



BSI Standards Publication

Solid recovered fuels — Guidance for the specification of solid recovered fuels (SRF) for selected uses

National foreword

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**Solid recovered fuels — Guidance for
the specification of solid recovered
fuels (SRF) for selected uses**





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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO-specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 300, *Solid recovered materials, including solid recovered fuels*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Waste-to-energy is a broad term that covers much more than waste incineration. It includes various treatment processes that have different environmental impacts but also offer potential for the progress desired towards a low-carbon and circular economy. Processes that convert waste into solid fuels and generate electricity and/or thermal energy from it can play an increasing role in achieving such goals.

Traditionally, solid fuels recovered from waste have been used as an integrative fuel in incineration or co-incineration plants treating a mix of wastes, so as to improve the energy performance of the plant. There are also some dedicated SRF-EfW plants (e.g. incineration plants and industrial combustion plants recovering thermal and/or electrical energy from the solid recovered fuel alone).

An increasing role as substitutive fuel has occurred over time to allow a reduction of fossil fuel consumption and the impact on climate change and greenhouse gas emission of industrial activities with a high energy consumption. In recent years, the use of solid recovered fuels has expanded to other interesting and promising fields, such as gasification or combined gasification and pyrolysis. Waste gasification and co-incineration of the resulting syngas in a combustion plant, co-processing to power and material recovery in cement kilns and waste incineration in dedicated facilities can be highlighted as best proven techniques to increase the energy efficiency of waste-to-energy processes and optimize their contribution to national and global climate and energy goals.

All the above-mentioned waste-to-energy processes rank differently in the waste hierarchy and have different needs for fuel quality to ensure better plant management as well as compliance with requirements set by national and supranational legislation.

Quite an extensive family of solid fuels can be recovered from waste, with different physico-chemical properties and a quality that is not always well defined. Those produced from non-hazardous waste, classified as SRF (Solid Recovered Fuel), are specifically of interest in this document. The term SRF itself identifies a family of fuels that can differ in origin (input waste streams), composition and quality.

Many barriers still hamper the extensive development of SRFs. As discussed later, a continuing confusion in terminology can be highlighted. Solid fuels recovered from non-hazardous waste are identified in different countries by different terms (e.g. CSS, CDR, CDR-Q, RPF, SBS, CSR), shipped with different waste codes, and an ambiguous use of the terms RDF and SRF still occurs. SRF is largely produced and traded as waste, different countries labelling it with different waste codes based on local waste legislation. An end-of-waste of SRF is allowed in some countries (e.g. Austria, Italy) if the fuels produced comply with specific and mandatory requirements legally set.

Solid recovered fuels are intended to be classified and specified according to ISO/TC 300 standards. Fuel specification is also the subject of national guidelines, in places addressed to specific end uses of the fuel (e.g. in cement kilns), and of local voluntary commitments on fuel properties between the producer and the end user aimed at ensuring that the latter meets its own technological, economic and environmental needs.

Generic (all solid waste) or specific (SRF) quality requirements are set by national or local regulators (e.g. administrative bodies authorized to issue plant permits), mainly to ensure that waste-to-energy plants at least meet the requirements for environmental and human protection and to regulate the role of waste-to energy plants within the national/regional waste management systems as a whole.

There are still acceptance problems in several countries that need to overcome, for example by reliable data, a high level of information and transparency.

To foster the application of SRFs in existing and new fields and to overcome existing barriers, it is therefore strategically essential for all interested stakeholders to define what quality requirements the SRF meets based on homogeneous, unambiguous and well-accepted criteria.

Solid recovered fuels — Guidance for the specification of solid recovered fuels (SRF) for selected uses

1 Scope

This document addresses the provision of background references that are helpful in defining a more detailed specification for SRF according to its specific end use for energy conversion (EfW plants) and to support the SRF market. The aim is to enable all the interested stakeholders – producers, end users, legislators, local authority bodies and standardization bodies – to guarantee that the SRF complies fully with technical, environmental and economic requirements and to facilitate its social acceptability when utilized for energy conversion.

This document is intended to provide references for the specification of SRF produced from non-hazardous waste streams and traded to EfW plants as waste. The quality of such SRF is specified through values for relevant fuel properties, appropriate to the subsequent end uses that have an expected growth or an established/well consolidated role in heat and power generation in waste-to-energy systems:

- coal co-combustion in cement kilns,
- gasification,
- coal co-combustion in power plants.

The SRF can also be used in other end-use applications but these are not addressed in this document.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviations

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 Terms and definitions

3.1.1

BAT

best available technique

term used within the European Union for the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole

Note 1 to entry: “Techniques” includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.

Note 2 to entry: “Available techniques” means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator.

Note 3 to entry: “Best” means most effective in achieving a high general level of protection of the environment as a whole.

[SOURCE: Directive 2010/75/EU, Art. 3 (10)]

3.1.2

BAT reference document

term used within the European Union for a document, resulting from the exchange of information drawn up for defined activities, that describes, in particular, applied techniques, present emission and consumption levels, techniques considered for the determination of best available techniques as well as BAT conclusions and any emerging techniques

Note 1 to entry: “BAT conclusions” means a document containing the parts of a BAT reference document laying down the conclusions on best available techniques, their description, information to assess their applicability, the emission levels associated with the best available techniques, associated monitoring, associated consumption levels and, where appropriate, relevant site remediation measures.

Note 2 to entry: “Emission levels associated with the best available techniques” means the range of emission levels obtained under normal operating conditions using a best available technique or a combination of best available techniques, as described in BAT conclusions, expressed as an average over a given period of time, under specified reference conditions.

Note 3 to entry: “Emerging technique” means a novel technique for an industrial activity that, if commercially developed, could provide either a higher general level of protection of the environment or at least the same level of protection of the environment and higher cost savings than existing best available techniques.

[SOURCE: Directive 2010/75/EU, Art. 3 (11)]

3.1.3

classification of solid recovered fuels

categorization of *solid recovered fuels* (3.1.18) into classes by focusing on the key properties net calorific value, chlorine and mercury, that are defined by boundary values

Note 1 to entry: The classes are defined by boundary values for the chosen fuel characteristics to be used for trading as well as for the information of permitting authorities and other interested parties.

[SOURCE: ISO 21637, 3.12, modified — Note 1 to entry is added.]

3.1.4

co-incineration plants

term used within the European Union for any stationary or mobile technical unit whose main purpose is the generation of energy or production of material products and which uses *waste* (3.1.19) as a regular or additional fuel or in which waste is thermally treated for the purpose of disposal through the incineration by oxidation of waste as well as other thermal treatment processes, such as pyrolysis, gasification or plasma process, if the substances resulting from the treatment are subsequently incinerated

[SOURCE: Directive 2010/75/EU, Art. 3 (41)]

3.1.5

combustion plant

term used within the European Union for any technical apparatus in which fuels are oxidized in order to use the heat thus generated

[SOURCE: Directive 2010/75/EU, Art. 3 (25)]

3.1.6**composition of solid recovered fuels**

breakdown of *solid recovered fuels* (3.1.18) by types of components

Note 1 to entry: This is typically expressed as a percentage of the mass fraction component in the fuel on an as received basis (m % ar).

Note 2 to entry: Examples of components - wood, paper, board, textiles, plastics, rubber.

[SOURCE: ISO 21637, 3.14]

3.1.7**dedicated SRF- EfW plants**

any technical unit in which the energy conversion is from the *solid recovered fuel* (3.1.18) alone

3.1.8**EfW plants**

energy from waste plants like municipal waste incineration (MWI), mono- and co-combustion plants including cement kilns

3.1.9**energy conversion**

use of the calorific value of the *solid recovered fuel* (3.1.18) for energy purposes alone or with other fuels

Note 1 to entry: Solid recovered fuels may be an intermediary energy carrier and used directly or indirectly for the energy conversion such as in multi-stage production and use of synthetic gas. Examples of energy conversion processes are incineration, co-incineration, combustion, co-combustion, gasification and pyrolysis, in which energy is used for supplying heat, cooling and/or electric power.

[SOURCE: ISO 21637, 3.27]

3.1.10**energy purposes**

use of the calorific value within industrial processes or for the supply of heat and electrical power

Note 1 to entry: For industrial processes, the use of solid recovered fuel may contribute to the energy source within the process of producing specific materials, such as cement clinker, bricks and lime.

[SOURCE: ISO 21637, 3.29]

3.1.11**EoW****end-of-waste**

term used within the European Union for status of a specified substance or object that ceases to be a *waste* (3.1.19) when it has undergone a recovery, including recycling, operation and complies with specific criteria, to be developed in accordance with the following conditions: (a) the substance or object is commonly used for specific purposes; (b) a market or demand exists for such a substance or object; (c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; (d) the use of the substance or object will not lead to overall adverse environmental or human health impacts

[SOURCE: Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste, art. 6]

3.1.12**gasification plant**

any stationary or mobile technical unit whose purpose is converting feedstock fuels into a syngas (synthesis gas) for different final uses

3.1.13

hazardous waste

waste (3.1.19) which has proprieties that may be harmful to human health or the environment

Note 1 to entry: These wastes are categorized by waste streams and hazardous characteristics. The hazardous characteristics relevant to solid wastes are: explosives substances; flammable solids; wastes liable to spontaneous combustion; wastes which, in contact with water emit flammable gases; wastes which oxidizing; organic peroxides; acute poisoning and infectious substances.

Note 2 to entry: Further identification of the waste's status can be determined using the Annex I and Annex III tables of the Basel Convention on the control of transboundary movement of hazardous wastes and their disposal.

Note 3 to entry: Additional categories of hazardous waste to those in the Basel Convention Annex I and Annex III may be established by stakeholders to the agreement or at a national level.

[SOURCE: ISO 21637, 3.35, modified — Example and Notes 4 and 5 to entry were removed.]

3.1.14

incineration plant

term used within the European Union for any stationary or mobile technical unit and equipment dedicated to the thermal treatment of waste (3.1.19), with or without recovery of the combustion heat generated, through the incineration by oxidation of waste as well as other thermal treatment processes, such as pyrolysis, gasification or plasma process, if the substances resulting from the treatment are subsequently incinerated

Note 1 to entry: According to the US Environmental Protection Agency, incinerators are any furnace used in the process of combusting solid waste for the purpose of reducing the volume of the waste by removing combustible matter. A solid waste incineration unit is defined as a distinct operating unit of any facility which combusts any solid waste material from commercial or industrial establishments or the general public (including single and multiple residence, hotels and motels). The term does not include: a) materials recovery facilities (including primary or secondary smelters) which combust waste for the primary purpose of recovering metals; b) qualifying small power production facilities or or qualifying cogeneration facilities which burn homogeneous waste (such as units which burn tires or used oil, but not including refuse-derived fuel) for the production of electric energy or in the case of qualifying cogeneration facilities which burn homogeneous waste for the production of electric energy and steam or forms of useful energy (such as heat) which are used for industrial, commercial, heating or cooling purposes; c) air curtain incinerators provided that such incinerators only burn wood wastes, yard wastes, and clean lumber.

[SOURCE: Directive 2010/75/EU (40); US Environmental Protection Agency. Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units; [Technical Amendments] Federal Register / Vol. 83, No. 116 / Friday, June 15, 2018 / Proposed Rules 3.17]

3.1.15

MSW

Municipal Solid Waste

waste (3.1.19) collected and treated by or for municipalities

Note 1 to entry: It typically covers waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, as well as yard and garden waste, street sweepings, the contents of litter containers, and market cleansing waste if managed as household waste.

3.1.16

non-hazardous waste

waste (3.1.19) that is other than *hazardous waste* (3.1.13)

3.1.17

specification of solid recovered fuels

list of properties that characterize *solid recovered fuels* (3.1.18)

[SOURCE: ISO 21637, 3.76]

3.1.18**SRF****Solid Recovered Fuel**

solid fuel for energy purposes according to ISO 21640, derived from *non-hazardous wastes* (3.1.18)

Note 1 to entry: According to EN 15359, SRF are solid fuels prepared from non-hazardous waste s meeting the classification and specification requirements laid down in this European Standard. “Prepared” means processed, homogenized and upgraded to a quality that can be traded amongst producers and users.

Note 2 to entry: Whether the input material is hazardous or non-hazardous is determined through national laws and Directives or by categorization of the fuel through the Annexes in the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal*.

[SOURCE: ISO 21637, 3.75, modified – Original Notes 1-2 to entry were replaced by a new Note 1.]

3.1.19**waste**

substances or objects which are discarded or are intended to be discarded

Note 1 to entry: The provisions of national laws can apply.

Note 2 to entry: The Basel Convention on the control of transboundary movements of hazardous wastes and their disposal provides the user with the ability to determine whether a material is deemed to be a hazardous waste or non-hazardous waste. By following the Convention’s requirements and Annexes, along with national laws, operators have a clear understanding of the distinction between the different categories of waste.

[SOURCE: Basel Convention on the control of transboundary movements of hazardous wastes and their disposal, 2019]

3.2 Symbols and abbreviated terms

BAT	Best Available Technique
CDW	Construction and Demolition Waste
ICW	Industrial and Commercial Waste
H	Hazardous Waste
NH	Non-Hazardous Waste
MSW ^a	Municipal Solid Waste
EoW	End-of-Waste
RDF ^b	Refuse Derived Fuel
SRF ^c	Solid Recovered Fuel
ar	as received
d	dry basis
BD	bulk density, kg/m ³
DM	dry matter, % in mass
NCV	net calorific value, MJ/kg; kcal/kg
M	moisture content, $q_{p, net}$, % in mass

A	ash content, % in mass
TC	total carbon content, % in mass

^a Municipal solid waste is a *waste* (3.1.18) collected and treated by or for municipalities. It typically covers waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, as well as yard and garden waste, street sweepings, the contents of litter containers, and market cleansing waste if managed as household waste.

^b RDF differs from SRF (*solid recovered fuel* as defined in 3.1.17) in that it is not in compliance with standardized classification and specification requirements. RDF includes high calorific fractions, which are coarser fractions from waste streams that contain materials with a high calorific value that have not been processed as extensively as fractions for power plants running on secondary fuels such as SRF.

^c As defined in 3.1.17.

4 Compilation, structure and use of data

Background references and data provided in this document have been collected from:

- national/international legislation, standards, guidelines and statistics on waste management;
- sectoral statistics reported in documents or websites (e.g. Global Cement; AITEC, Italian Cement Technical and Economical Association; VDZ, German Cement Works Association; Japan Cement Association; European Recovered Fuel Organisation; German Quality Assurance Association for Solid Recovered Fuels and Recycled Wood (BGS e. V.; Japan RPF Association);
- reference documents on the best available techniques;
- public documents of national producers/end users;
- a review of literature studies;
- international databases (e.g. the ECN Phyllis Database);
- responses sent to questionnaires. Four online surveys were promoted in 2017 by the ISO TC 300/WG2 to collect background information on:
 - profiles of the SRF-RDF produced. Responses (25) were provided from European (88 %: Germany, Italy, Sweden, Spain, Finland) and Japanese (12 %) producers;
 - market, production and use of SRF-RDF. Only a few responses were collected (5) that refer to European countries (Spain, France, Italy, Austria);
 - legislation, standards and guidelines that have an impact on SRF-RDF. Responses (11) were provided by European stakeholders (60%: Germany, France, Italy, Denmark and Serbia) and Asia (40 %, Japan);
 - needs for the classification and specification of SRF-RDF. Responses (15) were provided by stakeholders (end users, producers, authorities, mirror committees) of European countries only (Sweden, Spain, Italy, France, Austria and Germany);
- personal communications (e.g. Italian producers/end users of SRF; Japanese producers of RPF).

Background references on the main characteristics of the end-user plants of interest are provided in [Annex C](#), while the collected background references on provisions in national legislations, standards, plant permits, guidelines, voluntary agreements, results of statistical assessments for typical values, reference data for properties of the produced SRF/RDF, are reported in [Annexes A, B and D](#).

It is highlighted that:

- the background references for fuel specification are presented as reported in the documentary source;
- the use of non-homogeneous units occurs in the documentary sources, in particular in the case of fuel requirements for trace elements;
- the time dating is not necessarily homogeneous, and a geographical origin, largely from European countries, characterizes most of that background reference material, as well as the collected measured values, on which the statistical assessments for typical values in [Annex D](#) are based.

In the body of this document, an introductory framework is given in [Clause 5](#). This is aimed at clarifying what this document means by SRF/RDF, what are the most widely used terms and the available rules for the classification and specification of solid recovered fuels, and to provide a brief overview of global markets. For each of the end users of interest, a summary description of technological needs, main requirements for quality achievable from mandatory provisions, guidelines, voluntary specifications, and references for typical values in the solid recovered fuels produced, are then provided in [Clauses 6 to 8](#).

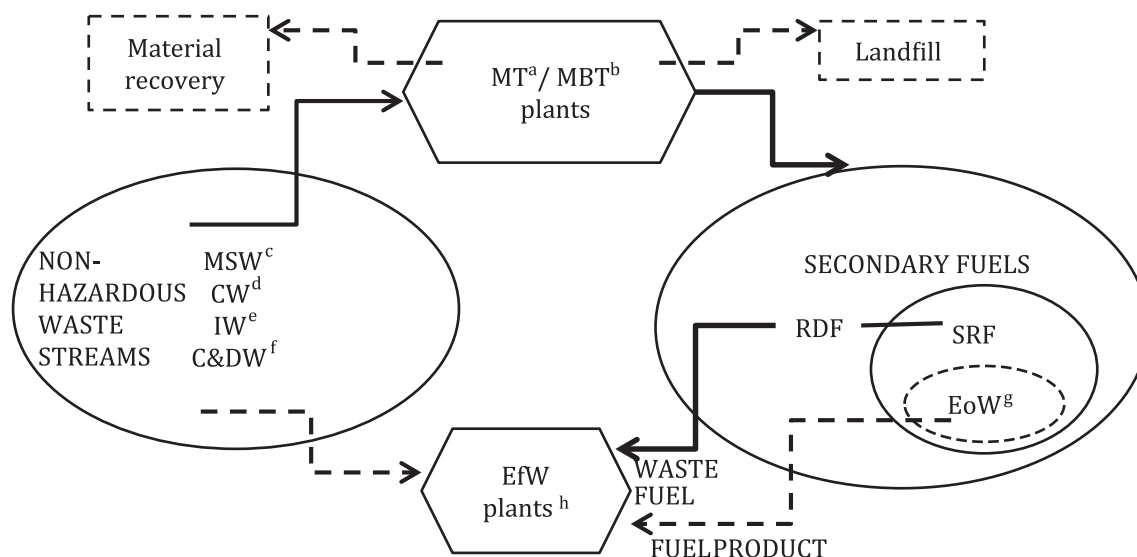
5 SRF and other waste derived fuels

5.1 General

Waste-to-energy is a broad term that identifies a value chain aimed at exploiting the energy potential of waste by means of the generation of electricity and/or heat in different forms of energy-from-waste (EfW) plants.

Within that value chain, waste can follow a “first address” or a “second address” pathway to the EfW plant, as [Figure 1](#) shows schematically. The waste fuels that fall within the field of interest of this document are those referred to as “secondary fuels” in [Figure 1](#) that are:

- produced from non-hazardous (NH) waste streams of urban, industrial or commercial origin, through a treatment process; this means that, if sent to EfW plants as generated, the same input waste streams are excluded;
- traded in national markets or shipped for energy recovery in EfW plants as waste; this means that waste fuels traded as fuel products in all respects, as long as they comply with mandatory requirements legally set to declare their end-of-waste status (the EoW subset in [Figure 1](#)), are excluded.



Key

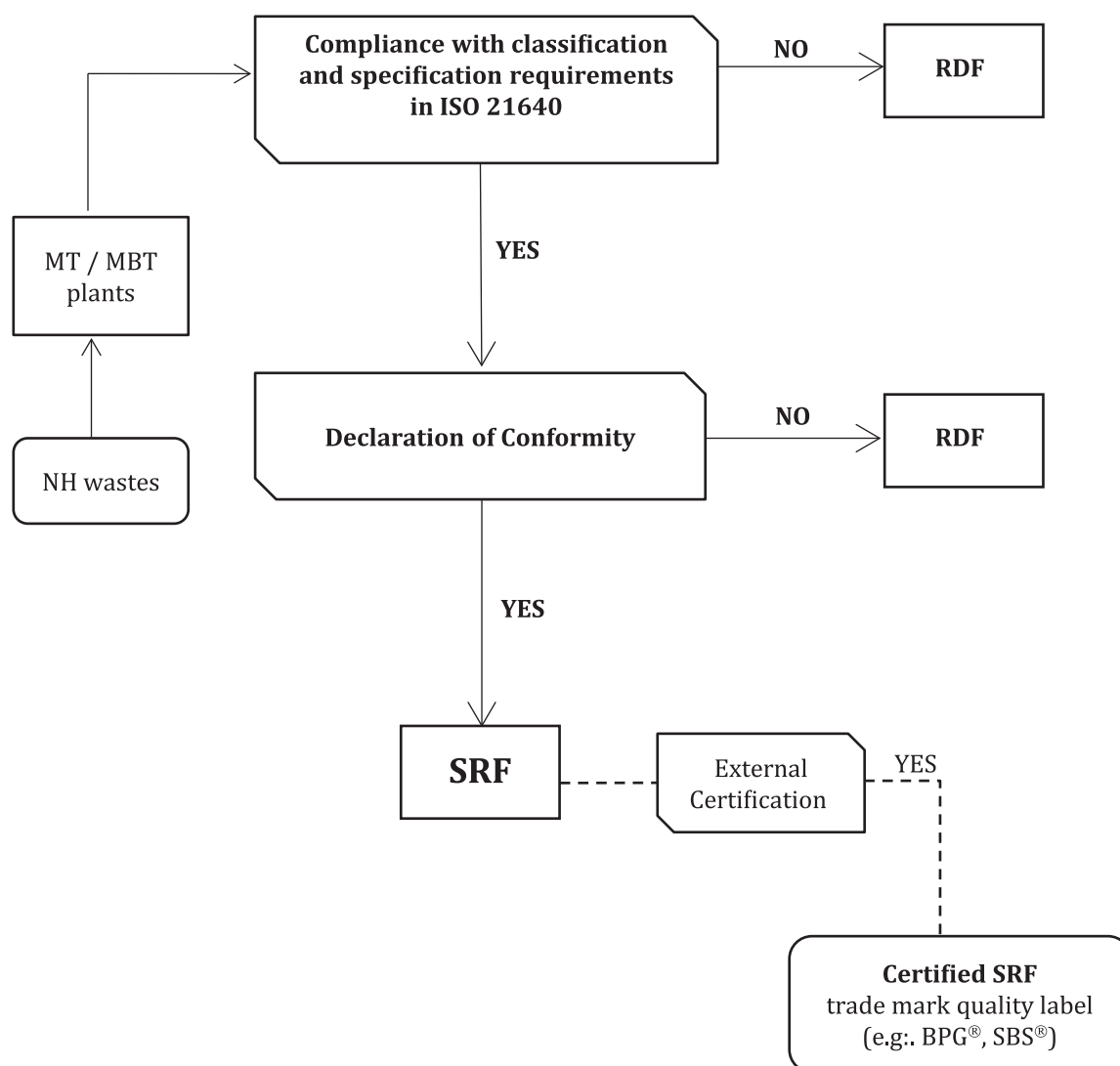
- ^a Mechanical treatment plants.
- ^b Mechanical-biological treatment plants.
- ^c Municipal solid waste.
- ^d Commercial waste.
- ^e Industrial waste.
- ^f Construction & demolition waste.
- ^g End-of-waste (secondary fuel as fuel product, not waste).
- ^h Energy from waste plants, including cement and lime kilns.

NOTE Dashed arrows and boxes identify paths/fuels that do not fall within the field of interest of this document.

Figure 1 — A schematic view of the waste-to-energy value chain

Given the above, all the secondary fuels are assumed to fall under the generic and common name of Refuse Derived Fuel (RDF) and the Solid Recovered Fuel (SRF) are identified as a subset of that large family. Only secondary fuels that meet the classification and specification requirements laid down in a well shared standard can be considered as SRF (see [Figure 2](#)). A complementary assumption is that wastes not suitable for re-use, preparation for re-use or for efficient material recovery are intended to be used in MT/MBT plants for the production of SRF.

The meaning of the proposed assumptions is to identify a waste fuel – specifically the SRF - whose added value is to be a more “processed, refined and defined” fuel than a generic RDF not submitted to specific regulations. Therefore, a fuel that is well characterized and known for its properties, that is better able than unregulated RDF to meet the technical and environmental needs related to its specific use for energy recovery, and, in fact, can give results truly complementary to the waste recycling priority, based on the treatment technologies currently available for its production.



NOTE The external certification of SRF mentioned in Figure 2 is a national/company initiative that does not take part in standardization.

Figure 2 — A proposed approach to distinguish between RDF and SRF (adapted from^[1])

Countries belonging to the EU have a common reference in in the European standard EN 15359^[2] that defines SRF in terms of a solid fuel prepared from non-hazardous wastes to be utilized for energy recovery in incineration or co-incineration plants that meets the classification and specification requirements laid down in that standard. Such a definition is recognized by the European reference document on the best available techniques (BAT) for waste treatment^[3]; it explicitly mentions EN 15359 as a reference and assumes that the refuse-derived fuel (RDF) differs from the SRF due to it not being produced in compliance with the specific criteria defined in the European standard.

ISO 21640,^[4] developed based on the European standard, confirms that definition of SRF, emphasizes the origin of SRF from wastes that are not more suitable for efficient reuse and recycling of materials and provides shared rules (classification and specification requirements) that can be applied in different countries to identify a secondary fuel as SRF. Therefore, ISO 21640 is here assumed as a reference to distinguish between RDF and SRF (Figure 2).

An overview of national markets clearly showed that secondary fuels can take on different names locally and, above all, how a widespread use of the term RDF occurs that does not always allow a clear identification as a generic, non-standardized, or a standardized solid recovered fuel (an SRF). A list of the most common terms that are locally used to identify secondary fuels and that are referred to in

this report, is given in 5.2 (see Table 1), along with an assessment of their compliance with the above-mentioned assumptions in respect of SRF and generic RDF.

SRF and RDF are locally produced in MT and MBT plants from individual or mixed streams of municipal (MSW), commercial (CW), industrial (IW) and construction and demolition (CDW) wastes that can differ in their share of residual fractions and, based on this, also in their elemental composition.^{[5],[6],[7]} Different types and degrees of treatment are applied by the producers to the input waste streams that modify to some extent their properties and determine the achievable yield in waste derived fuels, in both quantitative and qualitative terms. Based on the type of input waste stream, the type and intensity of the pre-treatment process, SRF with a different level of quality can be obtained: indicative references derived from literature and from the statistical assessment of measured values carried out for the purposes of this document are given in Annex A.

5.2 Terms used for secondary fuels from waste

A list of acronyms for waste-derived fuels, which are used in different countries and that are referred to in this report, is provided in Table 1.

Table 1 — List of terms (acronyms and extended names) used in different countries to identify the waste derived fuels and of their local identification as SRF or a generic secondary fuel (labelled RDF in the table)

Acronym (extended name)	Country	Description [Ref.]	SRF	RDF
BPG® (<i>Brennstoff aus produktionsspezifischen Gewerbeabfällen</i>)	Germany	The term (brand mark) is commonly used in the country, ^{[1],[8],[9]} to identify a solid waste derived fuel, produced from separately collected industrial and commercial wastes, that meets specification requirements as set by BGS e.V (BGS e.V. Quality Assurance Association for Solid Recovered Fuels and Recycled Wood) and that complies with rules laid down in national standards RAL-GZ 724 ^[10] .	•	
CDR (<i>Combustíveis derivados de resíduos</i>)	Portugal	The term is legally adopted in the country ^{[11],[12]} to identify a solid fuel prepared from non-hazardous waste, the use of which is aimed at energy recovery in incineration or co-incineration in strict compliance with the law; the term “prepared” means processed, homogenized and improved to a quality that allows its exchange/commercialization between producers and users. Within the country, the CDR is assumed to be a solid recovered fuel (SRF).	•	
CDR (<i>Combustibile derivato da rifiuto</i>)	Italy	The term is legally adopted in the country ^[13] to identify a waste derived fuel (indicated as normal quality) that is prepared from non-hazardous wastes to be used for energy recovery in incineration or co-incineration plants and that complies with rules laid down in a national standard. ^[14] Within the country, the CDR is assumed to be a solid recovered fuel (SRF) and is shipped and used as waste under the EWL code 191210.	•	
CDR-Q (<i>Combustibile derivato da rifiuto di elevata qualità</i>)	Italy	The term is legally adopted in the country ^[15] to identify a waste derived fuel (indicated as high quality) prepared from non-hazardous waste to be used for energy recovery in defined co-incineration plants and that complies with rules laid down in a national standard. ^[14] Within the country, the CDR-Q is assumed to be a solid recovered fuel (SRF) and is shipped and used as waste under the EWL code 191210.	•	

Table 1 (continued)

Acronym (extended name)	Country	Description [Ref.]	SRF	RDF
CSR (Combustibles solides de récupération)	France	The term is legally adopted in the country ^[16] to identify a solid non-hazardous waste derived fuel that: consists of wastes which have been treated in a such way as to extract the waste stream fractions recoverable in the form of material, under the prevailing technical and economic conditions; is prepared for use in plants falling within heading 2971 of the French list of facilities classified for the purpose of environmental protection ^[17] ; meets requirements set in a French regulatory framework in terms of characterization and thresholds, quality control and obligation to respect the waste hierarchy. Within the country, the CSR is assumed to be a solid recovered fuel (SRF).	•	
CSS (Combustibile solido secondario)	Italy	The term is legally adopted in the country ^[18] to identify a secondary fuel produced from non-hazardous wastes that complies with rules laid down in CEN standard on SRF and in the UNI/TS 11553. ^[19] Within the country, the CSS is assumed to be a solid recovered fuel (SRF) and is shipped and used as waste under the EWL code 191210.	•	
CSS-C (CSS-Combustibile)	Italy	The term is legally adopted in the country ^[20] to identify a secondary fuel that complies with rules (e.g. input waste streams, production process, specifications) laid down in a national decree for the declaration of end-of-waste. The term only applies within the country to a recovered fuel that is produced and shipped as a fuel product.	•	
RDF (Refuse derived fuel)	Germany	The term is commonly used in the country ^{[1],[8]} to identify a waste-derived solid fuel in differing coarser grain sizes, without any compliance to a standard and without a comprehensive quality assurance system.		•
RDF (Refuse derived fuel)	Austria	The term is legally adopted in the country ^[21] to identify a fuel waste: that is used entirely or to a significant extent for the purpose of energy generation and which satisfies the quality criteria laid down in this directive; that is produced through an adequate and extended pre-treatment of non-hazardous waste streams [sewage sludge, waste wood, high-calorific fractions, from mechanical-physical (MT) or mechanical-biological (MBT) treatment plants, calorific fractions of household and commercial wastes, shredder light fractions (e.g. from old vehicles and waste electrical and electronic equipment), scrap tyres, waste oil, used solvents and animal fat and bonemeal, carried out in facilities with a quality assurance system; that can be used in co-incineration plants. Within the country, the RDF is shipped and used as waste under the EWL code 191212.		•
RDF (Refuse derived fuel)	United Kingdom	According to the national Department for Environment, Food & Rural Affairs, ^[22] the term is used to define a fuel that consists of residual waste and whose utilization in EfW facilities is subject to a contract between the producer and end user. The guideline sets a minimum number of properties (in fact, all the end user's technical needs: calorific value, moisture content, form) to be specified in the contract, but without any mention of standards or reference values that define the required degree of quality for each property.		•

Table 1 (continued)

Acronym (extended name)	Country	Description [Ref.]	SRF	RDF
RDF (Refuse derived fuel)	Irish Republic	According to the national Environmental Protection Agency and the Irish Trans Frontier Shipment Office (TFSO), ^[23] the term is used to identify a recovered fuel with a final NCV that is higher (indicatively, falling in the range 9-12 MJ/kg) than the waste stream it is produced from; as well as for the municipal waste stream itself; incineration and co-incineration plants for electricity and heat production are reported as the main final destinations of RDF. Within the country, the RDF is shipped and used as waste under the EWL code 191212.		•
RDF (Refuse derived fuel)	Japan	The term is legally used in the country to identify a recovered fuel produced from combustible fractions of MSW. The RDF is regulated through specific national standards. ^{[24],[25]} Due to a relatively low calorific value (e.g. NCV > 12 MJ/kg) and a high moisture and ash content, it is considered a low quality fuel, essentially intended for use in urban EfW facilities (e.g. power generation plants mainly but also district heating facilities) to satisfy the local demand for electricity and heat.		•
RDF (Refuse derived fuel)	South Korea	Until 2012, the term identified a type of solid fuel produced from MSW and legally regulated through the national law on solid fuels. Two classes of RDF (pelleted and non-pelleted) each one with quality requirements (limit values) set for several properties (size; NCV; moisture; ash, Cl, S, Hg, Cd, Pb, As and Cr content) were legally defined. ^[26] The term RDF was changed to SRF in 2013.	•	•
RDF (Refuse derived fuel)	Thailand	The term is used in the country ^{[27],[28]} to identify waste fuels derived from MSW and classified according to the ASTM standards. ^[29] Of the seven classes of RDF, a particular relevance within the country is given to RDF-5 5. This identifies a combustible waste densified (compressed) into a form of pellet, slug, cube, or briquette, mainly derived from plastic wastes (quite similar for example to the RPF produced in Japan)] but also from organic sludge that can be combusted in various existing boilers (fluidized bed combustors, gasifiers, cement and brick kilns). The RDF-5 (as well as the RDF-3 and 4) could an SRF; the ASTM class RDF 1 and RDF-2 can reasonably consider to be a generic RDF.	•	•
RDF (Refuse derived fuel)	India	According to Guidelines provided by national Official Boards ^{[30],[31]} the term is used in the country to identify a waste fuel derived from combustible waste fractions of solid waste, such as plastic, wood, pulp or organic waste, other than chlorinated materials, that can be used as alternative fuels in various industries (cement manufacturing plants, in particular). Norms for the production and the use of RDF in cement kilns are provided that identify three class of RDF (grade I-III) based on their compliance to reference values (such as range, maximum permissible content or mean value) set for five main properties (size; NCV; ash, moisture, Cl and S content).	•	
RDF (Refuse derived fuel)	USA	The term is used in the country ^{[32],[33],[34],[35]} to identify a waste fuel recovered from MSW produced according to a set of standards established by the <i>American Society for Testing and Materials</i> (ASTM).	•	•
RPF (Refuse plastic fuel)	South Korea	Until 2012 the term was used in the country to identify a type of solid fuel produced from plastic wastes, legally regulated through the national law for solid fuels that set quality requirements (limit values) for several properties (size; NCV; moisture; ash, Cl, S, Hg, Cd, Pb, As and Cr content). ^[26] The term RPF was changed to SRF in 2013.	•	•

Table 1 (continued)

Acronym (extended name)	Country	Description [Ref.]	SRF	RDF
RPF (Refuse derived paper and plastics densified fuel)	Japan	The term is legally used in the country to identify a pelletized recovered fuel that originates from dry and non-hazardous paper and plastic waste streams of industrial origin (residual wood, textile and rubber waste streams are also permitted) and is mainly intended as substitute fuel for the Japanese paper and steel and cement manufacturing industries. ^{[36], [37]} The RPF is regulated through a specific national standard ^[52] : according to limit values set for key parameters (NCV, moisture, ash and Cl content), four classes of RPF are defined, of which one (the RPF-coke class) identifies a high quality RPF with a calorific value close to that of coal.	•	•
SBS® (Substitutbrennstoff)	Germany	The term (brand mark) is commonly used in the country, ^{[4], [8], [9]} to identify a solid waste-derived fuel, produced from separately collected high calorific fractions from municipal waste treatment, industrial and commercial wastes, that meets specification requirements as set by BGS e.V (BGS e.V. Quality Assurance Association for Solid Recovered Fuels and Recycled Wood) and that complies with rules laid down in national standards RAL-GZ 724.	•	
SCF (Segregated combustible fractions)	India	According to <i>Guidelines</i> provided by national Official Boards ^{[30], [31]} the term is used to identify in the country non-recyclable fractions of the MSW that contain plastics and other combustible materials (not biodegradable and that do not release toxic gases when they are burnt or dumped in the dump yards/landfills). These fractions can be directly processed in waste-to-energy plants or used in pre-processing facilities to produce a refuse derived fuel (RDF).		•
SRF (Solid recovered fuel)	Austria	The term is commonly used in the country ^{[38], [39]} to identify a subset of RDF: that is produced from selected or mixed non-hazardous wastes according to well defined pre-treating processes [e.g. multistage shredding, classifying, separation of Fe- and non-Fe-metals, exclusion of heavyweight inert materials, sorting out of unwanted materials such as polyvinyl chloride (PVC) or of recycling materials such as PET]; that complies with quality requirements (production, classification and specification) set in EN 15359. Within the country, the SRF is shipped and used as waste under the EWL code 191210.	•	
SRF (Solid recovered fuel)	Rep. of Ireland	According to the national Environmental Protection Agency and the Irish Trans Frontier Shipment Office (TFSO), ^[23] the term is used to identify a waste derived fuel of “good quality”; this means a fuel with a higher NVC than RDF (indicatively, from 13 to over 20 MJ/kg), that complies with quality requirements (e.g. for Cl, Hg, Cd, Tl: a reference standard is not specified by the source) suitable for use as a substitutive fuel (e.g. in the cement industry). In the country, the SRF is shipped and used as waste under the EWL code 191210.	•	
TDF (Tyre derived fuel)	South Korea	Until 2012 the term was used in the country to identify a type of solid fuel produced from end-of-life tyres, legally regulated through the national law for solid fuels that sets quality requirements (limit values) for several properties (size; NCV; moisture; ash, Cl, S, Hg, Cd, Pb, As and Cr content). ^[26] The term TDF was changed to SRF in 2013.	•	•

Table 1 (continued)

Acronym (extended name)	Country	Description [Ref.]	SRF	RDF
WCF (Wood chip fuel)	S o u t h Korea	Until 2012, the term was used in the country to identify a type of solid fuel produced from wood (waste wood), legally regulated through the national law for solid fuels that set quality requirements (limit values) for several properties (size; NCV; moisture; ash, Cl, S, Hg, Cd, Pb, As and Cr content). ^[26] The term WCF was changed to biomass-SRF in 2013.	•	•
WDF (Waste derived fuel)	United Kingdom	According to the Guidelines of the national Waste and Resources Action Program (WRAP), ^[41] the term is used to identify an unspecified waste fuel obtained by submitting the waste streams to basic processing that increases the calorific value. It can be reasonably assumed that the term 'unspecified', not defined in the Guideline, means not corresponding to quality requirements set in standards or in private commitments among producers and end users. It means that the WDF is essentially an RDF. Only if it reaches - a high market value so as to satisfy higher quality specifications, the WDF is considered to be a solid recovered fuel (SRF) according to EN 15359	•	•

5.3 Rules for the classification and specification of SRF

Rules for the classification of SRF are given in EN 15359^[2] and ISO 21640.^[4] ISO 21640 is developed based on the European standard EN 15359 and will replace it as ISO 21640 when it has been published.

The classification system is based on three fuel properties – the net calorific value (economic relevance), the chlorine content (technical relevance) and the mercury content (environmental relevance) – with limit values for each property. These are assigned to five classes, as [Table 2](#) shows, which are adopted in both the standards, and compliance rules for the SRF classification are detailed. The selected properties are considered to be equally important and a combination of the class numbers makes up the class code for the SRF (e.g. SRF class code: NCV 3; Cl 2; Hg 2).

Regarding the specification of SRF, EN 15359 and ISO 21640 agree on the choice for identifying a list of relevant properties that are intended to be specified (mandatory properties) or can (voluntary properties: e.g. the producers and the users are free to agree upon which of these properties are relevant) be specified to define the quality of the fuel. The mandatory and non-mandatory properties are summarized in [Table 3](#) and [Table 4](#).

Table 2 — Rules for the classification of SRF according to EN 15359^[2] and ISO 21640^[4]

Standard	Fuel property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5	Statistic
EN 15359	Net calorific value (NCV)	MJ/kg (ar)	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3	mean
	Chlorine (Cl)	% in mass (d)	≤ 0,2	≤ 0,6	≤ 1,0	≤ 1,5	≤ 3	mean
	Mercury (Hg)	mg/MJ (ar)	≤ 0,02	≤ 0,03	≤ 0,08	≤ 0,15	≤ 0,50	median
		mg/MJ (ar)	≤ 0,04	≤ 0,06	≤ 0,16	≤ 0,30	≤ 1,00	80th percentile

Table 2 (continued)

Standard	Fuel property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5	Statistic
ISO 21640	Net calorific value (NCV)	MJ/kg (ar)	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3	mean
	Chlorine (Cl)	% in mass (d)	≤ 0,2	≤ 0,6	≤ 1,0	≤ 1,5	≤ 3	mean
	Mercury (Hg)	mg/MJ (ar)	≤ 0,02	≤ 0,03	≤ 0,05	≤ 0,10	≤ 0,15	median
		mg/MJ (ar)	≤ 0,04	≤ 0,06	≤ 0,10	≤ 0,20	≤ 0,30	80th percentile

Table 3 — Specification of SRF: list of fuel properties it is obligatory to specify according to the EN 15359 and ISO 21640 standards (adapted from [2], [4])

Standard	General	Physical properties	Chemical properties
EN 15359	Class code ^a Origin ^b	Traded form Particle size, (mm) ^c Ash content % in mass (d) ^d Moisture content % in mass (ar) ^d NCV, MJ/kg (ar), (d) ^d	Cl % in mass (d) ^d Sb, As, Cd, Cr, Co, Cu, Pb, Mn, Hg, Ni, Tl, V mg/kg (d) ^d Sum of heavy metals mg/kg (d) ^{d e}
ISO 21640	Class code ^a Origin ^b	Traded form Particle size (mm) ^c Ash content (A) % in mass (d) ^d Moisture (M) % in mass (ar) ^d NCV MJ/kg (ar), (d) ^d	Cl % in mass (d) ^d Sb, As, Cd, Cr, Co, Cu, Pb, Mn, Hg, Ni, Tl, Sn, V mg/kg (d) ^d

NOTE

- (a) According to the classification system specified in the standard (EN 15359, Table 1; ISO 21640, Table 2).
- (b) The origin of the input wastes utilized for the preparation of the SRF; it is specified: according to EN 15359, either by test or by the digit code as reported in the European Waste List; according to ISO 21640, either by text or by the three-digit codes listed in 7.2 (Table 3) of the standard.
- (c) By sieving or equivalent techniques; it is expressed as dx , where d is the particle size on the distribution curve where x percent passes, according to CEN test methods (EN 15415-1). According to ISO 21640, the value could either be specified directly or as a P-designated value.
- (d) Typical and limit values per parameter are required. According to EN 15359: the typical value is the mean value for the physical properties and the chemical, except for heavy metals and trace elements, in which case the median value is used, over an agreed or specified period of time; the limit value (minimum, maximum or 80th percentile, where the median has been used as a typical value) will be agreed upon and defined by the user and the producer and refers to a consignment. According to ISO 21640, a typical (mean value) and a limit value (minimum, maximum or 80th percentile value), in case of physical properties, a typical (median value) and a limit value (maximum or 80th percentile value), in case of chemical properties, are required.
- (e) Sum of Sb, As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, according to the Waste Incineration Directive (IED). [42]

Table 4 — Specification of SRF: List of fuel properties it is not obligatory to specify according to EN 15359^[2] and ISO 21640^[4]

Standard	General	Physical properties	Chemical properties
EN 15359	Fuel preparation Fuel composition % in mass (d), (ar) Biomass fraction % by mass, by energy, by C content ^a	Bulk density kg/m ³ ^a Ash melting behaviour °C ^a Volatile matter content % in mass (d) ^a	C, H, N, S % in mass (d) ^a Metallic Al % in mass (d) ^a Br, F, Al, Fe, K, Na, Si, P, Ti, Mg, Ca, Mo, Zn, Ba, Be, Se, mg/kg (d) ^a PCB mg/kg (d) ^a Others ^{a b}
ISO 21640	Fuel preparation Fuel composition % in mass (d), (ar) Biomass content % by mass, by energy, by C content ^a Fossil content % by mass, by energy, by C content ^a	Particle size distribution (including defining fines and coarse material) Bulk density (BD) kg/m ³ (ar) ^a Ash melting behaviour °C ^a Volatile matter content (VM) % in mass (d) ^a	Major and trace elements % in mass (d) mg/kg (d) ^{a b}
NOTE			
(a) Typical and limit values per parameter are reported, see Note d) in Table 3 .			
(b) Other chemical properties relevant for the end user and agreed with the producer.			

National Standardization Bodies have also intervened over time in respect of the classification and/or the specification of waste-derived fuels and SRF, which is locally well accepted by producers and end users and assumed as a reference in administrative approval procedures. Details on national standards are provided in [B.1](#). Like those mentioned above, the national standards also generally mediate technological, economic and environmental needs for use in EfW plants, but in some cases provisions for specific end uses are given. Different choices have been made about the number and types of key parameters and the limit values to be used for the classification and/or the specification of the recovered fuel, with or without an explicit definition of the boundaries, e.g. the origin of the waste stream, the end use of the fuel.

For example, SFS 5875,^[43] was introduced in the past (year 2000) in Finland to regulate the production process and the quality of SRF. According to that standard, currently replaced by EN 15359, three classes of SRF (see [Table B.1](#)), based on a compliance with limit values for seven key parameters (operational parameters, mainly: Cl, S, N, K+Na, Hg and Cd), were defined.

In Italy, first (year 2004) two classes of solid recovered fuel, a “normal” (CDR) and a “high quality” (CDR-Q), legally permitted^[15] as fuel substitutes in cement kilns and thermoelectric power plants), were introduced through the national standard UNI 9903,^[14] based on a fuel complying with limit values for a set of physico-chemical properties (NCV, moisture, ash, Cl and S content) and eight trace elements (see [Table B.3](#)). UNI/TS 11553^[19] which was then intended to provide a reference for the specification of the waste fuel named CSS, legally identified in Italy as a secondary solid fuel.^[18] With the exception of the sum of heavy metals, limit values for the chemical properties assumed as obligatory parameters in EN 15359 are defined in that standard (see [Table B.4](#)).

In Germany, a quality assurance system for solid recovered fuels has been provided since the early 2000s through the RAL-GZ 724 standard.^{[8],[9],[10],[44],[45],[46],[47],[48],[49]} The specification of the fuel quality takes into account properties assumed as relevant with respect to the economic and technological needs of the main domestic end users (co-incineration plants with high quality needs, such as cement kilns,

coal-fired power plants), other than the environmental ones. Limit values are defined (see [Table B.2](#)) for a set of trace elements that include those it is obligatory to specify according to EN 15359 and Sn. Thus a clear difference was introduced in the country between a “qualified” SRF and selectively separated portions of MSW which in any case have a calorific value higher than the original waste mixture, but are less pre-treated and not submitted to the same quality assurance system (incineration is the main destination for the latter).

In Japan,^{[50],[51]} the standard JIS Z 7311^[52] regulates an SRF, known in the country as RPF, that is mainly utilized as an alternative fuel in industrial processes, e.g. the national cement, paper and steel industries.^[36] According to the standard, four classes of RPF are defined (see [Table B.5](#)), one of which (RPF coke) identifies a high quality solid recovered fuel with a calorific value close to that of coal. The classification is based on the fuel complying with limit values for the key parameters NCV, moisture, ash and Cl content only. No requirements for the Hg content in RPF occur in the standard, due to the assumption that waste streams that are Hg-free are to be utilized for its production, according to the national legislation on waste management. As data reported in [Annex D](#) show, the previously mentioned properties are the main ones recorded to assess the quality of RPF, jointly with the content of Al, as a voluntarily chosen parameter.

Some countries have legal rules (see [Clause B.2](#)) to regulate the quality of the waste fuels utilized as waste in EfW plants and largely intended to ensure adequate compliance with the main goals of safeguarding human health and environmental protection according to existing regulations^{[42],[53]–[67]} and reference limit values for industrial emissions^{[68],[69]}.

In Austria, limit values are legally defined^[21] for a set of eight trace elements (Sb, As, Pb, Cd, Cr, Co, Ni and Hg) that apply to a “generic” waste fuel utilized in cement kilns, power plants or co-incineration facilities (see [Table B.6](#)). In France, quality requirements for Hg, Cl, Br and the sum of Br, Cl, F, I (see [Table B.8](#)) are now legally set^[16] for non-hazardous wastes in the form of CSR to be used in relevant EfW facilities; this means in plants that produce heat or electricity falling into a specific class of the national nomenclature of plants relating to the protection of the environment.

In Italy, two ministerial decrees^{[13],[15]} have been introduced in the past to specify the quality of CDR and CDR-Q that identified limit values for the trace elements Pb volatile, Cr, Cu soluble, Mn, Ni, As, Cd and Hg and the EfW plants permitted to use CDR and CDR-Q (see [Table B.10](#)).

The government of South Korea^[26] has addressed the matter of waste fuels from the point of view of classification, quality and grade by changing the rules previously in force (see [Table B.12](#)). Since 2013 a *Solid Refuse Fuel*, produced and traded in pellet form or otherwise, is regulated in the country and distinguished as SRF and bio(mass) SRF, based on the type of waste stream it derives from. More restrictive requirements than in the past have been introduced for such SRFs e.g. in the case of the content of Cl, Hg, Pb, Cd, As, and Cr. The documentary source does not specify whether the quality requirements legally set apply to all the existing/planned EfW plants or to a specific end use of the RDF.

In India, central authorities^{[30],[31]} recently moved to support the co-processing of wastes (SCF, RDF, plastic wastes) in domestic industrial sectors and, first of all, in the cement manufacturing industry, assumed to be technically ready to adopt higher rates of alternative fuels. A proposal for “standardization” was made in 2018 by MoHUA,^[31] based on which the waste fuels are classified as SCF and RDF (three RDF grades) according to the maximum permissible values set for the above parameters (NCV, particle size; moisture, ash, Cl and S content) that substantially refer to technological and economic needs (see [Table B.9](#)).

A mention can also be made in respect of the end-of-waste classification for the recovered fuels. It is now legally permitted in some countries, e.g. Italy^[20] and Austria^[21] and regulated by binding rules that refer to the origin, the production process, the end use and the fuel quality (see [Table B.7](#) and [Table B.11](#)).

Producers and end users of SRF/RDF can also be asked to comply with further or more restrictive provisions by local authorities. Only a few examples of local authority prescriptions have been collected that exclusively refer to quality requirements set in plant permits issued to cement kilns and power plants in some European countries (see [B.3](#)). A summary discussion on specifications in such plant permits is provided in [Clauses 6](#) and [7](#).

An effort to provide a reference (not mandatory) for the specification of SRF/RDF has been made by national associations of end users/producers, national bodies or studies. The derived general guidelines (see [B.4](#)) can support: the end users, in the choice of the best performing fuel according to their own technological, economic and environmental needs; the producer, in making available a quality-controlled or a certified SRF (e.g.: the “medium quality” and “premium quality” SRFs produced in Austria and Croatia; the SRF protected under the trade marks *BPG^R* and *SBS^R* in Germany) suitable for an end use in cement kilns, lime kilns and coal power plants. A summary discussion on specifications in such guidelines is provided in [Clauses 6, 7 and 8](#).

The above-mentioned rules for the specification of SRF/RDF, do not in any case exclude the creation of “plant-specific” requirements defined in a private commitment between the producer and the end user, which can take into account further relevant parameters and provide typical/limit values for fuel properties, according to the specific needs of the end user plant. A summary discussion of the collected voluntary specifications (see [B.5](#)), is provided in [Clauses 6, 7 and 8](#). Indicative needs for the specification of SRF/RDF can also be derived from responses given by producers, end users and other stakeholders to some of the ISO/TC 300/WG 2 online surveys promoted in 2017, as summarized in [B.6](#).

5.4 Market for SRF and other waste-derived fuels

A brief analysis of the production, domestic use and transboundary shipment of secondary fuels in different countries emphasises that:

- Secondary fuels (SRF/RDF/other combustible fractions) are currently produced from different waste streams (MSW, C&IW, C&DW), in sorting (MT) and mechanical-biological treatment (MBT) plants, with different shapes (e.g. fluff, pellets, briquettes, chips, crushed).

The origin of SRF from urban wastes seems to be prevalent in most of the countries, followed by that from selected industrial/commercial fractions, such as paper and plastic wastes. Indicatively, an average SRF yield ranging from 35 % (input stream: MSW) to 15 % (input stream: C&IW, and C&DW) can be assumed^[20].

It is noted that the residues coming from domestic and industrial/commercial activities are submitted worldwide (e.g. Europe, China and Japan) to different regulations that apply to both their classification as waste and their management. This can have a spin-off on the composition of the input streams that the MBT/MT plants are locally allowed to treat for the production of SRF/RDF and other combustible fractions.

The reprocessing of wastes into solid fuels such as SRF can play a role in meeting the objectives of the climate, energy and waste management policies, and the expected transition towards a circular economy, as policy choices adopted for example in Europe^[21] clearly underline. Regarding the role in waste management and the circular economy, the complementary assumption mentioned in [5.1](#) according to which wastes not suitable for re-use, preparation for re-use or for efficient material recovery are intended to be used in MT/MBT plants for their production, is relevant. It can be noted that a new area of application for SRF/RDF could in the future be their use as feedstock for thermochemical recycling processes; these are aimed at producing liquid fuels or base chemicals that can be used to produce materials such as plastics. Nowadays the commercial facilities in this area are limited, but with the right incentives these technologies could develop further and become an important market for SRF/RDF.

- Secondary fuels enter the market with different names, as [Table 1](#) shows, and a clear identification as a standardised (SRF) or non-standardised (RDF) fuel cannot always be made.

The relevance of standardisation for the SRF/RDF market is now well recognized. Provisions for the classification and the specification of SRF are already available in international and national standards (see [Annex B](#)) as well as (specification) in national legislation and guidelines (see [Annex B](#)). India is now actively working on the development of national standards and guidelines for the production and the end use of SRF/RDF mainly in industrial sectors, and China is moving towards an alignment of its own standards to the international ones. The efforts put into ISO standardization will most probably lead to an increased trust in SRF as a secondary fuel. This in turn might also lead to a growing demand in countries that do not have an active market in

e.g. Pakistan, Egypt, Canada, and Australia, that have recently chosen to start undertaking standardization work or are in any case interested in exploiting energy recovery from waste.

- There is a lack of statistics for the global market in secondary fuels and, in some cases, of consolidated, homogeneous and updated assessments on a country basis.

The markets analyzed largely refer to countries (European countries, Japan and the USA) that were historically the first to start exploiting the potential of SRF/RDF in their energy and manufacturing sectors.

Regarding Europe, ERFO and Cembureau^[70] highlighted cement kilns and incineration plants as the biggest customers, with a total consumption of about 12 Mt/y in the year 2015, to which cement kilns contributed 40 % (about 5 Mt/y), followed by other EfW plants (e.g. power plants, gasification/pyrolysis plants, dedicated industrial combustion plants, blast furnaces and lime kilns) with a reported consumption of about 1,5 Mt/y of SRF/RDF. A different extent of both yearly production and domestic consumption of SRF/RDF in EfW plants can be observed in European countries^{[2],[12],[17],[45],[78-85],[107],[108],[109],[110]}.

In the USA,^{[32],[33],[34],[86-89]} a total consumption of about 0.72 Mt of RDF/y can be indicatively assumed in existing RDF facilities, designed to combust the waste fuel alone or in mixture with MSW. The refuse-derived fuels and other types of substitute fuels are currently utilized in about 73 % of all the US cement plants.

In Japan,^{[36],[37],[50],[51],[90]} low-quality secondary fuels (RDF: about 300,000 tonnes produced in the year 2015) are essentially intended for use in urban EfW facilities (e.g. power generation plants, mainly along with district heating facilities to satisfy the local demand for electricity and heat). In the same year, production of about 1,25 Mt of RPF (SRF) is reported in Japan, mainly utilized as a substitute fuel in the paper, steel and cement manufacturing industries.

Other South-East Asian countries, such as Korea, Thailand, India and China that annually manage large amounts of wastes (MSW, mainly) and need to satisfy the internal demand for energy, have more recently started to implement their EfW systems (e.g. incineration plants, gasification plants and cement kilns) as well as waste pre-treatment systems to SRF, so as to support the planned increases in domestic consumption^{[26-28],[91-104]}.

China, in particular, could become a large producer and end user of SRF as it moves into a period of intense growth in the incineration industry with a major focus on the use of FBB technology and since it is also the largest cement producer in the world.

In India MSW-RDF is considered to be one of the most promising alternative fuels for the national cement industry, with an estimated potential availability for co-processing of about 1,37 Mt/y of MSW-RDF. The waste management policies adopted in Korea include a comprehensive plan for waste-to-energy, with an expected increase to 3,8 Mt in 2020 (1,8 Mt in 2013) of combustible fractions (e.g. paper, plastics and wood) of municipal/industrial wastes transformed into SRF, to be combusted or converted to energy in boilers and cogeneration plants.

In Thailand, various new RDF facilities, MSW/RDF-incineration plants and RDF gasification plants are planned or under construction in the country; a potential yearly production of 2,46 Mt of RDF is estimated, even while the expected increase to around 40 % of fossil fuel substitution in the cement industry could mean a need for around 2,7 Mt/y of RDF.

On the whole, incineration with recovery of electricity and thermal energy seems to be a typical end use of SRF/RDF in most countries and developments are taking place locally in the power and district heating sector. Over time, energy-intensive industrial sectors, such as the cement manufacturing industry and coal fired power plants in the energy sector, have become large consumers of SRF as a substitute fuel to reduce the need for fossil fuels and achieve benefits (plant environmental performance, e.g. reduction of GHG emissions).

The use as a fuel substitute in the steel/iron, pulp/paper, glass and chemical industries seems to be as yet unexplored in most countries. Industrial co-incineration plants are also exploiting the potential of SRF to satisfy their heat/electricity demand or (in some European countries to

example) to benefit economically from placing electricity on the national grid. Advanced conversion technologies, such as SRF/RDF gasification pyrolysis, are being explored e.g. in the UK, France, Norway, Japan, Korea, and Thailand.

- Active transboundary shipments of SRF/RDF can be observed in Europe, but also in South-East Asia, where the production of SRF/RDF is a way of tackling the management of very large volumes of urban wastes produced annually. India and China now seem to play a relevant role as recipient countries^[90] and look with increasing interest to secondary fuels as a suitable feedstock to support the needs and the planned development of their national EfW systems (incineration and co-incineration plants).

As regards trade within Europe, an analysis performed by the Chartered Institution of Wastes Management (CIWM)^[105] shows that the United Kingdom leads the export of SRF/RDF with 60 % of the total of 5,9 Mt exported by the European countries in 2016. However, SRF still represents a relatively small share (< 7 %) of the total RDF exported by the UK. On the other hand, the RDF exported by the Republic of Ireland also includes SRF. The Netherlands, Sweden and Germany top the list of importing countries. A scenario analysis carried out with the aim of forecasting the residual waste supply, (i.e. waste generation and waste recycling performance) and the internal demand (e.g. the capacity of operational and planned/proposed facilities) by 2030, resulted in a potential long term decrease of exports from both the UK and Ireland. It has also been evaluated^[106] that the greatest treatment capacity surplus (1,3 Mt) could occur in future years in countries such as the Netherlands, Germany, Sweden, and Denmark, even if different factors (e.g. new national policies and legislation on waste, creation of new EfW capacity, decommissioning of existing EfW facilities and an increase in waste recycling) might have a significant upward or downward influence on the real capacity gap in these countries.

Different factors with an upward or downward trend exist locally that are able to determine a capacity gap for SRF/RDF. These include an internal supply (e.g. waste generation, waste management policies and waste recycling performance; strong local bureaucracy; public acceptance; treatment capacity of the local MT/MBT system) that is higher/lower than the internal demand (e.g. the number and treatment capacity of EfW facilities; strong local bureaucracy; public acceptance; low availability of end-user plants equipped with technologies that allow the use of SRF as feedstock).

Gasification of solid recovered fuel and the co-incineration of the syngas in a combustion plant to replace fossil fuels in the production of electricity and heat, co-incineration in the cement and lime manufacturing industry and incineration in dedicated facilities have been recently underlined as the most energy-efficient waste-to-energy techniques^[71].

6 Coal co-combustion in the cement manufacturing industry

6.1 General

A brief description of the production process and the main technologies in the cement manufacturing industry is provided in [C.1](#).

Mandatory requirements for the use of SRF/RDF and other waste fuels in cement kilns have been introduced in some national legislations, such as in Austria (see, [Tables B.6](#) and [B.7](#)), India (see [Table B.9](#)), Italy (see [Tables B.10](#) and [B.11](#)).

Some national standards give limit values for fuel properties to regulate the use of SRF/RDF or other waste fuels as suitable feedstock in cement kilns. Data reported in [Annex B](#) mainly refer to: the SRF specified, in Italy, CDR-Q and CSS and regulated according to UNI 9903:1 and UNI/TS 11553 (see [Table B.3](#) and [Table B.4](#)); the SRF that in Germany complies with RAL-GZ 724 (see [Table B.2](#)); and the solid recovered fuel known as RPF in Japan (see [Table B.5](#)).

With respect to the environmental performance, cement kilns comply with emission limits legally set for polluting substances. As an example, common legal rules have been introduced in Europe with the *Industrial Emissions Directive*^[42] that give, in particular, specific provisions for trace elements (He

Cd+Tl, sum of As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V; dioxins and furans). Some European countries have already transposed these common rules into their own legislation, even if different and/or more restrictive provisions may be required e.g. by local authorities in plant permits. In Japan,^[57] no emission limits for Hg are set in the *Air Pollution Control Act*^[58]; furthermore, following the *Minamata Convention*,^[61] an amendment of the Act was approved in the country (in force by the end of 2015) to limit mercury emissions^[59] and special measures have also been legally introduced for dioxins.^{[59],[60]} In China,^[64] the standard GB 30485:2013 was issued to regulate the matter of air pollutants in the case of solid waste co-processing in cement kilns. Limit values for heavy metals and dioxins are defined in that standard. In India, new regulations and emission limits, (heavy metals, dioxins and furans) substantially aligned with the European IED Directive, were legally introduced in 2016 by the Central Government^[30] for MSW and RDF co-processing in cement kilns. The matter of toxic air pollutants is regulated in the USA under the *Clean Air Act* and in the EPA CISWI standards^{[65],[66],[67]}; the latter define specific limit values for the emission of Pb, Cd, Hg, dioxins and furans – from kilns that burn non-hazardous wastes; these emission limits do not apply in the case of cement kilns that burn tyres, used oil, biomass, and wood waste as these fuel feedstocks do not fall within the definition of “non-hazardous solid wastes”.

6.2 End use requirements of SRF and other waste derived fuels

6.2.1 Technical limitation of the technologies

The ongoing switch of cement kilns from conventional to alternative waste fuels, to a low extent on a global level but locally, e.g. in different European countries, at a very high level, includes the use of different kind of wastes, both totally biogenic (e.g. waste wood and sawdust) and partially so in nature, such as: discarded or shredded tyres; waste oils and solvents; sludge from water and wastewater treatment plants; pre-processed or raw industrial waste, including lime sludge from paper and similar industries; non-recyclable plastics, textiles and paper residues; fuels recovered from municipal solid waste such as SRF and RDF.

That switch presents different technical challenges, e.g. availability of a fuel with an adequate calorific value, selection of the right feeding point, poor heat distribution, unstable pre-calciner operations, blockages in the pre-heater cyclones, build-ups in the riser ducts and the formation of rings in kilns. But there are also some environmental challenges with regard to the emission of SO₂, NO_x, CO and of some heavy metals that can be affected not only by the composition of the raw meal (the natural or alternative raw materials utilized for the production of the cement clinker) but also of the combusted fuels. The raw material/fuel mass ratio for clinker production is approximately 10:1^{[68],[72],[107]}.

The volume, the origin and the properties of wastes are considered so to obtain appropriate quality assurance and compliance with plant requirements legally set or additional specifications from the end user that generally mainly refer, other than to the NCV, to the fuel particle size, the chlorine, sulfur, ash, water and biogenic carbon content as well as that of heavy metals (As, Sb, Pb, Cd, Cr, Co, Cu, Zn, Ni, Hg, Tl, V, Sn, Mn)^{[108],[109]}.

Cement kilns could utilize up to 100 % of alternative fuels. In practice, the calorific value of the waste fuel may be a limiting factor. For firing the main burn of the cement kiln, an average calorific value of at least 20 to 22 GJ/t is generally required; the pre-calciner section of the kiln system (up to 60 % of the fuel input) that works at a lower temperature, may be fed with low calorific value waste fuels. Different solid alternative fuels can offer a calorific value significantly lower than that of conventional fuels (coal, petroleum coke (pet-coke)). In the case of RDF/SRF, the NCV is not as high as in conventional fuel, generally around 20-25 MJ/Kg or lower. For example, NCV values in the range 12-18 MJ/kg and in the range 18-25 MJ/kg are reported^[73] for what are called “SRF of medium quality” and “SRF of high quality”, respectively, produced in Austria and utilized in secondary firing systems of cement kilns and/or in special pre-combustion chambers for the former and in the primary firing systems of cement kilns for the latter.

Well-established technology allows the cement kilns to be fired with low-volatile fuels such as pet-coke, low-volatile bituminous coal, and anthracite, without problems. High volatile-low calorific value alternative fuels are used more in the pre-calciner firing (unless the NCV is about or >16,8 MJ/kg). The use of low-volatile fuels in a pre-calciner has required operational modifications of the pre-calciner, or specially designed pre-calciners^[107].

The choice of *feeding point* is also relevant for cement kilns. It is selected according to the physical, chemical, and toxicological characteristics of the waste fuel. If containing stable toxic components, the waste fuels are fed to the main burner to ensure complete combustion due to the high temperature and the long retention time. Alternative fuels are always fed into the high-temperature combustion zones of the main kiln system^[110]. Wastes, which are fed through the main burner, will be decomposed in the primary burning zone, at high temperatures of up to 2,000 °C. Multi-channel burners are designed for the use of different types of fuels including waste fuels. When fed to a secondary burner, pre-heater or pre-calciner, they are burned at lower temperatures, which is not always enough to decompose halogenated organic substances. Wastes containing volatile metals (mercury, cadmium, thallium) or volatile organic compounds can result in an increase in the emissions of mercury, cadmium, thallium or organic emissions (e.g. VOCs) when improperly used^[68].

The lump size of the waste fuel also will be considered^{[38],[111]}. Solid residues of municipal or commercial/industrial origin, or their high calorific fractions, are pre-processed and comminuted into finer particles of adequate size, according to the selected feeding point in the kiln system (Figure 3). A low particle size ($d_{95} < 30$ mm) is normally required when the feeding point is at the main burner; this can be increased up to < 80 mm when the wastes are utilized in a secondary firing point (calciner) and to < 250 mm in special pre-combustor chambers. The Step-Combustor mentioned in the figure refers to a combustion chamber (e.g. the Hotdisc solution) specifically developed to handle high feed rates of low calorific and large-sized alternative fuels for which a typical retention time of the suspension flow calciner can be quite insufficient (it can allow the retention time to be increased to up to 15 minutes).



Figure 3 — Waste treatment and objectives with respect to the requirements of the burning process (adapted from^[111])

The scheme reported in Figure 4 highlights the relationship between the particle size and the calorific value of SRF, its suitability as an alternative fuel in cement kilns and the specific manner of use in the kiln system (feeding point). It refers to three types of SRF – low, medium and premium quality – currently produced in Austria (and in other European countries), of which the last two are a suitable and typical fuel feedstock for the local cement kilns.

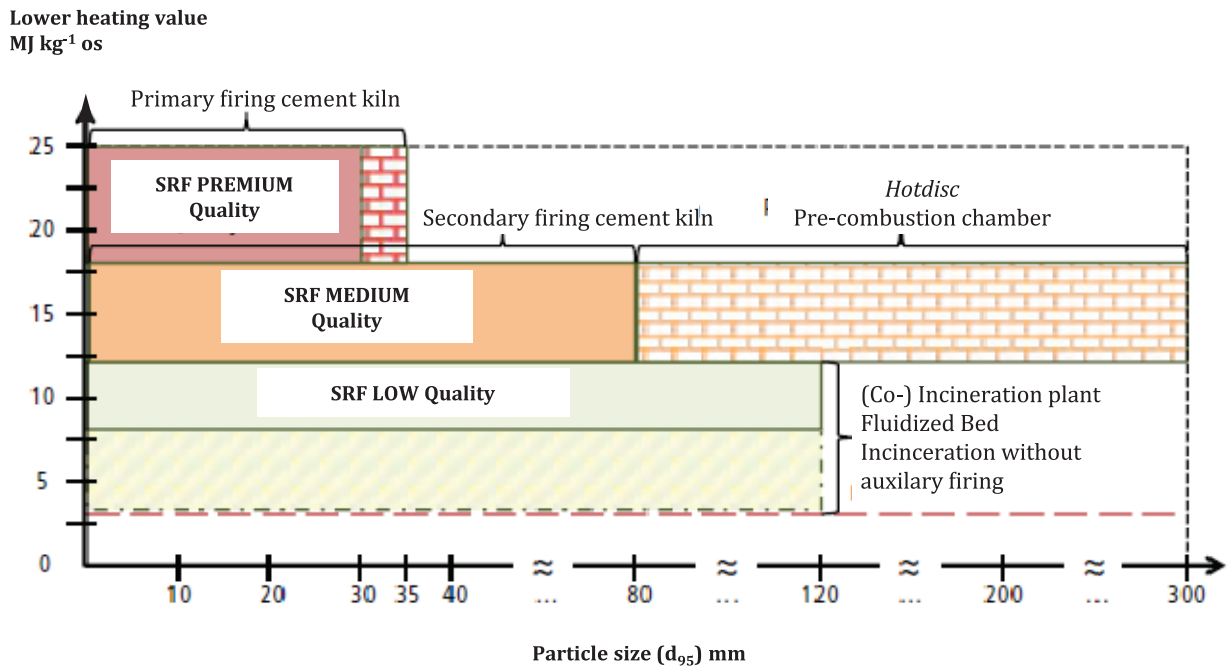


Figure 4 — Relationship between SRF particle size and lower heating value with regard to the energy recovery options (adapted from^[38])

In cement manufacturing, constituents of the feedstock will be avoided that, even in small amounts (<1 %), may have adverse effects upon the performance of the product and/or the production process.

High levels of alkalis in cement can give rise to cracking in concretes and mortars and high levels of alkali sulfates in cements can affect their reactivity. From the point of view of kiln operation, it is better for alkalis (and sulfates) to be discharged from the system with the clinker, to avoid disruptive effects especially in kiln systems with highly efficient heat exchangers such as cyclones^[107]. Sulfur levels in substitute fuels are generally lower than in conventional fossil fuels (0,1–0,2 % in RDF, 3–5 % in fossil fuels): negative effects of precipitation or clogging can be excluded, although issues of alkali sequestration and transfer in the clinker will be verified^[112]. A sulfur content lower than 2,5 % is reported as a reference for the use of alternative fuels in the cement industry^[113].

If chloride is introduced into the kiln system, either through the raw meal or the alternative fuel, sulfate-spurrite, stable within the temperature range 900–1,200 °C, can be formed, which is involved in the formation of rings in cement kilns. The requirement is to keep the chloride content low (as a reference, below 0,02 %) to avoid the formation of kiln rings and preheater deposits.^[107] Fuels containing high levels of Cl (>0,7 %) can have an adverse effect on the performance of some types of electrostatic precipitators in wet process kilns. Clogging can occur in the cyclone pre-warmer, if the chlorine content of the fuel is higher than 0,2–0,5 percent^[107]. Alternative waste fuels, such those enriched with polyvinylchloride (PVC) and chlorinated hydrocarbons, sewage sludge, meat and bone meal, can increase the amount of chlorine introduced into the kiln system^[107]. A Cl content lower than 0,2 % is reported as a reference level for the use of alternative fuels in the cement industry^[113].

The Cl content is less than 0,1 % in coke and, on average, around 0,3–0,5 % in RDF^[112]. Chlorine content is also known to affect the quality of the final product: standards for Portland cements generally limit the amount of chloride to 0,10 % in the raw meal feedstock^[107].

Problems can be created by high levels of circulating alkalis, chlorides and sulfur coming from the raw meal and/or the fuel, which can lead to build-ups in cyclones, blockages and stoppages of the kilns, due to the internal circulation between the kiln and the pre-heater that works as an enrichment cycle.

The use of a kiln gas bypass has been widely introduced to solve that problem and allow continuous kiln operation; typical bypass rates are of up to 15 % for a chlorine bypass and up to 70 % for a sulfur bypass^[68].

The content of trace elements in alternative waste fuels can be quite different from that of conventional fossil fuels. In cement kilns, as well as in lime kilns, most of the heavy metals introduced with raw materials and fuels are trapped in the clinker (and the cement), with the main exception of volatile elements such as Hg and Tl that are relevant factors for air emission control in kiln systems.

Emission factors that give an indicative reference on the performance of modern dry kiln systems (rotary kiln systems with cyclone preheaters), equipped with the best available techniques for the abatement of inorganic and organic pollutants, are available^[72] for the German cement industry, where widespread use of well upgraded kiln technologies and very high substitution rates (>60 %, on average) has been already reached, with extensive use of SRF, quantitatively the main component of the mix of alternative fuels. Low levels, below the legal requirements, have been observed in air emissions of some trace elements (e.g. As, Co, Sn, Be, Se, Tl, Zn), with most of the measured values above the detection limit. Very low or, sometimes, undetectable concentrations of dioxins and furans and of polychlorinated biphenyls (PCB), have been measured in the exhaust gas from German rotary kilns. The rotary kiln systems seem to ensure the virtually complete destruction of such organic pollutants.

An assessment of metal emissions^[114] was recently carried out based on data from some Italian cement kilns fired with pet-coke and SRF, alone or in mixture with other alternative fuels such as meat and bone meal, plastics, waste oil, sewage sludge and end of life tyres. No substantial changes in the air emissions of trace pollutants (metals, dioxins and furans) were observed by enhancing the substitution rates, both when the kiln technology and the kind of alternative fuels are considered. When evaluated with respect to the kiln technology, better performance in term of both the total metal content in the flue gas and, particularly, of volatile (Hg, Tl) and semi-volatile (Cd) metals, has been observed in the case of pre-heater/calciner dry kilns.

It is noted that, for the control of air emissions of inorganic and organic pollutants, some innovative technologies have been developed and are locally applied such as the *Ex-mercury split preheater system* to reduce emissions of Hg, a typical volatile trace element, the *CTP-off-gas treatment system* for the reduction of both organic (CO, TOC, PCDD/F, odour) and inorganic (NO_x) emissions.

Transfer factors are commonly used to define the proportion of a metal occurring in the feedstock that is emitted in flue gases and can be a useful tool for managing the kiln feedstock. In the case of waste co-incineration in cement kilns, transfer factors for trace elements,^[112] and specifically for Pb, Cd, Hg,^[115] are reported, the latter calculated by modelling the clinker production process based on data from individual plants (e.g. some grate-type pre-heater and cyclone pre-heater plants). These calculations were based on some assumptions: trace elements, introduced by raw materials and fuels have the same incorporation rate in the electrostatic precipitator and the heat exchanger/rotary kiln of the plants; with respect to trace elements added by raw materials, those coming from the fuel feedstock have a much lower probability of entering the air emissions (high resistance in the heat exchanger/rotary kiln system). Transfer factors specifically related to SRF are reported in CEN/TR 15508^[116] as derived from the operational data of wet and dry cement kilns (Belgium; Germany). According to these TFs, maximum possible concentrations in SRF have been proposed in the document, as orientation values (see [Table B.16](#)).

Regarding the impact of alternative fuels and SRF on the quality of the end product,^{[114],[115]} metals in the cement produced are reported as being substantially due to the input coming from raw materials. The impact on their level in cement is reported as not being statistically significant. Only in the case of Zn, mainly introduced into the process through SRF and end-of-life tyres (ELT), an effectively higher content in the final product was observed when the share of fuel substitution was increased. These conclusions seem to agree with measured values published by the German Cement Works Association (VDZ) for some Portland cements.^[117] With respect to Hg, the concentration in the main product, intermediate products (clinker) and by-products (bypass dust; filter dust) were analysed in a German study published in 2018.^[118] A low level of heavy metals was observed in the produced cement, with a median value of 0,019 mg/kg d, (range: 0,005 to 0,200), for CEM I; 0,030 mg/kg d (range: 0,006 to 0,220), for CEM II; 0,010 mg/kg d (range 0,001 to < 0,060), for CEM III. The observed median value

of Hg in clinker was of 0,005 mg/kg d (range: 0,001 to < 0,100). As for by-products, a median value of 0,012 mg/kg d (range: 0,002 to 1,100) is reported in the case of bypass dust, while the filter dust shows a higher level of Hg, with a median value of 1,785 mg/kg d (range: < 0,010 to 16).

6.2.2 Quality requirements in plant permits

Some examples of plant permits are provided in [Annex B](#), which define the permitted content of trace elements in fuel feedstocks utilized in the European cement manufacturing industry. Limit values for a different alternative fuels (see [Table B.15](#)), a generic waste derived fuel (see [Tables B.14](#) and [B.15](#)) or specifically for an SRF produced from high calorific fractions of MSW (see [Table B.13](#)), are defined.

With respect to SRF, the reported examples include requirements issued in Germany to cement kilns (and coal-power plants), according to rules established by the Environmental Ministry of North Rhine Westphalia and subsequently introduced in the country by other Länder^{[68],[110]}.

The chosen trace elements (see [Table B.13](#)) show a good alignment with requirements for SRF already established by the national RAL GZ 724 standard (see [Table B.2](#)). If compared with specifications set in the EN 15359 standard and today in the ISO 21640 standard (see [Table 3](#)), all the obligatory chemical properties are included, with the addition of Sn and Zn.

Limit values for trace elements are defined by mass, as both practical (typical value: to be compared with the 50th percentile value of one month) and maximum permitted value (to be compared with the 80th and 90th percentile value of one month). The reported “practical” values substantially coincide with limits (median value) set in RAL GZ 724: 2008 ¹⁾, except for a lower value being required in the case of Co.

6.2.3 Quality requirements in general guidelines

General provisions are outlined by national guidelines, some examples of which are given in [Annex B](#). Aimed at supporting and driving the end use of waste fuels, these guidelines do not always uniquely refer to SRF or to a specific type of waste recovered fuel.

Desirable values for physico-chemical properties of RDF, co-processed in cement kilns and in other industrial activities, are defined in a guideline provided in India^{[30],[31]} by the national Ministry of Housing and Urban Affairs of India and by the Central Public Health and Environmental Engineering Organisation (see [Table B.19](#)). In summary, RDF are assumed to be suitable with:

- Size (mm) falling in the range < 70-120;
- Chlorine content (%in mass ar) <0,7;
- Moisture content (%in mass ar) <20;
- NCV (MJ/kg ar) >12,6.

The guideline of the Swiss Federal Department for the Environment, Forests and Landscape (BUWAL) provides limit values for trace elements in a “generic” waste fuel utilized in cement kilns (see [Table B.18](#)). The list of chemicals covers all the obligatory properties now required by the existing standards for SRF (see EN 15359 and ISO 21640) and Sn, for which the limit values are detailed in [Table B.18](#). In particular, the guideline provides a requirement for a fuel not exceeding a mean value by energy, of:

- Hg (mg/MJ d) 0,02;
- Tl (mg/MJ d) 0,12;
- Cd (mg/MJ d) 0,08.

1) The RAL GZ 724:2008 has been replaced by RAL GZ 274:2012, which defines the quality requirements in relation to energy

Valuable orientation values for trace elements in SRF have been proposed in CEN/TR 15508,^[116] as maximum possible concentrations in the case of the use of SRF in wet and dry kiln processes (see [Table B.16](#)). The following limit values (by energy) are defined in CEN/TR 15508:

- Hg (mg/MJ ar) 0,17 (wet kiln) – 0,082 to 0,33 (dry kiln);
- Sum of Cd and Tl (mg/MJ ar) 6,9 (both kilns);
- Sum of As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V (mg/MJ ar) 1,650 (both kilns).

Fuel specifications that have been defined in Germany to approve a solid recovered fuel, (the BPG^R 2 and the SBS^R 2 in [Table B.20](#)) suitable for an end use in cement kilns, could be considered as further general guidance.

For the physico-chemical properties of traded SRFs (BPG[®] 2 and SBS[®] 2) the following reference values are assumed:

- NCV (MJ/kg ar) in the range 18 -24;
- Chlorine (% in mass d) <1,0;
- Ash content (mg/kg d) in the range < 15 - < 20.

Limit values by mass (BPG[®]) are detailed for all the trace elements assumed as relevant in CEN/TR 15508 (see [Table B.20](#)). If assessed by energy, the following indicative limit values on a dry basis can be derived:

- Hg (mg/MJ d) < 0,03 to < 0,04;
- Sum of Cd and Tl (mg/MJ d) < 0,27 to < 0,39;
- Sum of heavy metals as previously (mg/MJ d) < 30 to < 82.

The set of chemical properties includes other trace elements (Se, Sn, Be, Te) whose limit values by mass are detailed in [Table B.20](#).

6.2.4 Quality requirements in voluntary end user specifications

A valuable statistical assessment of statements in private agreements among European producers and end users, (Belgium, Germany and France), was provided in CEN/TR 15508. Properties that are relevant for the classification of SRF, (NCV and chlorine), are considered in that document (see [Table B.24](#)), for which the reported mean/maximum values fall in the range:

- NCV (MJ/kg ar) 5/10 to 12/22 (mean);
- Chlorine (wt% ar) 0,5 to 1 (mean) – 1 to 3 (maximum).

The requirement for Cl depends on the composition of the input stream. At high substitution rates, a maximum limit of around 3 % is highlighted in cement kilns equipped with a salt bypass system and in the range 0,5 %-1 % without that system. In the case of a wet process cement kiln, a maximum limit of 6 % is reported.

The same geographical origin characterizes further references to voluntary requirements given in [Annex B](#), such as local specifications derived from literature or provided by personal communications of producers/end users (see [Tables B.26](#) to [B.29](#)) and the profile of properties relevant for the fuel specification (see [Table B.35](#)) made available by the ISO survey among producers.

By taking the classification and specification system in the EN 15359 standard as a general reference, these data highlight a requirement for an SRF:

- NCV classed from 1 to 3, (more frequently classed as 1-2), based on the ISO survey.
Requirements in local voluntary specifications (see [Annex B](#)) show values < 15-16 (MJ/kg ar);
- Chlorine classed from 2 to 4 (more frequently classed as 2-3), based on the ISO survey.
Limit values < 1-1,5 (% in mass d) occur in local voluntary specifications (see [Annex B](#));
- Hg classed as 1, based on the ISO survey.
Maximum allowable concentrations in the range 1 – 1,7 (mg/kg d) can be found in local voluntary specifications (see [Annex B](#)).

The moisture and ash content of SRF are generally identified as relevant physico-chemical properties. Other than NCV, Cl and, to some extent, Hg, these are the only two parameters that seem to be the properties of main interest in the case of the solid recovered fuel RPF produced and utilized in Japan, as borne out by both the ISO survey and the statistical assessment of measured values ([D.2](#)). The local voluntary specifications in [Annex B](#) set maximum levels that fall in the range:

- Moisture (% in mass ar) < 25 – 30;
- Ash content (% in mass d) < 15 – 30.

General agreement with the set of obligatory chemical properties defined in the EN 15359 standard can be observed in the case of responses to the ISO survey and in the local voluntary specifications reported in [Annex B](#). The former includes Sn as an additional parameter for the fuel specification. Some of the latter set specifications for further chemical properties (e.g. Zn, Be, Ba, Se, Te).

All the voluntary specifications in [Annex B](#) provide limit values by mass. The following indicative limit values by energy can be derived for SRF:

- Hg (mg/MJ d) < 0,044 to < 0,068;
- Sum of Cd and Tl (mg/MJ d) < 0,497 to < 1,10;
- Sum of heavy metals (as previously) (mg/MJ d) < 61 to < 73.

6.3 Typical values for SRF

A valuable statistical assessment of typical values for SRF combusted in cement kilns was produced for the purposes of CEN/TR 15508, based on measured values from national sets of data from several European countries. Typical values for properties that are relevant for the classification of SRF (NCV, Cl, Hg and the sum of Cd and Tl) are given as a general reference (see [Table D.1](#)) and specifically for SRF with a low or high ash content (see [Table D.2](#)), as secondary fuels may take part in the substitution of raw materials in the cement industry and the ash composition is intended to meet the requirements dealing with the quality of the product.

The median values provided by energy, generally fall into the range:

- NCV (MJ/kg ar) 3,2 – 25,5;
- Chlorine (% in mass ar) 0.07 -1,7;
- Hg (mg/MJ ar) < 0,02 – 0,406;
- Sum of Cd and Tl (mg/MJ ar) < 0,12 - < 0,93.

Based on the ash content of the fuel, the derived range of medians are as follows:

- in the case of low-ash fuels
 - NCV (MJ/kg ar) 11,7 – 25,5;
 - Chlorine (% in mass ar) 0,04 - 1,7;
 - Hg (mg/MJ ar) 0,004 – 0,042;
 - Sum of Cd and Tl (mg/MJ ar) 0,008 – 0,121;
- in the case of high-ash fuels
 - NCV (MJ/kg ar) 3,2 – 10,0;
 - Chlorine (% in mass ar) 0,07 – 0,77;
 - Hg (mg/MJ ar) < 0,05 – 0,406;
 - sum of Cd and Tl (mg/MJ ar) 0,26 - < 0,93.

Reference ranges of average values for physico-chemical and trace elements measured locally are provided in [Annex D](#), some of which (see [Tables D.3](#) to [D.5](#)) also give a comparative view of values occurring in the hard coal or the pet-coke utilized in European cement kilns.

For the purposes of this document, a search for measured values for SRF utilized in cement kilns was carried out. The derived dataset covers quite many physico-chemical and chemical properties that characterize solid recovered fuels utilized in the cement industry of different European countries and Japan. The collected measured values characterize European SRF (a total of 74 assays) produced mainly from MSW (70 %) and from mixed waste streams, while all the analysed data for RPF (a total of 166 assays) refer to a solid recovered fuel that originates from industrial and commercial waste (ICW) streams only, essentially plastic and paper wastes, and with an end use in cement kilns and other co-incineration industrial facilities (paper and steel industry).

The monitored physico-chemical parameters show a generally good compliance with requirements for the fuel classification and specification in existing standards.

About 98 % of the assays provide a characterization of the ash content in SRF, a parameter monitored by all the assays in the case of the RPF.

Differences occur in the fuel specification for trace elements, especially for mercury (see [Annex D](#), [Figure D.1](#) and [D.2](#)). That heavy metal falls within the parameters required for the fuel classification according to EN 15359, while in the case of the RPF it is not a required parameter (only two of the collected assays really provide a measured value). Data provided by the Japanese producers of RPF show that the aluminium content of the fuel is assumed to be a relevant property for its end users.

Summary statistics (median and 80th percentile values) have been produced by processing the whole dataset of measured values (see [Table D.15](#)) and, individually, the subsets within it that specifically refer to a European SRF (see [Table D.17](#)) or to the Japanese RPF (see [Table D.16](#)). Moreover, measured values for SRF have been selected according to the fuel origin (MSW, ICW streams) and statistically processed (see [Tables D.18](#) and [D.19](#)). The lack of sufficient information in the dataset about the end-user plant (technology and feeding point) did not allow for a statistical analysis of measured values based on that criterion. Further details of the main statistical outcomes per fuel property are provided in [Annex D](#) ([Tables D.20](#) to [D.21](#)-a, b).

In summary, according to the available data sets of [Annex D](#), the following typical values can be derived for SRF produced and utilized in the European cement industry (median value):

— NCV (MJ/kg ar - MJ/kg d)	18,3 – 21,7;
— Ash (% in mass d)	15,1;
— Chlorine (% in mass ar)	0,58;
— Hg (mg/kg d - mg/MJ d - mg/MJ ar)	0,268 – 0,014 – 0,023;
— Cd (mg/kg d - mg/MJ d - mg/MJ ar)	0,750 – 0,031 – 0,057;
— Tl (mg/kg d - mg/MJ d - mg/MJ ar)	0,217 – 0,010 – 0,020.

Futher informations are available in [Annex D](#).

Depending on the origin of the European SRF, the following references for typical values have been obtained:

— in the case of MSW-SRF

— NCV (MJ/kg ar - MJ/kg d)	16,6 – 21,2;
— Ash (% in mass d)	17,1;
— Chlorine (% in mass ar)	1,27;
— Hg (mg/kg d - mg/MJ d - mg/MJ ar)	0,723 – 0,036 – 0,050;
— Cd (mg/kg d - mg/MJ d - mg/MJ ar)	1,060 – 0,050 – 0,078;
— Tl (mg/kg d - mg/MJ d - mg/MJ ar)	0,215 – 0,010 – 0,019;

— in the case of mixed-SRF

— NCV (MJ/kg ar - MJ/kg d)	21,4 – 23,7;
— Ash (% in mass d)	14,0;
— Chlorine (% in mass ar)	0,53;
— Hg (mg/kg d - mg/MJ d - mg/MJ ar)	0,200 – 0,009 – 0,010;
— Cd (mg/kg d - mg/MJ d - mg/MJ ar)	0,180 – 0,007 – 0,008.

Regarding the solid recovered fuel RPF, the measured values made available by Japanese producers provided the following references for typical values:

— NCV (MJ/kg ar - MJ/kg d)	26,6 – 23,1;
— Ash (% in mass d)	5,1;
— Chlorine (% in mass ar)	0,13;
— Al (mg/kg d - mg/MJ d - mg/MJ ar)	1 600 – 61,4 – 63,8.

7 Coal co-combustion in power plants

7.1 General

A brief description of the main technologies adopted in coal combustion power plants is given in [C.2](#).

Mandatory requirements for the use of SRF/RDF and other waste fuels in coal combustion power plants have been introduced in some national legislation. In Austria for example, (see [Table B.6](#)), limit values for trace elements legally apply to boilers employing predominantly hard coal or lignite and used for the generation of electricity and district heating. The Austrian legislation also limits the proportion of thermal output from the incineration of waste relative to the total thermal output to a maximum of 15 %. Mandatory requirements have also been legally set in Italy that apply to the use in well-defined power plants of the SRF referred to in the country as CDR-Q and CSS end-of waste (see [Tables B.10](#) and [B.11](#)).

Some national standards provide specifications for solid recovered fuels that apply to their use in coal co-combustion power plants. This happens for example in the case of: the CDR-Q (see [Table B.3](#)) and the CSS (see [Table B.4](#)) produced in Italy according to UNI 9903-01 and UNI/TS 11553; the SRFs that comply in Germany with the RAL-GZ 724 standard (see [Table B.2](#)) and, as already discussed, are largely produced and traded under the brand mark SBS^R 1 and SBS^R 2 for co-combustion with lignite in the former and with hard coal in the latter.

Regarding the environmental performance, coal co-combustion power plants should comply with emission limits legally set for polluting substances. As an example, common legal rules have been introduced in Europe through the *Industrial Emissions Directive*^[42] that gives, in particular, specific provisions for the emission of trace elements (Hg, Cd+Tl, sum of As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V; dioxins and furans) in such large combustion plants. Common rules have already been transposed by some European countries in their own legislation, even if different and/or more restrictive provisions may be required e.g. by local authorities in plant permits. In the USA, a federal law, the *Clean Air Act*, and the EPA CISWI standards^{[65],[66],[67]} regulate the emission of toxic air pollutants (Pb, Cd, Hg, dioxins, furans) from energy recovery units combusting solid waste or designed to burn solid (coal, biomass, waste)/liquid (waste)/gas.

7.2 End use requirements for SRF and other waste derived fuels

7.2.1 Technical limitations of the technologies

Wastes generally contribute to the fuel feedstock of coal co-combustion power plants at a rate lower than 10 % on a thermal basis; higher rates are usually associated with fluidized bed boilers or the co-incineration of separately pulverized wood waste in pulverized coal-fired boilers.^[69] The substitution of conventional fuels with solid recovered fuels depends on the compatibility of properties of the RDF/SRF with the thermal recovery process, typically designed for fossil fuels.

Requirements can vary according to the plant design and the type of coal but are generally higher than alternative options for RDF/SRF thermal recovery, e.g. their incineration especially in grate boilers.

The easiest way to introduce waste into the combustion process is by mixing it with the main fuel and burning it in the combustion chamber or boiler. This may lead to technical and/or environmental constraints in the combustion plant related to the milling and drying capacity of existing solid fuel mills (if the waste is dried and pulverized together with the main fuel) and to the feeding of the waste. In a solid-fuel-fired boiler, fuel/waste mixing is possible in the following locations: on the fuel conveyor belt; in the fuel bunker; in the fuel feeder; at the fuel mill; on the pulverized fuel lines. In the first three cases, the waste is spread over the main solid fuel to achieve adequate mixing of the fuel/waste streams. This results in grinding of the waste together with the main fuel in the coal mill. Due to grinding behaviour constraints, this technique is usually only associated with dried sludge. It is only possible to apply this technique when the grinding behaviour of both fuel and waste are more or less the same or when the amount of waste is very small compared with the main fuel flow.

Wastes that are shredded separately from the main fuel can be injected into the fuel mill or into the pulverized coal pipelines between the coal mill and the boiler. Liquid wastes are typically blended with liquid fuels before the mix is used. Separate lances or modified existing burners (separate feeding of the waste to the burners) are required to handle waste that cannot or is not intended to be mixed with the main fuel or to increase the percentage of waste. This occurs when the waste has different physical properties (e.g. viscosity, particle size) or may cause health risks (sewage sludge).

The burners are specially designed for the fuel/waste in order to achieve good ignition, a stable flame, and good mixing with the main fuel flame in the boiler. The location of these burners in relation to the main burners is important for good burnout of the fuel.

General references for some properties of interest from a technical and environmental point of view, when SRF is co-combusted in power plants with different boiler technologies, are summarized in [Table 5](#)^[119].

In *pulverized coal combustion plants* (DBB and WBB), the raw coal and other solid fuels utilized as feedstock are properly prepared to ensure optimal performance of the process and pulverized (or the liquid fuels atomized) before combustion.

Solid fuels are dried to reduce the moisture content, where high; that step is typically required in the case of a sewage sludge with moisture contents exceeding 50 %. The waste fuels are also grounded (lignite particles are typically reduced to less than 90 µm, for example). Fine grinding ensures rapid ignition and complete combustion to achieve maximum efficiency and minimize ash and particulate deposits on heat-exchanger surfaces. Waste milling to less than 75 µm is typically required in pulverized fuel-fired boilers^[69].

Pulverized hard coal-fired plants with wet-bottom boiler types (WBB) are considered more tolerant to the shape and dimensions of SRF, in comparison to plants with dry-bottom boilers (DBB)^[119].

Table 5 — Reference data for the quality of SRF utilized in coal fired power plants and in other fluidized bed combustion plants [data from^[119]]

Parameter (Unit)	Pulverized coal power plant	Hard coal DBB power plant	Hard coal WBB power plant	Brown coal (lignite) power plant	FBC
Form	Soft pellets Hard pellets			Soft pellets	Fluff Soft pellets Hard pellets
Bulk density (Mg/m ³)	0,35	range 0,24 - 0,35	range 0,24 - 0,35	0,35	
Particle size (mm)	range 10-25 median 20 < 25	range 10 - 25 median 20 < 25 < 20	range 10 - 25 median 20 < 25 < 20	range 10 - 25 median 20 < 25	range 10 - 150 median 50
Cl content (% in mass d)		< 1 (depending on the S content) mean 0,6 max 1,3	< 1 (depending on the S content) mean 1,1 max 2,5	< 1 (depending on the S content) mean 0,5 max 0,6/1,0	mean 0,4 (ar) max 0,5/0,8/1,4
Hg (EN 15359 class)		class 1 to 2	class 1 to 2	class 1 to 3	class 1 class 1 to 4, when with activated carbon equipment
KEY - DBB: dry-bottom boiler - WBB: wet-bottom boiler - FBC: fluidized bed combustion plant					

Table 5 (continued)

Parameter (Unit)	Pulverized coal power plant	Hard coal DBB power plant	Hard coal WBB power plant	Brown coal (lignite) power plant	FBC
NCV, (MJ/kg, ar)	range 16 - 19 range 11 - 17 median 17 min 14	> 20 mean 13,5 range 11 - 18 range 16 - 19 range 11 - 17 median 17 median 14	> 20 mean 17 range 13 - 22 range 16 - 19 range 11 - 17 median 17 median 14	> 11 mean 13,5 range 11 - 18 range 16 - 19 range 11 - 17 median 17 median 14	mean 13,5 range 11 - 18 range 6 - 18 median 14,5
Ash		Low	Low	Can be high	
Contrary mate- rials		Fe and non Fe free 3D particle free	Fe and non Fe free 3D particle free	Fe and non Fe free	
KEY - DBB: dry-bottom boiler - WBB: wet-bottom boiler - FBC: fluidized bed combustion plant					

In the case of *fluidized bed combustion*, fuels are not necessarily pulverized or dried when used. Due to the combustion temperatures and the long residence time, the burnout of the fuel is very high and therefore the related emissions of combustion products are relatively low.

Fluidized bed combustion plants need waste fuels to be crushed: based on fuel properties, maximum grain sizes of between 3 mm and 20 mm are reported as suitable. On a general basis, fluidized bed boilers require mechanical milling (size reduction) of the solid waste so as to facilitate feeding into the bed and ensure good performance of the process. In that respect, a need for a particle size typically no larger than 100 mm is reported^[69].

That type of boiler can tolerate fuels with a high moisture content (stabilizing effect of the bed) but not fuels with a low ash melting point (as the fluidization can be quickly disturbed by the accumulation of melted ash; plastic foils, for example, have a lower melting point and can melt in the coal mill, which leads to technical issues) and fuels with heavy physical impurities such as metal particles which can occur in domestic, commercial or industrial wastes if not well pre-treated (they disturb fluidization and are difficult to remove from the furnace).

Metallic particles in the fuel feedstock are to be avoided to prevent mechanical damage or obstruction.

Bubbling fluidized bed combustion boilers are considered highly suitable for the combustion of non-homogeneous biofuels. A particle size distribution in the fluidizing bed that falls in the range 0.5–1.5 mm typically occurs, with smaller particles being carried out with the fluidizing gas flow, while larger particles go down to the distribution plate^[69].

Waste co-incineration can have an impact on plant energy efficiency and performance, emissions to air and water and the quality of the combustion residues. The main potential effects can be associated with the size, the moisture and the ash content of the waste fuel, the sulfur and chlorine content, the heavy metals content and the alkali content. A suitable choice, pre-treatment or pre-conversion of the waste, or a limited degree of waste co-incineration, can help to prevent these effects.

The conversion efficiency of wastes can be influenced by their calorific value, ash and moisture content and reactivity, as well as by the grindability and the efficiency of the required waste pre-treatment process. The waste can also influence the energy conversion of the main fuel, e.g. due to excess air being required to ensure proper combustion, a change in the flue-gas temperature and flow in the boiler or increased unburnt carbon in the fly ash. A decrease in the nominal load or the load control speed of the power plant, corrosion and erosion of boiler parts due to the sulfur and chlorine content of the waste, slagging and fouling due to the alkali content and the melting trajectory of the ash, are issues that can

affect the plant performance. The designed capacity of the combustion units, the combustion properties of the waste – e.g. ignition, flame stability, flame temperature, NO_x formation and burnout, that may differ from those of the main fossil fuel – disruptions induced by waste (e.g. corrosion and erosion, slagging and fouling) and the thermal behaviour of the boiler can affect both the energy efficiency and the performance of the power plant.

With respect to technological issues, operational experiences in several power plants in Germany^{[120],[121]} seem to emphasize that a failure of the co-firing of SRF (from both MSW and ICW-SRF) can occur in pulverized power plants, mainly due to an incomplete burnout or collapse of combustion and to chlorine corrosion. These items are possible final exclusion factors for the use of SRF in pulverized power plants.

Again, fouling and slagging induced by SRF/RDF are assumed to be a possible permanent limiting factor, and the same is true for the potential increase in the chlorine load of the flue gas (due to the need for economic investment; retrofitting of emission control systems, mainly at CFB plants). Other problems experienced – e.g. fuel dosing, mechanical damage due to metallic contaminants in the fuel, chemical and thermal problems due to the aluminium content in CFB boilers, erosion of boilers and ash formation are, on the other hand, regarded as manageable issues, through optimization of SRF production so as to increase its quality and/or an improvement of plant components.

On the matter of the emission of air pollutants, the content of Hg in wastes is one of the most critical factors because of its high volatility. Due to the limitation of the waste input (only a few per cent of the total thermal input of a power plant generally come from wastes), the raw gas concentration of Hg is reported not to change significantly with respect to pure coal-fired power plants.^[69] The emitted loads can, however, increase by means of the higher flue-gas volumes. For other metals, such as Pb, Co, Tl, and Se, a potential increase of air emissions is reported^[69].

Transfer factors from SRF to the waste gas (TFs for Hg, sum of Cd and Tl, sum of heavy metals) have been provided in CEN/TR 15508,^[116] based on data from Dutch plants. These TFs refer to SRF utilized in hard/brown coal fired power plants with a dry bottom (DBB) or a wet bottom (WBB) boiler. Based on such TFs, maximum possible concentrations in SRF have been proposed in the document, as orientation values (see [Table B.17](#)).

The air emissions from coal-fired plants of volatile organic compounds such as dioxins and furans is typically low; it is due to the specific combustion characteristics and the sulfur content of fuels which impedes the formation of these compounds, even when wastes (urban, commercial, industrial or solid recovered fuels) that contain these pollutants or their precursors and have a quite high chlorine content are co-combusted^[69].

Regarding combustion residues from waste co-incineration, their utilization or disposal is an important economic factor; power plants control their quality by limiting the input of waste into the firing system and by monitoring waste parameters such as the content of alkalis, sulfates, chlorides, silicates, unburnt carbon and metals. Technical quality is considered: it is defined by various parameters (e.g. stiffness, porosity, particle size, moisture content, chloride, phosphorus, sulfate and carbon content) that determines their usability as a by-product. Environmental quality is considered too, that is related to how pollutants can leach from the product in which residues are utilized.

The impact of co-incineration on the quality of residues and by-products has been investigated in some countries. Due to the high removal rates of the dust control techniques applied in large combustion plants, more than 99 % of elements are found in the ashes. Generally, changes in the composition of the fuel can result in equivalent changes in the composition of the ashes; based on their volatility, a redistribution of elements can take place, resulting in a different concentration in the fly ash and in the bottom ash.^[69] The ash composition can therefore change according to the waste composition.

Metals present a risk of leaching into the environment. This is less significant in relation to the fly ash when used in immobilized applications, e.g. in the cement and concrete industry. Bottom ash, utilized for example as a layer under a road, can leach trace elements in the long term: a shift in composition and leaching may be a constraint on the application of bottom ash from waste co-incineration. The immobilization and stabilization of metals in residues are taken into account, as well as the calculation of the total content. Comparative data on the effect on combustion residues of waste co-incineration

(specifically, co-firing of sewage sludge at a share of 10 %) and of the combustion of conventional fuels (coal) alone,^[69] highlighted a relatively low risk of mobilization in the residues for metals. An increase of the content of Hg, Pb and Cd in the fly ash dry sorption residue and of Pb, Zn, Cu and Cr in the coarse was observed, while the leaching behaviour result was not significantly influenced, in particular when the residues had been stabilized.

Gypsum is a by-product that can be affected by a change in the composition of the fuel. The leaching risk is assumed to be small,^[69] due to its main use being inside buildings, where contact with water does not occur.

7.2.2 Quality requirements in plant permits

An example of SRF specifications issued in plant permits, not properly updated (year 2005), was found (see [Table B.13](#)). As already mentioned for cement kilns ([6.2.2](#)), it shows requirements set for the use of an SRF produced from high calorific fractions of MSW in both power plants and cement kilns in Germany^{[68],[110]}.

The chosen trace elements are well aligned with the requirements for SRF established at that time by the national RAL GZ 724 standard (see [Table B.2](#)). If compared with specifications set in EN 15359, and today in ISO 21640 (see [Table 3](#)), all the obligatory chemical properties are included, with the addition of Sn and Zn. Limit values for trace elements are defined by mass, as both a practical (typical value: to be compared with 50th percentile value for a defined lot) and a maximum permitted value (to be compared with the 80th and 90th percentile values for a defined lot). The reported “practical” values substantially coincide with the limits (median) set in RAL GZ 724: 2008²⁾, with the exception of a lower value being required in the case of Co.

7.2.3 Quality requirements in general guidelines

Valuable orientation values for trace elements in SRF have been proposed in CEN/TR 15508, as maximum possible concentrations by energy for DBB and WBB coal fired power plants (see [Table B.17](#)). These values have been derived according to the evaluated transfer factors and take into account the type of fossil fuel (hard coal, in WBB plants; hard and brown coal, in the case of DBB plants).

On the whole, the proposed maximum possible concentrations, expressed by energy, are:

- Hg (mg/MJ ar) 0,034/0,65 (hard coal) - 0,085 (brown coal);
- Sum of Cd and Tl (mg/MJ ar) 0,25/1,21 (hard coal) - 1,21 (brown coal);
- Sum of As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V (mg/MJ ar) 34/106 (hard coal) - 170 (brown coal).

As discussed in [7.2.4](#), CEN/TR 15508 also provides general references on the net calorific value and the chlorine content of SRF utilized in brown and hard coal power plants that are based on data from voluntary specifications.

Specifications defined in Germany to approve a trade mark SRF suitable for an end use in lignite power plants, (the SBS^R 1), and in hard coal power plants, (the SBS^R 2), could be considered as further general guidance (see [Table B.20](#)). Regarding the physico-chemical properties of that traded SRF, the following specifications are given:

- NCV (MJ/kg ar) in the range 13 - 18 (lignite power plants),
in the range 18 - 23 (hard coal power plants);
- Chlorine (% in mass d) <0,7 (lignite power plants),

2) The RAL GZ: 2008 has been replaced by RAL GZ 274:2012, which defines the quality requirements in relation to energy.