*, 100101, 100102, 100103, 100104*, 100114*, 100115, 100116*, 100117, 100118*, 100207*, 100208, 100907*, 100908, 100909*, 100910, 100911*, 101005*, 101006, 101007*, 101008, 101203, 101312*, 101313, 110107*, 120112*, 120115, 120116*, 130501*, 130502*, 130503*, 140605*, 160708*, 160709*, 161001*, 161002, 170201, 170204*, 170301*, 170302, 170303*, 170601*, 170605*, 170903*, 190111*, 190112, 190113*, 190203, 190204*, 190205*, 190206, 190207*, 190208*, 190211*** (filter material from air cleaning only)**, 190304*, 190305, 190306*, 190307, 190801, 190802, 190805, 190810*, 190811*, 190812, 190813*, 191301*, 191303*, 191305*, 191307*, 191308, 170303*** (only tar-containing material from deconstruction)	See the above certificate pages 14 - 20
RDF production capacity	unknown, specialized to produces different kinds of alternative fuel mixtures	
Further details	fuel mixtures are partly suitable for use in the cement industry	
Membership in BGS - German Quality Assurance Associat.	No *(status checked 03/2021)*	

Annex 2: Additional reference book on process equipment

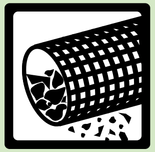
This annex delivers further details on essential process equipment used in the processing of RDF. Pls. note that the generalized process graphic on this page and the following tables contain activated elements and links to jump to desired descriptions and view additional details. **To see them, pls. move the cursor while keeping the Ctrl button pressed**.



Graphic modified after IP@ (www.abfallbewertung.org)

To compare with a practical process design from a commercial supplier firm, pls. check this example

Equipment / Process unit	Process symbol	Where employed in RDF processing	Main types employed	Typical technical features	Non-exhaustive list of suppliers	Examples
Comminutor/ Disintegrator		Comminutors/Shredder devices are used at different stages in RDF processing. Mainly these are the • **Pre-shredding stage** and • **Secondary crushing** *(also called fine crushing or post-shredding stage/s)* Main purpose of the comminution is a decomposition of the material into fragments which are of a favourable size for the further processing or product usage.	Choppers, Crushers, Mills	low-speed or fast-speed devices Crucial criteria for selecting the appropriate device are: – type of material to be processed, – breaking behavior of the material (tough-elastic content), – pollutant content of the material, – moisture level of the material, – subsequent processing needs.	Eggersmann (DE) Vecoplan (DE) BHS Sonthofen (DE) Erdwich Zerkleinerungs-Systeme (DE) UNTHA shredding technology (DE/AT) Lindner (AT)	*See the below examples for the different types of devices*
–Pre-shredding		**Pre-shredding** should allow the material to be fed into the process and pass through it in a more even and homogenous manner, it also makes components better accessible for subsequent material detection and separation. Where bagged material (e.g. waste filled in sacks) is part of the process input, pre-shredding should ensure these components to be gently opened.	Single-shaft shredder, Multi-shaft shredder, Rotary shears, Rotor ripper **(usually as low-speed devices)**	Fragmentation intensity is geared to generate an output flow with the individual components still being easily recognizable and not ground to a completely homogeneous material stream (50-350 mm, →low-speed devices 20-100 rpm). Low-speed units are characterized by: – lower specific energy consumption, – lower risk to cause explosions, dust and noise emissions during operations, – an overall higher availability, – longer service life.	Eggersmann, Forus and Teuton series BHS Sonthofen, VR and VSR series Vecoplan, vrz-series Untha, XR-series Lindner, Jupiter and Atlas-series	Image#1 Image#2 Image#3
–Secondary shredding		**Secondary shreeding** is applied to about 20-60% of the pre-shredded material during subsequent process stages or as a single comminution step in order to generate outputs of the desired particle size and homogeneity. The high- and medium-calorific fraction of a MBT process must pass such process step to obtain RDF of fluff quality.	Cutting mill/ granulator, Impact mill, Hammer mill, Flail rotor **(usually as fast-speed devices)**	Fragmentation intensity is geared to generate a material flow suitable in size for further steps of component separation (e.g. optical sorting) or to match the quality parameters of the final product in terms of size and homogeneity. By applying devices rotating at faster speeds (120-420 rpm) smaller particle sizes (<40 mm) as compared to low-speed units can be attained.	Vecoplan, vez and vnz-series BHS Sonthofen, NGU series Untha, RS-series Lindner, Komet series	Image#1 Image#2 Image#3 Image#4

Equipment / Process unit	Process symbol	Where employed in RDF processing	Main types employed	Typical technical features	Non-exhaustive list of suppliers	Examples
Sieve/ Size separator *–Sizing*		**Size separation** divides the input in dependence from the particle size of the different components into grain size classes. In addition to the separation according to size, a sorting according to materials and shape (2D, 3D) may indirectly occur and generate separate material streams for subsequent processing. The fraction with a higher calorific value is usually obtained as overflow or light fraction during sieving, fine particles that ultimately pass through the sieve are separated from the waste mixture. These smaller components normally comprise inert materials (mineral, glass) and organic particles of lower heating value.	Drum screen, Vibrating or flip-flop screen, Bar sizer, Disc screen, Star screen	There exists a considerably wide range of technical options for realizing a separation by size and shape (which limits the possibility to describe individual technical features in detail). Drum screens made of one or more rotating, cylindrical or angular designed sieving plates with holes of varying size (30-600 mm) are most widely used for size separation. The material moves through the drum which also results in a mixing of the input and homogenized material flows. An adaptation to changing input properties or output requirements is possible by adjusting the drum's inclination or rotating speed. The other types devices suit better where the input material is more wet or sticky in nature. One type works with a vibrating surface of sieve plates. Other types use discs or rods at different distances one from another set in motion in opposite direction. The material moves forward this way, passes over the varying sieve slots and is separated accordingly.	STADLER Anlagenbau (DE) Eggersmann (DE) HOMBAK Maschinen- und Anlagenbau (DE) Sutco RecyclingTechnik (DE) Vecoplan (DE) Neuenhauser Maschinenbau (DE)	Image#1 Image#2 Image#3 Image#4 Image#5
Metal separator		Metallic components comprise not only a recyclable material of high value, they also can be disturbing the processing (e.g. damages to machinery) and the behaviour/properties of RDF when used. Different type metal separators are employed at various stages of RDF production in order to **recover metals for recycling**, assure a smooth processing and to meet the specific requirements for **metal removal from the final product**.	Separator for magnetic metals, Separator for the non-magnetic metals	To separate the different types of metal, their different reaction to magnetic influences are used. This is done on the one hand with devices in which the ferromagnetic components are separable by means of magnetic forces of attraction. Other devices generate changing magnetic fields by means of loops of electrical current creating repulsive forces that effect the separation of non-ferromagnetic metal components.	Steinert (DE) Vecoplan (DE)	*See the below examples for the different types of devices*

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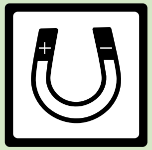
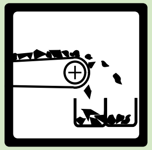
–Fe-Separation		For the **recovery respectively removal of ferromagnetic components** (Ferrous metals) from the material stream	Overbelt magnetic separator, Magnetic drum separator	Magnetic separators are continuous-process machines, and separation is carried out on a moving stream of material passing into and through a stable magnetic field created either from electromagnets or permanent magnets. The electromagnetic variant uses wire coils and direct current. Belts or drums are normally used to transport the material through the field. Controlling the speed of passage of the particles through the field is essential. The magnets are either installed above the belt or integrated into the drum, both controllable in their moving speed.	**Steinert (DE)** **Vecoplan (DE)**	Image#1 Image#2 Image#3
–Non-Fe-Separation		For the **recovery respectively removal of non-ferromagnetic components** (Non-Ferrous metals) from the material stream	Eddy-current separator	A rapidly increasing inhomogeneous magnetic field repels closed good conductors. Loops of electrical current induced within conductors (eddy current) provide for the effect. A rotating drum with permanent magnets, or an electromagnet does induce a changing current flow and magnetic field effect depending on the type of device used. The separator is applied to a conveyor belt carrying a thin layer of mixed material. At the end of the conveyor belt is an eddy current rotor. Non-ferrous metals are thrown forward from the belt into a product bin, while non-metals simply fall off the belt due to gravity.		Image#1 Image#2
Sifter/ Separator *–Sifting*		Sifter type separators serve in the **upgrading of the material** towards the targeted quality parameters (quality improvement) **and removal of unwanted matter** from the further process. They effect a splitting of the feed stream into a	Wind sifter, Ballistic separator	The materials are diverted into different streams based on the technological principle according to which the separation of the material components placed in a current of fall takes place according to different flight curves or individual density.		*See the below examples for the different types of devices*

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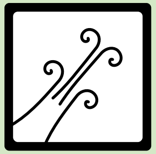
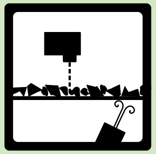
		desired number of separate streams. Correlations between physical behaviour and properties of a material are used to separate streams each having up-concentrations of those material components that are either of interest (e.g. calorific value) or detrimental (e.g. harmful content) to product quality.				
– by wind		**Splitting up heavy and lightweight material** components into separate fractions.	Cross flow sifter, Zigzag sifters	A steady air blow takes lightweight components out of a falling material stream, which are subsequently won as light fraction in a cyclone. Creating the air blow is very energy consuming.	Neuenhauser Maschinenbau (DE) NESTRO Lufttechnik (DE) Schulz & Berger Luft- und Verfahrenstechnik (DE) Sutco RecyclingTechnik (DE) Eggersmann (DE) Vecoplan (DE)	Image#1 Image#2 Image#3
– by ballistic force		**Splitting into up to three fractions**, a screen fraction for takeout, the light fraction and the heavy fraction which are then conveyed to subsequent steps of processing	Ballistic separator	The material falls on an inclined bottom and starts rotating. The rotation transmits a pulse and generates a movement of flight contrary of the individual parts. These react differently; light fractions (flat and thin), such as paper, medium-sized plastic film, textiles are thrown upwards along the trajectories flat and low and transported by the rotary movement of the base towards the machine top where the upper hopper catches the light fraction. Heavy fractions (cubic, solid) are thrown upwards by the movement of the bottom and flow from the inclined position of the same in a position of flight directed downwards the machine where is the lower hopper.		Image#1 Image#2 Image#3
Classifier/ Sorter		Additional classifier and sorters might be integrated into processing where the material composition of the process input and/or the requirements on the RDF quality demand certain components to be removed with the utmost precision.				

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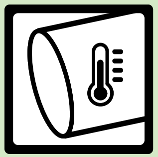
– Optical sorting		Integration into the process can be flexible although mostly these devices are employed towards the end of the production line to perform the **final takeout of unwanted matter or** as a means for a **monitoring/checking of the product quality**. Optical sorting in RDF processing is particularly geared to detect components made of PVC and others known for harmful matter content (e.g. heavy metal carriers), and to get these removed.	Sorters using Near-infrared (NIR), cameras, XRF-technology, combined multi-sensor applications	Optical sorting systems comprise a feed control, the optical system, image processing software, and the separation system as the major components. The optical system forms the central unit housing lights, sensors and/or cameras. These lights, cameras and sensors can be designed to function within visible light wavelengths and with such from the invisible spectrum. They are installed above and/or below the material flow being inspected. Image processing software compares objects to user-defined thresholds to classify objects and steer the separation process. The processed images will determine whether a material should be accepted or rejected.	Steinert (DE) REDWAVE of BT-Wolfgang Binter GmbH (AT) Tomra-TiTech (NO)	Image#1 Image#2
Dryer		A **drying** may have to be undertaken when the moisture content of the material exceeds the level which is required for a good material processing or acceptable for the product quality. It can become necessary at the entry to the RDF production process (process input) or at the very end (RDF output).	Tunnel dryer / Drying drums *(for MPS and other RDF processing),*	Drying is a highly energy-consuming process step unless it can be achieved by biological means (MBT) or the use of solar energy (using glass houses and the heating effect that is produced within)	IST-Anlagenbau (DE)	Image#1
– Drying		Where RDF is generated during a MBT (mechano-biological treatment) or MPS (mechano-physical stabilization), the drying step is done on the process input. Other RDF processing schemes usually work without drying or a drying is applied on the RDF output only.	Belt dryer / solar drying *(for sewage sludge)*	The main difference between the applications derives from the energy source used and way how this energy is effectively transferred to the material for an optimal drying effect (contact drying or convection drying). The hardware solutions used are often customized installations tailored to attain the most efficient drying	STELA Laxhuber (DE) NEW eco-tec Verfahrenstechnik (DE)	Image#1 Image#2 Image#3
Material conveyor		The **trouble-free flow of material** within the production facility requires conveyor systems that must be	Belt conveyor (or conveyor belts)	Rubber belts with fabric inserts are mostly used. They are giving the most common solution in RDF processing facilities.	**Supplier of turnkey facilities usually take care that appropriate conveyor**	

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		planned and designed very carefully. The design of the conveyor elements depends on the installation of the process components in the facility. The investment costs for the conveyor equipment make up a large proportion of the overall investment, it can easily reach a 10% share of the total capex.	Apron or Slat conveyor	The material is transported on segments made of steel plates. This type conveyor is unsuitable for the transport of very moist or fine-grained, dry materials, most often they are used to transport large, sharp-edged particles.	**systems will be procured and installed. Here can be referred to as examples:** STADLER Anlagenbau (DE) Sutco RecyclingTechnik (DE) BHS Sonthofen (DE) Vecoplan (DE) Doppstadt (DE) Bezner Anlagen- & Maschinenbau (DE) Anlagenbau Günther (DE)	
			Trough chain or Drag-chain conveyors	Are used in particular to transport moist material in a vertical direction. Bulky and sharp-edged materials such as glass cause malfunctions and increased wear costs		