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A CLASSIFICATION SCHEME TO DEFINE THE QUALITY OF WASTE DERIVED FUELS

EXECUTIVE SUMMARY

This classification scheme aims to provide unambiguous and clear classification of waste derived fuel (WDF) properties for use by energy from waste (EfW) facilities. The system is designed to help fuel users define the fuel parameters of WDF they need to power their facilities, by the use of a system of 'Classes'. The system will also help fuel producers to classify their WDF in terms of the same Classes and therefore the potential end user is able to analyse the data to determine whether they can accept the WDF within their facility. This will enable direct and efficient trading of WDF and facilitate a good understanding between the seller and the buyer. The scheme is not intended to define end of waste criteria for waste derived fuels

The system classifies the fuel properties of WDF against 3 main criteria: economic, technical and environmental, within each of which are the key factors in need of determination:

- **Economic attributes:** characteristics that will affect the economics of the fuel's usage:
  - calorific value;
  - biomass* content; and
  - moisture content.

These determine the value of the fuel and any potential incentive payments.

- **Technical attributes:** characteristics that will affect the performance of the combustion facility:
  - chlorine (Cl) content which causes corrosion and fouling;
  - ash content which affects melting and sintering temperatures; and
  - bulk content which affects transport/space and infeed levels.

The facility will need to be designed to handle WDF with these qualities.

- **Environmental attributes:** characteristics that will influence emissions to the environment:
  - mercury (Hg);
  - cadmium (Cd); and
  - other heavy metals.

Failure to manage the environmental attributes may result in harmful emissions if not properly abated.

ACKNOWLEDGEMENTS

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The TAG consisted of the following members:

- Philip Cozens, Progressive Energy Ltd;
- Liam Oldershaw, Systems 4 Recycling;
- Will Spurr, Waste Recycling Group;
- Claire Downey, Indaver Ireland Ltd;
- David Lawrence, Lawrence Recycling; and
- Simon Little, Powerday.

* For the scope of this report, the term "biomass" is used to mean 'biogenic content of contemporary origin', but 'biomass' has been used as this is the more recognised industry-wide term. The more technically correct term 'biogenic' refers to the proportion of carbon present within the material which can be defined as the carbon isotope C-14 ('new' carbon which was absorbed from the atmosphere) as opposed to the somewhat decayed over time C-12 ('fossil' carbon which has been stored in the earth's crust for a minimum of 6,000 years). C-14 is sourced from wood, paper, cardboard and energy crops, and C-12 is sourced from coal, oil and gas (and their derivatives).

1.0 DEVELOPING A CLASSIFICATION SCHEME FOR WASTE DERIVED FUEL

1.1 Background

Recovering energy from waste (EfW) is playing an increasing role in generating 'low carbon' energy and will support achievement of the UK's target of 15% of its energy from renewable sources by 2020. This project is part of WRAP's EfW programme, the objective of which is to address market failures relating to a lack of information. One of the current unknowns in the sector is the quality and variability of waste derived fuels (WDF). As this is a relatively immature sector unfamiliar fuels could create a level of uncertainty and a lack of confidence amongst users, leading to limited market development and poor market confidence. This project seeks to address the barriers by defining a system of classification for WDF which clarifies the quality required for different end uses or the quality of the fuel actually produced. This system would assist in a number of ways by:

- producing a common understanding between producers and buyers;
- providing a measure/definition of fuel quality;
- defining a simple language to be used when describing the fuel; and
- ensuring the fuel is fit for purpose for use with the technology in place or planned.

The scheme is specifically aimed to help SMEs that either produce WDF, plan to utilise it for energy production or supply it to a third party fuel user. The TAG indicated that industry recognises that a formal classification scheme is necessary for supporting the use of WDF and to establish and maintain market confidence.

Classifying WDF could help businesses to assess the benefits of substituting fossil fuels in industrial plants, and will enable its quality to be compared with other WDF and virgin fuels based on a number of parameters.

The development of this classification scheme was made possible by the creation of a Technical Advisory Group (TAG) which was put together to ensure all recommendations and decisions were taken in the wider interests of industry representatives. It consisted of members of WDF producers, WDF users, energy from waste (EfW) industry experts and technology providers. The project has relied upon their significant experience and knowledge of the industry and the scheme was developed with the knowledge of, and agreement from, all members of the TAG.

1.2 Introduction

The classification scheme for WDF aims to help fuel producers and users to identify the appropriate specification to use when characterising the quality of WDF. This scheme can assist businesses and organisations operating and supplying gasification, pyrolysis, incineration and co-incineration plants in defining the minimum quality of the WDF required for their process. This classification scheme has been developed following extensive research into existing standards, specifications and quality criteria for WDF including publicly available specifications. A list of the current standards available for solid recovered fuel (SRF), refuse derived fuel (RDF) and biofuels is shown in the reference section.

The existing European standards (CEN 343) define the quality criteria for a wide range of WDF. Although these standards can be used to define the fuel quality of WDF, they do not guarantee market confidence in the use of WDF to generate energy in smaller scale facilities. For example, the European standard BS EN 15359: 2011[9] which defines the quality criteria for SRF was developed using data from large industrial WDF users such as cement kilns and coal fired power plants, therefore some of the classes are not appropriate for smaller scale EfW facilities which have tighter fuel requirements to ensure they are economically viable and to ensure permitting regulations are not breached.

This was confirmed by the Technical Advisory Group TAG and the scheme as shown in Section 3.0 was developed to address that.

1.3 What is waste derived fuel?

For the purpose of this project's classification scheme, WDF is defined as 'A heterogeneous group of non-hazardous wastes that do not cease to be such by virtue of their being used to generate energy without a greater negative environmental impact than landfill disposal'.

To improve the marketability of WDF, the industry adopted the term 'solid recovered fuel' (SRF) for waste fuels that meet a tighter quality specification.

The term 'refuse derived fuel' (RDF) is generally used to define unspecified waste after basic processing to increase the calorific value (CV) of municipal solid waste (MSW), commercial or industrial waste materials.

1.4 Scope of the classification scheme

The wastes listed below are considered to be outside the scope of this scheme:

- Products from anaerobic digestion (AD) – the markets for biogas and digestate are normally readily available and accessible. Work in this area is covered by a separate programme within WRAP.
- Untreated municipal solid waste (MSW) -treatment of MSW increases the recovery rates of certain materials and therefore only post-treatment residual MSW is considered within the scope of this scheme.
- Hazardous wastes (other than waste oil) - defined in the Environment Agency document 'Hazardous Waste: Interpretation of definition and classification of hazardous waste (2nd edition v2.3)'.
- Wastes that currently fall outside the scope of Waste Framework Directive (2008/98/EC): - These are:
    - a. gaseous effluents emitted into the atmosphere; and
    - b. where they are already covered by other legislation;
        - i. radioactive waste;
        - ii. animal carcasses, faecal matter and other natural, non-dangerous substances used in farming; and
        - iii. decommissioned explosives.
        - iv. Any waste material which is subject to an end of waste criteria under the waste protocols project. The development of this scheme is not in any way attempting to define end of waste

2.0 THE DEVELOPMENT AND NATURE OF THE CLASSIFICATION SCHEME

2.1 Introduction

This system has been designed to assist WDF producers and users to define the variables which will classify their WDF. This system identifies existing European Quality Standards and defines a classification system for WDF that can be applied to fuel for smaller scale EfW facilities. Where appropriate the existing European Standards should be applied (see Figure 1 for decision tree to help highlight which system to use).

In addition to this classification system, the British Standards and specifications also considered are:

- British Standard for SRF - BS EN 15359: 2011; and
- British Standard for solid biofuels - BS EN 14961-1: 2010.

Further detail on each of the standards is included in Appendix 1

The specification and classes for defining the quality of WDF are determined by the appropriate quality standard. The 'quality' of a fuel can be defined by a number of variables. Key parameters include:

- calorific value (CV);
- moisture content;
- ash content;
- levels of undesirable material contamination;
- physical properties; and
- chemical properties.

These parameters are required by the EfW operators to define the minimum quality of WDF that can be accepted within their process. The parameters required for defining the quality of WDF and the limit value of each parameter for their particular application will vary according to the operating parameters of the end user of the fuel. Within this classification scheme the end users shown in Section 2.2 are considered.

2.2 End users considered within this classification scheme

The main end users considered as appropriate to use this scheme are:

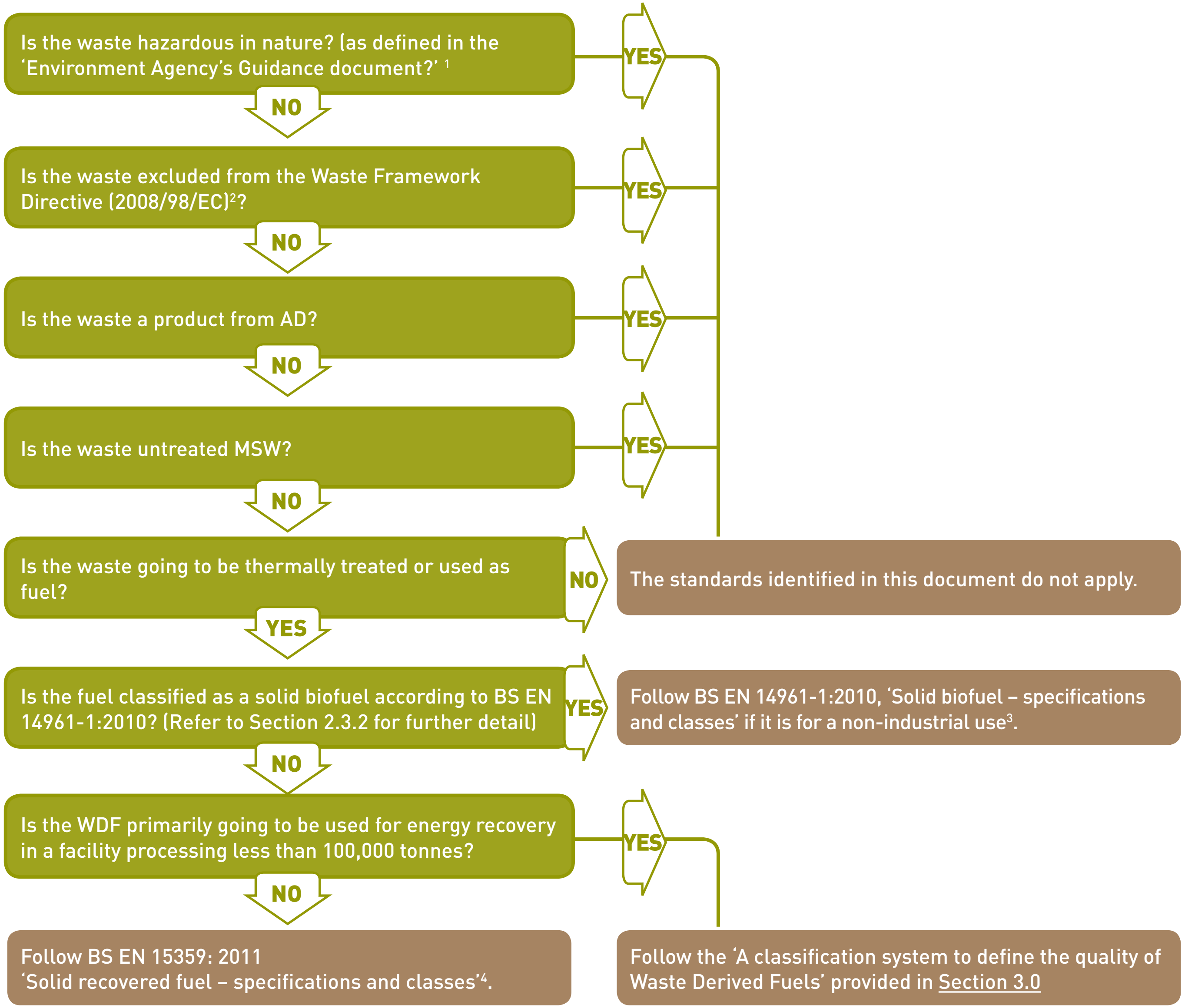
- fluidised bed and moving grate combustion plants;
- advanced thermal treatment users (mostly, but not exclusively, gasification and pyrolysis)
- cement kilns; and
- coal-fired power plants.

More detail is available on these technologies in Appendix 2

To identify the quality standard that is applicable for each type of WDF, it is necessary to understand the nature of the WDF, the proposed end use of the fuel and the scope of each quality standard included within this framework. The decision tree illustrated in Figure 1 contains a series of questions on the nature of WDF and its end use. Depending on the answers for each question, the appropriate quality standard which should be followed to define the quality of a particular fuel can be determined.

Once the usage of the classification scheme has been confirmed, the producer/supplier can follow the guidance supplied to specify the relevant Classes of WDF as detailed in Section 3 and summarised in Appendix 3.

Figure1: Decision tree to determine the most suitable classification scheme - footnote - Please note the usage of any classification scheme is non-obligatory.



1 A guide to the Hazardous Waste Regulations and the List of Waste Regulations in England and Wales, Environment Agency 2008 (http://publications.environment-agency.gov.uk/PDF/GEHO0506BKTR-E-E.pdf)
2 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:EN:PDF
3 http://shop.bsigroup.com/ProductDetail/?pid=000000000030200086
4 http://shop.bsigroup.com/ProductDetail/?pid=000000000030202007

3.0 CLASSIFICATION OF WASTE DERIVED FUELS FOR USAGE IN SMALL SCALE ENERGY FROM WASTE FACILITIES

3.1 Introduction

This classification scheme aims to provide unambiguous and clear classification of waste derived fuel (WDF) properties for use by small scale EfW facilities. The system is designed to help fuel users define the fuel parameters of WDF they need to power their facilities, by the use of a system of 'Classes'. The system will also help fuel producers to classify their WDF in terms of the same Classes and therefore the potential end user is able to analyse the data to determine whether they can accept the WDF within their facility. This will enable direct and efficient trading of WDF and facilitate a good understanding between the seller and the buyer.

The system classifies the fuel properties of WDF against 3 main criteria: Economic, Technical and Environmental, within each of which are the key factors in need of determination:

- Economic attributes: characteristics that will affect the economics of the fuel's usage:
  - biomass content;
  - calorific value; and
  - moisture content.

These determine the value of the fuel and any potential incentive payments.

- Technical attributes: characteristics that will affect the performance of the combustion facility:
  - chlorine (Cl) content which causes corrosion and fouling;
  - ash content which affects melting and sintering temperatures; and
  - bulk content which affects transport/space and infeed levels.

The facility will need to be designed to handle WDF with these qualities.

- Environmental attributes: characteristics that will influence emissions to the environment:
  - mercury (Hg);
  - cadmium (Cd); and
  - other heavy metals.

Failure to manage the environmental attributes may result in harmful emissions if not properly abated.

3.2 Economic attributes

The economic attributes of the WDF are those variables which will affect the financial value of the fuel (in terms of energy generation, gate fees and the ability to claim revenue from Government incentive schemes such as Renewable Obligation Certificates - ROCs). The economic attributes covered by the scheme are:

- biomass content (wt% as received basis);
- net calorific value (MJ/kg as received basis);
- moisture content (wt% total).

The reasons for the inclusion of each of these parameters within the economic characteristics of the classification scheme and the limit values for each class are explained in the following sections.

3.2.1 Biomass content 'as received' (ar)

The biomass content of WDF consists of its biodegradable fraction and is usually represented by the percentage of biogenic carbon (C-14) in comparison to the total carbon present in WDF. Biomass content is considered within the economic characteristic because:

- The electricity and/or heat generated from the biodegradable fraction of waste is characterised as renewable energy and may be eligible for receiving ROC or RHI payments from the government.
- Knowing the biomass/biodegradable content of waste could help operators and end users quantify the landfill cost saved as a result of diversion of these wastes from landfill.

Classification

Table 1 sets out the classification categories for the biomass content of WDF expressed as wt/wt% as received.

Table 1: Biomass content classification

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Biomass content (as received)	wt/wt% (mean)	≥90	≥80	≥60	≥50	<50

3.2.2 Net calorific value 'as received' (ar)

The calorific value of any fuel describes the amount of heat or energy generated when it is completely combusted. It is expressed as a gross calorific value (GCV) and net calorific value (NCV). NCV is determined by calculation and is equal to the GCV minus any heat lost due to moisture present in the fuel and various chemical processes. The NCV is more representative of the heat available in practice when fuels are combusted in boilers and furnaces. The NCV (ar) ensures that the calorific value takes account of the moisture content as received at the laboratory before any processing or conditioning takes place, giving a more representative result.

Classification

Table 2 sets out the classification categories for the NCV content of WDF expressed as MJ/kg as received.

Table 2: Net calorific (as received) value classification

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Net calorific value (as received)	MJ/kg (mean)	≥25	≥20	≥15	≥10	≥6.5

3.2.3 Moisture content 'as received'

Moisture content is used to describe the water present in WDF. Moisture content is included in the economic attributes as the amount of moisture present in WDF impacts on the NCVar. The heating value of the fuel decreases with increased moisture content (2009[25]). In addition, moisture content is an important fuel parameter as:

- a higher moisture content increases the volume of flue gas produced per energy unit, requiring larger waste heat boilers and flue gas cleaning equipment;
- high moisture content will reduce the combustion temperature, hindering the combustion of the reaction products resulting in higher emissions (2004 [21]) and higher fuel quantities. Supplementary fuel may also be required to maintain combustion temperature; and
- the presence of moisture in WDF will influence the behaviour of the waste during the primary conversion stage in a gasification/pyrolysis plant and will also impact on the properties and quality of the syngas produced.

Classification

Table 3 sets out the classification categories for the moisture content of WDF expressed as % wt/wt.

Table 3: Moisture content classification system

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Moisture content	% wt/wt (mean)	≤10	≤15	≤20	≤30	<40

3.2.4 Summary of economic attributes

The classification system for describing the economic characteristics of WDF is summarised in Table 4.

Table 4: Classes for economic attributes of WDF

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Biomass content (as received)	% (mean)	≥90	≥80	≥60	≥50	<50
Net calorific value (as received)	MJ/kg (mean)	≥25	≥20	≥15	≥10	≥6.5
Moisture content	% wt/wt (mean)	≤10	≤15	≤20	≤30	<40

3.3 Technical attributes

The chemical and physical properties of WDF are important as they can affect the performance of an energy from waste facility. The parameters of WDF that can have a significant effect on the normal operation of the EfW plant are grouped within this attribute. These properties are important as they affect the operational parameters that are set for using the incoming fuel. The parameters included within the technical characteristics of WDF are:

- chlorine content (% wt/wt dry basis);
- ash content (% wt/wt dry basis); and
- bulk density (kg/m3 as received basis).

Moisture content could also be considered within the technical attribute as it can cause ignition issues, but as the influence of moisture content on the economic attributes is higher than it is on the technical attributes, it is included only within the economic parameter to avoid overlap. The reason for including all the above parameters within the technical attributes of this classification scheme and the limit values for each class are explained in the following paragraphs.

3.3.1 Chlorine content

Burning WDF with a high chlorine content can cause corrosion, slagging and fouling in boilers. The presence of chlorine can also increase emissions of hydrochloric acid (HCl) and cause the formation of Polychlorinated Dibenzodioxins (PCDD) and Polychlorinated Dibenzofurans (PCDF). Chlorine is a highly electro-negative halogen and is typically present in the following wastes:

- organic food waste which contain salts such as sodium chloride (NaCl) and potassium chlorides (KCl);
- plastic bags which are halogenated;
- polyvinyl chloride (PVC) which are present in pipes, insulation cables, and as a substitute for painted wood, films etc.;
- paper and wood pulp which have been bleached; and
- industrial solvents (e.g. degreasers, cleaning solutions, paint thinners, pesticides, resins and glues).

Most of these wastes can be present in WDF and higher amounts would result in higher chlorine content. The chlorine content of the whole of the fuel can be diluted by mixing with other waste fractions other than those listed above.

Classification

The thresholds for each classification category for chlorine content are taken from the existing standard BS EN 15359: 2011[9] and set out in Table 5. Chlorine content should be expressed as % wt/wt (dry).

Table 5: Chlorine content classification system

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Chlorine content (dry)	% wt/wt (mean)	≤0.2	≤0.6	≤0.8	-	-

3.3.2 Ash content

Ash is the inorganic and incombustible mineral fraction of WDF that is left after complete combustion. The mineral fraction consists of non-combustible minerals which are contained in the fuel and contaminants which can be added to the fuel during processing, such as dirt and dust. Typical elements present in ash are silicon (Si), aluminium (Al), iron (Fe), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulphur (S) and phosphorous (P). The concentration of each element varies according to the composition of the WDF. Ash content is included within the technical attributes of WDF because:

- WDF containing a high ash content will require an efficient dust removal system to reduce the amount of particulate emissions;
- WDF with a high ash content will have a lower calorific value; and
- the ash sintering, softening and melting temperature is determined by its elemental composition and therefore it is an important characteristic in determining the combustion temperature to avoid problems with ash handling.

Classification

The thresholds for each classification category for ash content are based on a review of the data available in technical report CEN/TR 15508: 2006, 'Key properties on solid recovered fuels to be used for establishing a classification system'[1] and 'Refuse Derived Fuel, Current Practice and Perspectives', European Commission, 2003[23] and is set out in Table 6. Ash content should be expressed as % wt/wt (dry).

Table 6: Ash content classification system

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Ash content (dry)	% wt/wt (mean)	≤10	≤20	≤30	≤40	<50

3.3.3 Bulk density

Bulk density is defined as the mass of the fuel that can occupy a specific volume. Bulk density is considered to be the most important physical property of a fuel for both economic and technical reasons. The bulk density of WDF is determined by the fuel preparation technique employed. This can include sorting, biological treatment, crushing, grinding, shredding, separation, screening, drying, compacting etc. Bulk density is included within the technical attributes as WDF with a lower bulk density can have the following disadvantages[25]:

- the calorific value per unit volume is lower when bulk density is low;
- controlling the process may be difficult;
- feeding control has to be accurate;
- a large amount of space may be required to store the WDF;
- transport costs may be increased as more WDF would be required; and
- WDF with a low bulk density may be unsuitable for some technologies.

Some WDF applications require a lower bulk density to enable the WDF to be blown into the furnace using air pressure.

Classification

The thresholds for each classification category for bulk density are based on a review of the data available BS EN 14961-1: 2010, 'Solid biofuels – Fuel specification and classes – Part 1: General requirements' [3] and CEN/TS 15401:2010, 'Solid recovered fuels - Determination of bulk density' [11] and is set out in Table 7. Bulk density should be expressed as kg/m3 (as received).

Table 7: Bulk density classification system

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Bulk density (as received)	kg/m3 (mean)	>650	≥450	≥350	≥250	≥100

3.3.4 Summary of technical attributes

The classification system for the technical attributes of the WDF is summarised in Table 8.

Table 8: Proposed classes for technical attributes of the WDF

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Chlorine content (dry)	% wt/wt (mean)	≤0.2	≤0.6	≤0.8	-	-
Ash content (dry)	% wt/wt (mean)	≤10	≤20	≤30	≤40	<50
Bulk density (as received)	kg/m3 (mean)	>650	≥450	≥350	≥250	≥100

3.4 Environmental attributes

Some elements present in WDF can cause harmful emissions when thermally treated and these elements are included within the classification of environmental attributes. The elements considered are:

- mercury (mg/MJ as received basis);
- cadmium (mg/MJ as received basis); and
- other heavy metals (mg/MJ as received basis).

It should be noted that the environmental performance of a plant generating energy from WDF is not only determined by the composition of WDF but is also influenced by the design, operating procedures, permitting requirements and type of flue gas abatement technology used. The classification of environmental attributes in this classification scheme alone will not give the end-user sufficient information to assess the impact on emissions from the facility. It should be noted also that biomass content, whilst listed within this scheme as an 'economic attribute', also provides environmental benefits in the usage of biogenic carbon over fossil carbon, but biomass content is listed only under economic attributes to avoid overlap.

The actual emissions from the facility will depend on the relationship between the input and output of these elements within the WDF which is termed as the transfer factor. The transfer factor will be different for each facility and technology and end-users are advised to carry out a study to determine the transfer factors for each element mentioned. A detailed description of the transfer factor and information on how these can be measured can be found in CEN/TR 15508:2006, 'Key properties on solid recovered fuels to be used for establishing a classification system'[1].

3.4.1 Mercury Content

Mercury (Hg) is a heavy metal and is toxic to the environment and human health. Mercury is typically found in the following types of wastes:

- industrial sludge and filter cake; and
- Waste Electrical and Electronics Equipment (WEEE).

Mercury is included in environmental attributes because of its high vapour pressure and volatility which can allow it to escape with the flue gas upon combustion. Mercury has been recognised as one of the most significant global environmental pollutants because of its middle and long term impacts on health[31].

Classification

The classification of mercury content of WDF is shown in Table 9.

Table 9: Mercury classification

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Mercury (Hg) (as received)	mg/MJ (Median)	≤0.02	≤0.03	≤0.06	-	-
	mg/MJ (80th percentile)	≤0.04	≤0.06	≤0.12	-	-

3.4.2 Cadmium Content

The heavy metal cadmium (Cd) is included in the environmental attributes because its toxicity and accumulation in agriculture has the potential to damage human health. Cadmium is a metal that is volatised as chlorides and oxides during combustion. Cadmium is typically present in the following wastes:

- paints and industrial solvents;
- WEEE including batteries; and
- electroplated metals.

The technical report CEN/TR 15508:2006, 'Key properties on solid recovered fuels to be used for establishing a classification system'[1] collected extensive data on the cadmium content of SRF derived from a number of sources and included a classification system for cadmium.

Classification

The threshold for each classification category for cadmium content, other than Class 5 is taken from the technical report CEN/TR 15508: 2006 'Solid recovered fuels – Key properties on solid recovered fuels to be used for establishing a classification system' [1]. These classes are appropriate for small scale EfW facilities as they do not exceed the normal design tolerance of a facility. The classification for the cadmium content of WDF is shown in Table 10.

Table 10: Cadmium classification system

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Cadmium (Cd) (as received)	mg/MJ (Median)	≤0.1	≤0.3	≤1.0	≤5.0	≤7.5
	mg/MJ (80th percentile)	≤0.2	≤0.6	≤2.0	≤10	≤15

3.4.3 Other heavy metals

Heavy metals are included within this classification scheme due to their detrimental impact on the environment and human health. The heavy metals covered by this parameter are Antimony (Sb), Arsenic (As), Lead (Pb), Chromium (Cr), Cobalt (Co), Copper (Cu), Manganese (Mn), Nickel (Ni) and Vanadium (V). There are environmental concerns associated with the volatile fraction of these metals which are volatised as chlorides and oxides during combustion (Khan et al., 2009 [25]). A large proportion of volatile metals present in the WDF would be captured and contained in air pollution control (APC) residues while the remaining are emitted through the stack. Non-volatile metals are contained within the bottom ash. The existing classification system set out in BS EN 15359:2011 does not include heavy metals.

Classification

The classification for the heavy metal content of WDF is shown in Table 11.

Table 11: Heavy metal classification system

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Sum of heavy metals (as received)	mg/MJ (Median)	≤15	≤30	≤50	≤100	≤190
	mg/MJ (80th percentile)	≤30	≤60	≤100	≤200	≤380

3.4.4 Summary of environmental attributes

The classification system for environmental characteristics of the WDF is summarised in Table 12.

Table 12: Classes for the environmental attributes of WDF

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Mercury (Hg) (as received)	mg/MJ (Median)	≤0.02	≤0.03	≤0.06	-	-
	mg/MJ (80th percentile)	≤0.04	≤0.06	≤0.12	-	-
Cadmium (Cd) (as received)	mg/MJ (Median)	≤0.1	≤0.3	≤1.0	≤5.0	≤7.5
	mg/MJ (80th percentile)	≤0.2	≤0.6	≤2.0	≤10	≤15
Sum of heavy metals (HM) (as received)	mg/MJ (Median)	≤15	≤30	≤50	≤100	≤190
	mg/MJ (80th percentile)	≤30	≤60	≤100	≤200	≤380

3.5 Summary of all WDF Classes and characteristics

The criteria and fuel parameters used for defining the characteristics of WDF are summarised in Table 13. It should be noted that the more 'desirable' attributes are always class 1 and desirability decreases with higher rated classes. This means that lower class numbers in the definition of the fuel suggest a 'cleaner' fuel.

Table 13: WDF characterisation

Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Biomass content (as received)	% (mean)	≥90	≥80	≥60	≥50	<50
Net calorific value (as received)	MJ/kg (mean)	≥25	≥20	≥15	≥10	≥6.5
Moisture content	% wt/wt (mean)	≤10	≤15	≤20	≤30	<40
Chlorine content (dry)	% wt/wt (mean)	≤0.2	≤0.6	≤0.8	-	-
Ash content (dry)	% wt/wt (mean)	≤10	≤20	≤30	≤40	<50
Bulk density (as received)	kg/m3 (mean)	>650	≥450	≥350	≥250	≥100

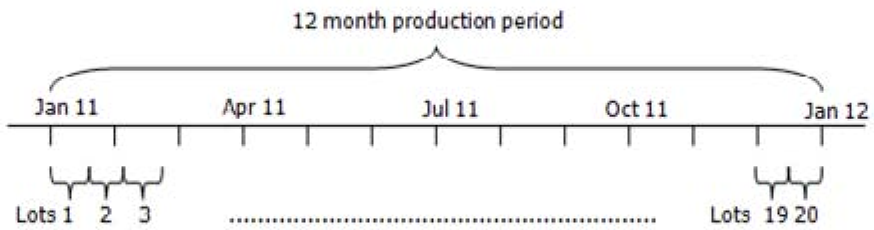
Classification property	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Mercury (Hg) (as received)	mg/MJ (Median)	≤0.02	≤0.03	≤0.06	-	-
	mg/MJ (80th percentile)	≤0.04	≤0.06	≤0.12	-	-
Cadmium (Cd) (as received)	mg/MJ (Median)	≤0.1	≤0.3	≤1.0	≤5.0	≤7.5
	mg/MJ (80th percentile)	≤0.2	≤0.6	≤2.0	≤10	≤15
Sum of heavy metals (HM) (as received)	mg/MJ (Median)	≤15	≤30	≤50	≤100	≤190
	mg/MJ (80th percentile)	≤30	≤60	≤100	≤200	≤380

3.6 Worked example

A sample template for reporting and specifying the characteristics of WDF is provided as Appendix 1. This is based on the template included in BS EN 15359: 2011 'Solid recovered fuels – Specifications and classes'[9] and should be completed by the fuel producer. The inclusion of all the fuel parameters mentioned within Section 3.0 is required.

A MRF produces a generally homogeneous WDF from its facility for a period of 12 months, producing a total of 30,000 tonnes per annum. 20 segments are used to study the characteristics of the fuel mentioned in the Economic, Technical and Environmental characteristics listed in Sections 3.2, 3.3 and 3.4.

Most testing facilities will require the producer to provide their samples via mail, meaning a reliable sampling process must be undertaken at the MRF. See WRAP Sampling Guidance document for a recommended sampling procedure.



Characteristics tested during each lot:

1. Economic: Biomass content (BM), NCV (as received), Moisture (M)
2. Technical: Chlorine, Ash content, Bulk density (BD)
3. Environmental: Mercury, Cadmium, Heavy metals (HM)

Partial results from measurement:

Lot number	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20
BM (%)	60.8	63.4	64.4	61.2	59.9	62.0	61.4	64.5	57.9	58.9
NCV (MJ/kg)*	8.5	9.9	9.9	10.0	10.1	10.5	10.9	11.1	11.5	12.0
M (%)	30.4	24.0	24.4	18.0	18.3	17.2	17.0	16.8	16.4	16.0
Cl (%)	0.61	0.71	0.56	0.5	0.62	0.43	0.54	0.60	0.58	0.65
Ash (%)	38.6	32.3	33.1	28.3	28.1	26.8	25.4	24.1	23.5	21.2
BD (kg/m3)	389	410	420	428	434	453	464	471	479	487
Hg (mg/MJ)	0.018	0.020	0.023	0.023	0.024	0.027	0.028	0.034	0.036	0.038
Cd (mg/MJ)	2.0	2.2	2.2	2.4	2.6	2.7	3.1	3.1	3.3	3.5
HM (mg/MJ)	63	64	67	67	69	71	71	73	74	75

* as received

Classification parameters calculation

1. Biomass (BM):

- the arithmetic mean is 61.44 wt/wt%;
- the standard deviation is 2.1 wt/wt%;
- the lower limit of 95% confidence interval is calculated according to Eq (2) (see Appendix 5);
- the lower limit is 60.13 wt/wt%. The calculated mean value is rounded down to 61 wt/wt%; and
- the calculated 95% confidence level is rounded down to 60 wt/wt%.

Class code BM: 3 (see Table 13)

2. NCV (ar):

- The arithmetic mean is 10.4 MJ/kg (as received);
- The standard deviation is 0.94 MJ/kg (as received);
- The lower limit of 95% confidence level is 9.8 MJ/kg and is calculated according to Eq (2);
- The calculated mean value is rounded down at 10 MJ/kg; and
- The calculated 95% confidence level is rounded down to 10 MJ/kg.

Class code NCV: 4 (see Table 13)

3. Moisture (M):

- The arithmetic mean is 19.85 % (wt/wt);
- The standard deviation is 4.54 % (wt/wt);
- The upper limit of 95% confidence level is 22.6 % (wt/wt) and is calculated according to the Eq (3);
- The calculated mean value is rounded at 20% (wt/wt); and
- The calculated 95% confidence level is rounded down at 22 % (wt/wt).

Class code M: 3 (see Table 13)

4. Chlorine (Cl)

- The arithmetic mean is 0.58 % (wt/wt);
- The standard deviation is 0.07 % (wt/wt);
- The upper limit of 95% confidence level is 0.62 % (wt/wt) and is calculated according to the Eq (3);
- The calculated mean value is rounded at 0.60 % (wt/wt); and
- The calculated 95% confidence level is 0.62% (wt/wt).

Class code Cl: 2 (see Table 13)

5. Ash content (Ash)

- The arithmetic mean is 28.14 % (wt/wt);
- The standard deviation is 4.96 % (wt/wt);
- The upper limit of 95% confidence level is 31.2% (wt/wt) and is calculated according to the Eq (3);
- The calculated mean value is rounded at 28% (wt/wt); and
- The calculated 95% confidence level is rounded to 31% (wt/wt).

Class code Ash: 2 (see Table 13)

6. Bulk Density (BD)

- The arithmetic mean is 453.5 kg/m3; and
- The standard deviation is 30.6 kg/m3

Class code BD: 2 (see Table 13)

7. Mercury (Hg)

- Number of samples = 10;
- Median will be at 5th and 6th sample (10/2 = 5);
- The median value is 0.0255 mg/MJ ((as received) (0.024 +0.027)/2 = 0.0255);
- The 80th percentile is 0.035 mg/MJ ((10/0.8 = 8; (0.034+0.036)/2 = 0.035);
- The calculated median value is rounded to 0.02 mg/MJ; and
- The calculated 80th percentile for Hg is rounded at 0.035 mg/MJ.

Class code Hg: 1 (see Table 13)

8. Cadmium (Cd)

- The median value is 2.65 mg/MJ ((as received) (2.6 +2.7)/2 = 2.65); and
- The 80th percentile is 3.2 mg/MJ ((10/0.8 = 8; (3.1+3.3)/2 = 3.2).

Class code Cd: 4 (see Table 13)

9. Heavy metals (HM)

- The median value is 70 mg/MJ ((as received) (69 +71)/2 = 70);
- The 80th percentile is 73.5 mg/MJ ((10/0.8 = 8; (73+74)/2 = 73.5).

Class code HM: 3 (see Table 13)

Therefore, taking all of the results from above, we arrive at:

WDF Class code: **BM 3 - NCV 4 - M 3**
Cl 2 - Ash 2 - BD 2
Hg 1 - Cd 4 - HM 3

The Class code above then, would list the fuel in the following manner, allowing fast, easy understanding of the fuel's content for each variable:

3 4 3, 2 2 2, 1 4 3
i.e.,
biomass Class3, CV Class4, moisture Class3.
chlorine Class2, ash Class2, bulk density Class2.
mercury Class1, cadmium Class4, OHM Class3.

Note that the factors are always shown in the order as listed above: first the 3 economic factors, followed by the 3 technical factors and finally the 3 environmental factors.

The Classes indicate the level, and the lower Class numbers always indicates a 'better', or more desirable fuel for that factor. So in the example above (graphically, Figure 1), the generally mid-high numbers in the economic section (left) and environmental section (right) indicate a fuel with a low economic value and high environmental risk (high levels of metals). This, for instance, may be a hazardous material.

A fuel with low Classes on the left and low Classes on the right (1 1 1, 2 2 2, 1 1 1) – Figure 2, would indicate the opposite, a high value, low risk fuel, which may, for instance, be a wood waste biomass fuel with little or no treatments. Similarly, high Classes in the central section (1 1 1, 4 4 5, 1 1 1) – Figure 3, would indicate a fuel which would be difficult for the plant to process (maybe bulky material which produces lots of ash, or contains material deleterious to the plant itself, e.g., chlorine).

Compare the graphical representations of these values as shown in Figures 1, 2 and 3

The WDF producer will share this class code with the EfW operator who can then check these values against their operating conditions and the process tolerance of specific fuel parameters. The operator must acquire this information from the plant designers or build an understanding of them based upon knowledge and experience of their own plant.

Figure 1 – Fuel classification: 343, 222, 143.

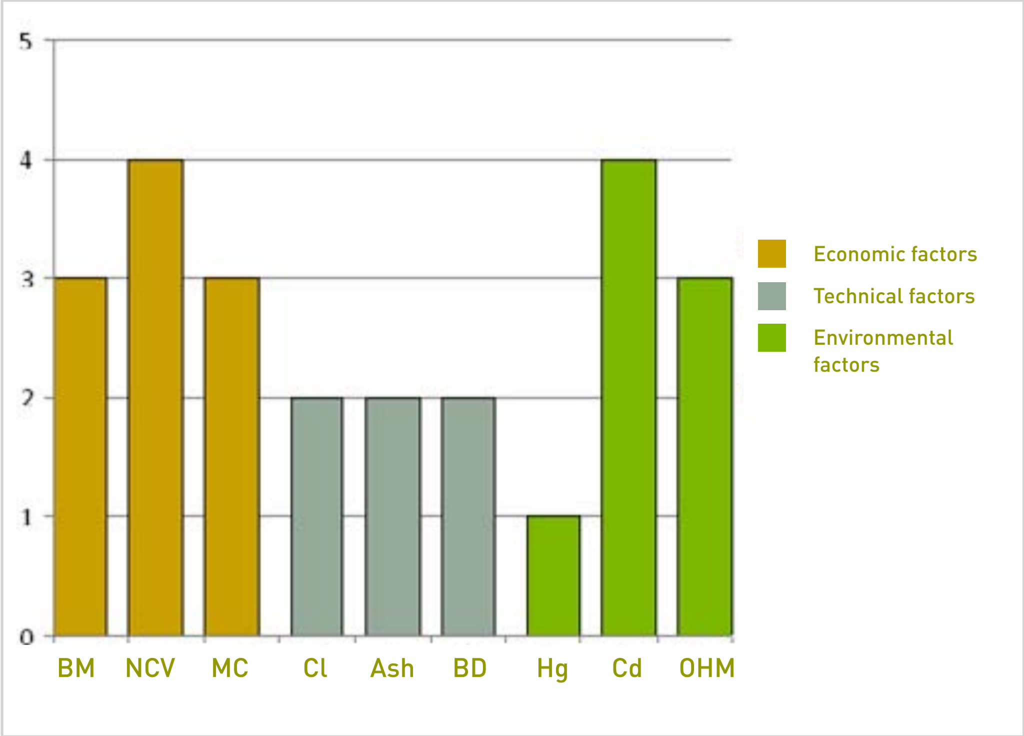


Figure 2 – Fuel classification: 111, 222, 111.

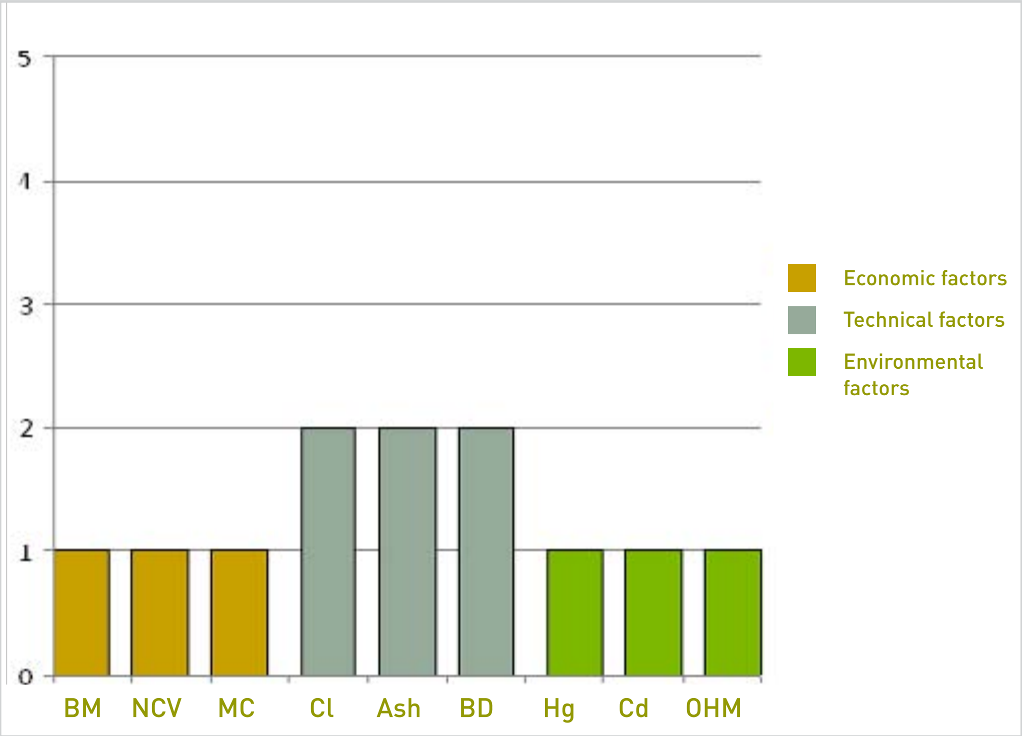
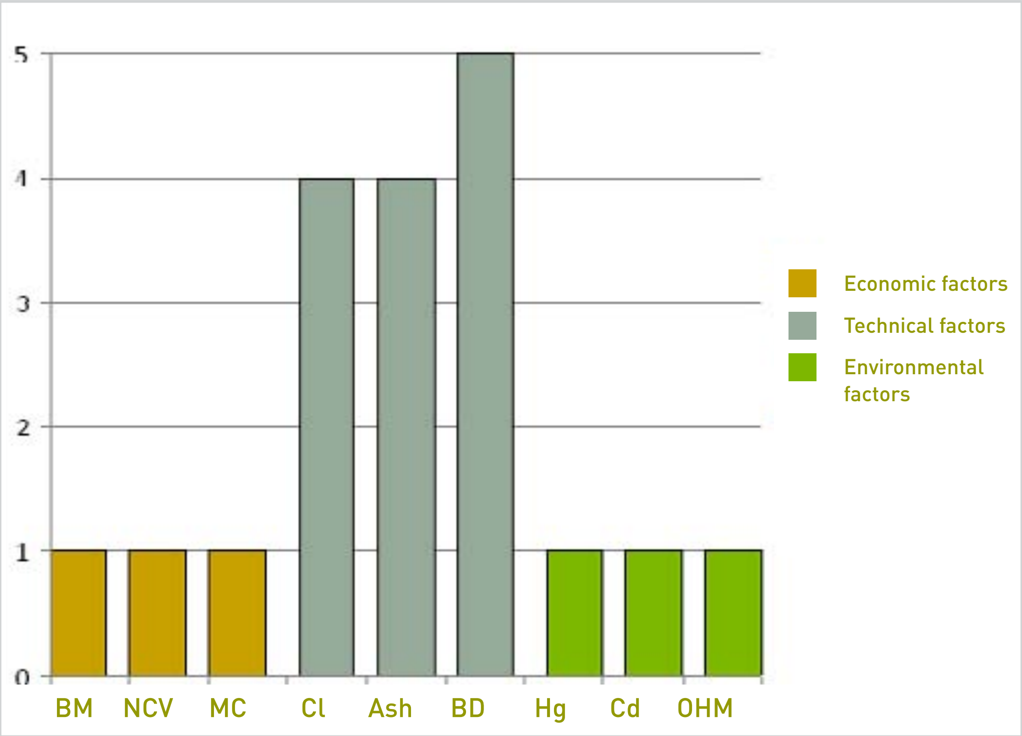


Figure 3 – Fuel classification: 111, 445, 111.



3.7 Summary

This classification scheme will help the WDF producer to provide an unambiguous and clear classification of the WDF to end users, to help them understand the fuel quality. This will improve knowledge and understanding within the WDF industry. Through usage of this scheme, if the EfW operator requires a different WDF quality, for example, a lower chlorine content, they can ask the WDF producer to achieve this through carrying out additional treatments prior to the use of the fuel (for instance removing PVC from the feedstock), and the Class indicator for chlorine will show if that requirement has been met. Similarly, the end user can request technical details from the designer of the plant, relating to operating parameters which must be followed during commissioning and on-going operation of the plant. The scheme delivers a list of 9 Class parameters for those variables which were considered to be the most important when discussed by the Technical Advisory Group. The simple graphical manner of representing these values helps to identify the primary characteristics of the fuel.

4.0 APPENDICES

Appendix 1 - Existing standards

4.1 Existing quality standards

The existing quality standards identified in Figure 1 are summarised in the following paragraphs.

4.1.1 BS EN 15359: 2011

This European specification was developed by the European Committee for Standardisation (CEN) technical committee for Solid recovered fuel (CEN TC 343). The specification covers the SRF prepared from non-hazardous wastes including MSW, specific waste, industrial waste, commercial waste, construction and demolition waste and sewage sludge. Waste wood from the demolition of buildings and civil engineering is included within the scope of this standard. Untreated MSW is not included in the scope of this standard. Solid biofuels excluded from the Waste Incineration Directive (2000/76/EC), i,e, 'clean' wood, are not included in this standard but are covered by BS EN 14961:2010

4.1.2 BS EN 14961:2010

The standard for solid biofuels was developed by the CEN technical committee for Solid biofuels (CEN TC 335). It covers solid biofuels utilised for non-industrial use which includes small scale appliances, such as households, small commercial and public sector buildings. Waste wood from the demolition of buildings and civil engineering is not included within the scope of this standard. Solid biofuel wastes originating from the following sources are included within the scope of this standard:

- products from agriculture and forestry;
- vegetable waste from agriculture and forestry;
- vegetable waste from the food processing industry;
- wood waste, with the exception of wood waste which may contain halogenated organic compounds or heavy metals as a result of treatment with wood preservatives or coating, and which includes in particular such wood waste originated from construction and demolition;
- fibrous vegetable waste from virgin pulp production and from production of paper from pulp, if it is co-incinerated at the place of production and heat generated is recovered; and
- cork waste.

4.2 Quality assurance

Quality assurance (QA) procedures are required to provide confidence to the end user that the WDF meets the specified requirements of the quality standard. A QA system helps WDF producers to produce a product with consistent properties and enables them to describe these properties to customers. A good Quality Management System (QMS) in the manufacturing and handling process of the WDF also helps in good record-keeping and may reduce the number of required samples.

Table 14: Quality management systems to be followed

Quality Standards and Classification scheme	Quality management system to be followed
BS EN 15359: 2011 – 'Solid recovered fuels – Specification and classes' 'A classification system to define the quality of Waste Derived Fuel'	BS EN 15358: 2011 – Solid recovered fuels QMS
BS EN 14961-1:2010 'Solid biofuels – specification and classes'	BS EN 15234 – 1: 2011 – 'Solid biofuels – Fuel quality assurance'

Appendix 2 - Relevant technologies

Cement kilns

Cement kilns and lime kilns can utilise large quantities of WDF and are capable of accepting a wide variety of hazardous and non-hazardous WDF. Cement kilns typically co-incinerate WDF with virgin fuels in various proportions depending on their operating parameters. Although cement kilns specify the minimum quality requirement and various parameters of WDF that can be accepted, the BS EN 15359: 2011 can be applied to define the quality of WDF.

Coal-fired power plants

Significant environmental benefits can be gained by substituting primary fossil fuels in coal fired power plants with WDF (2003[23]). Co-combustion of waste biomass in coal fired power plants has increased as a result of the implementation of the EC Directive on Renewable Energy as it contributes to the Renewable Obligation (2003) of power companies. The quality of WDF used in such plants must be defined in terms that are similar to those used for coal, e.g., GCV, ash content, volatile matter and total sulphur content. Coal fired power plants typically follow BS EN 15359: 2011 in defining the quality of the WDF.

Fluidised bed and moving grate combustion plants

Fluidised bed combustion (FBC) units can treat a wide range of fuels due to their flexibility in design and the large amount of inert bed material which allows them to treat low grade high-ash fuels efficiently. WDF from processed MSW is used in FBC in the UK for energy generation (2003[23]). Moving grate combustion is a well-developed and commonly used technology for the combustion of solid fuels. This grate system moves waste through the combustion chamber to ensure complete and effective combustion. The standard followed for specifying the quality of WDF for their application in FBC and moving grate plants would depend on the size of the facility as shown:

- If the plant has a treatment capacity higher than 100,000 tpa, then BS EN 15359: 2011 can be applied.
- If the plant has a treatment capacity lower than 100,000 tpa, then 'A classification system to define the quality of Waste Derived Fuel' can be applied (as shown in Section 3.0)

Advanced thermal treatment (e.g. gasification, pyrolysis).

Advanced thermal treatment technologies are primarily those that employ pyrolysis and/or gasification to process WDF. Gasification and pyrolysis processes transform the material content of the WDF into a number of synthetic gas (syngas), a 'char' and/or an oil products, each of which can be then used as a fuel. This is done by heating the materials to a high temperature in the absence of oxygen, which breaks down the materials into their constituent elements. Although these technologies are in their infancy in the UK, they have been built and are successfully operating in Europe, Japan and America. The standard followed for defining the quality of WDF for the specific application within advanced thermal treatment facilities would depend on the size of these facilities and the nature of waste treated as shown:

- If the plant has a treatment capacity higher than 100,000 tpa, then the specific industrial quality requirement is followed or BS EN 15359: 2011 can be applied.
- If the plant has a treatment capacity lower than 100,000 tpa, then 'A classification system to define the quality of Waste Derived Fuel'' can be applied (as shown in Section 3.0)

Appendix 3 - Template for recording the details of individual samples of WDF

The form presented here should be used as the primary method of data recording when analysing the fuel characteristics. Records should be kept of each sample's analysis using the form below, in order to analyse those records to arrive at the simple version.

Obligatory properties					
Parameters	Class 1	Class 2	Class 3	Class 4	Class 5
Biomass					
Net Calorific Value (as received)					
Moisture content					
Chlorine content				N/A	N/A
Ash content					
Bulk density					
Mercury				N/A	N/A
Cadmium					
Heavy metals					

Economic characteristic			
	unit	Mean Value	Test method
Biomass content	% as received		
Net Calorific Value	MJ/kg as received		
Net Calorific Value	MJ/kg dry		Calculated/Measured
Moisture content	% as received		

Technical characteristic				
	unit	**Mean Value**		**Test method**
Ash content	% dry			
Bulk density	kg/m3 as received	t		
	unit	Value		Test method
		median	80th per	
Chlorine (Cl)	mg/kg dry			

Environmental characteristic				
	unit	**Value**		**Test method**
		median	**80th per**	
Mercury (Hg)	mg/kg dry			
Cadmium (Cd)	mg/kg dry			
Other heavy metals	mg/kg dry			

Appendix 4 - 80th percentile of cadmium, mercury and other heavy metal calculations

Environmental attributes are expressed as mg/MJ rather than mg/kg. This unit allows them to be compared for fuels with a varying CV. The environmental attributes in this classification scheme are based on using the median and 80th percentile values compared to mean value which has been used for classifying the economic and technical attributes. The median and 80th percentile value is used due to the right skewed normal distribution of the elements considered within the environmental attributes. Refer to CEN/TR 15508: 2006, 'Key properties on solid recovered fuels to be used for establishing a classification system' [1] for a detailed discussion on the skewed distribution of mercury and cadmium. The right skewed normal distribution for heavy metals has been confirmed in the dissertation carried out by Prof. Dr. Ing. Sabine Flamme, ERFO [27]. The median should be used for classifying WDF and the 80th percentile value is also provided to ensure environmental protection as it is used for verifying whether the use of the WDF complies with the environmental permit.

The air emission limit values of the EfW facilities are used in determining the maximum limit value for each metal mentioned in the environmental characteristic. The air emission limits values are highlighted in the Directive 2000/76/EC on incineration of waste (WID). The following formula from CEN/TR 15508: 2006[1] was used to determine the maximum allowable concentration of mercury content in WDF:

Cs = Ce x Vs x 1/TF
Eq (2)

Where,
Cs = specific concentration of property in WDF mg/MJ ar

Ce = concentration of property in emitted gases mg/m3, the maximum value from WID is used

Vs = specific volume of gas m3/MJ ar

TF = transfer factor that is selected depending on the technology applied for combustion and gas treatment and the plant performance. CEN/TR 15508:2009 have calculated TF for mercury emissions from a fluidised bed combustion plant to be 0.6 for a plant without activated carbon abatement system and 0.065 for a plant using activated carbon.

For calculating the maximum allowable concentration of mercury, the following data were used.

Ce = 0.05 mg/m3 (Annex V of WID)

Vs = 0.1569 m3/MJ (data provided in CEN/TR 15508:2006 for Vs is 0.34 m3/MJ for a minimum CV of 3MJ/kg)

TF = 0.065 (data provided in CEN/TR 15508:2006 for fluidised bed combustion units)

The minimum CV considered within this classification scheme is 6.5 MJ/kg.

Cs = 0.12 mg/MJ

Appendix 5 - Test methods

Biomass:

The methods for determining the biomass content in SRF are set out in 'BS EN 15440:2011 – Solid recovered fuels – Method for determination of biomass content' [15]. These methods should be used to measure the biomass content in WDF and include selective dissolution, manual sorting or a measure of C14 content. The fraction of biogenic content in WDF should be expressed as the percentage of biogenic carbon content to total carbon content (wt/wt % as received).

Net calorific value:

The NCV of WDF can be calculated and reported as set out in 'BS EN 15400:2011, 'Solid recovered fuels - Determination of calorific value' [10].

If NCV data is available on a dry basis, you can use Eq (1) provided in 'BS EN 15296: 2011, 'Solid biofuels – Conversion of analytical results from one basis to another'[7] is used to determine the classification categories for NCVd:

$$NCVar = (NCVd \times (100 - Mar)/100) - 0.02443 \times Mar \qquad \text{...Eq (1)}$$

Where,

NCVd = Net calorific value, dry basis (MJ/Kg)

NCVar = Net calorific value, as received basis (MJ/Kg)

Mar = Moisture content, as received basis

0.02443 represents the correction factor of the enthalpy of vaporisation of water (constant pressure) at 25°C (in MJ/kg per 1 wt% of moisture).

NCV on a 'dry' basis (NCVd) might be required to set the optimal operating parameters for an EfW facility because they provide an accurate representation of the WDF. This is because there is a possibility of moisture loss during transportation and storage and hence the NCVar determined from samples might not be an accurate representation of the WDF as received at the plant.

Moisture content:

Moisture content is typically measured by heating the fuel to 105ºC and measuring the weight loss. It is expressed using the unit % wt/wt. The moisture content of WDF can be measured using one of the following two methods:

- BS EN 15414-1: 2010, 'Solid recovered fuels – Determination of moisture content using the oven dry method - Part 1: Determination of total moisture by a reference method' [4]or
- BS EN 15414-2: 2010, 'Solid recovered fuels – Determination of moisture content using the oven dry method - Part 2: Determination of total moisture content by simplified method' [5].

Chlorine:

The chlorine content of WDF can be measured and reported using the methodology set out in BS EN 15408: 2011, 'Solid recovered fuels – Methods for the determination of sulphur (S), chlorine (Cl), fluorine (F) and bromine (Br) content' [13]

Ash content

The ash content can be calculated using BS EN 15403: 2011, 'Solid recovered fuels – Determination of ash content' [12].

Bulk density

The bulk density of WDF can be measured using the methodology set out in BS EN 15401: 20101, 'Solid recovered fuels – Determination of bulk density' [11]

Mercury, cadmium and other heavy metals

The mercury, cadmium and 'other heavy metals' content of WDF can be measured and reported using the methodology set out in BS EN 15411: 2011, 'Solid recovered fuels – Methods for the determination of the content of trace elements (As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Sb, Se, Tl, V and Zn)'[14].

The testing methodologies that should be followed to measure specific parameters for the scheme are shown in Table 15.

Table 15: Testing procedures for various parameters

WDF parameter	Standard to be followed
Biomass content	CEN/TR 15440:2011, 'Solid recovered fuels - Determination of the biomass content'
Calorific value	EN 15400:2011 Solid recovered fuels - Determination of calorific value
Moisture content	CEN/TS 15414-1:2010 Solid recovered fuels - Determination of moisture content using the oven dry method - Part 1: Determination of total moisture by a reference method
	CEN/TS 15414-2:2010 Solid recovered fuels - Determination of moisture content using the oven dry method - Part 2: Determination of total moisture content by a simplified method
Chlorine content	EN 15408:2011 Solid recovered fuels - Methods for the determination of sulphur (S), chlorine (Cl), fluorine (F) and bromine (Br) content
Ash content	EN 15403:2011 Solid recovered fuels - Determination of ash content
Bulk density	CEN/TS 15401:2010 Solid recovered fuels - Determination of bulk density
Mercury, cadmium and other heavy metals	EN 15411:2011 Solid recovered fuels - Methods for the determination of the content of trace elements (As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Sb, Se, Tl, V and Zn)

Calculating the class of each parameter

To classify WDF under this scheme the class limit value of the following parameters should be compared with the 95% confidence interval. Using the 95% confidence interval ensures that any samples that are statistical outliers will have less of an impact on the arithmetic mean resulting in a more representative figure. This is an approach used within the BS EN 15359: 2011 'Solid recovered fuels – Specifications and classes'[9] for defining the classes for each parameter.

1. Biomass content
2. NCV (as received and dry)
3. Moisture content
4. Chlorine content
5. Ash content

The 95% confidence level is measured according to the formulae:

$$X = AM \pm 1.96 \times s / \sqrt{n} \qquad \text{... Eq (2)}$$

Where:

AM = arithmetic mean
s = standard deviation
n = number of measurements (10 lots so n =10)
1.96 is the functional characteristic of the normal distribution (95% confidence level)

Some parameters matter more than others with regard to the operational performance of the plant. These are biomass content, NCV, moisture content and chlorine content. It is therefore better to take a conservative approach to specifying these parameters and so each should be expressed in relation to mean. For example, it is better to express biomass content as slightly lower than the mean and moisture content slightly higher than the mean. This helps the operator to define a class that is suitable for their application with confidence that the WDF will have the minimum required characteristics. The table below shows how the value for each parameter should be calculated.

Table 16: Calculation of each parameter

Biomass content	Lower limit value of the 95% confidence interval of arithmetic mean (AM -1.96 x s/ √n)
NCV (as received)	Lower limit value of the 95% confidence interval of arithmetic mean (AM -1.96 x s/ √n)
Moisture content	Upper limit value of the 95% confidence interval of arithmetic mean (AM+1.96 x s/ √n)
Chlorine content	Upper limit value of the 95% confidence interval of arithmetic mean (AM+1.96 x s/ √n)

The class code for mercury, cadmium and heavy metals are determined using median and 80th percentile and again represent a conservative approach. This method is used to ensure that the facility can operate within the emissions limits of their environmental permit.

Appendix 6 - Notes

Notes on biomass content classification:

1. The upper limit value of up to 90% for Class 1 mirrors the CHPQA 'Guidance Note 44' [19] which defines eligibility for issuing ROCs as:

   i. "ROCs are issued to CHP Schemes using biomass (defined in the Renewables Obligation as a fuel where at least 90% of the energy content is derived from plant or animal matter) or waste"

2. The Class 2 threshold of up to 80% is drawn from the report 'Refuse Derived Fuel, Current Practice and Perspectives', European Commission, 2003[23] which calculates the typical biomass content of RDF to be 84% in the UK.

3. The Class 4 threshold of up to 50% was selected to take into account the minimum rational biomass content required while co-firing biomass with coal.

4. WDF falling in Class 5 have a low or no biomass content. For example, solvents.

Notes on NCVar classification:

1. The classification categories used to define Class 1 to Class 4 WDF are taken from 'BS EN 15359: 2011 Solid recovered fuels – Specifications and classes' [9] as they are also applicable for small scale EfW facilities.

2. Class 5 in BS EN 15359 has an NCV as received threshold value of less than 3 MJ/kg and was derived based on adiabatic flame temperature and experience in cement kilns using SRF with a high ash and high water content. It is not possible for small scale EfW facilities to use WDF with a NCV of less than 3MJ/kg (as received) and achieve self-sustaining combustion without the use of auxiliary fuels. The World Bank has recommended a minimum NCV as received for fuel to be a minimum of 6 MJ/kg to ensure self-sustaining combustion (World Bank Technical Report, 1999[30]). The TAG members with their prior experience in dealing with SRF for cement kilns and other EfW facilities agreed NCVar of 6.5 MJ/kg should give sufficient energy for any combustion process.

Notes on moisture content classification:

1. Class 1 covers WDF with a moisture content below 10%. A review of data on the moisture content of various SRFs and RDFs in CEN/TR 15508: 2006, 'Key properties on solid recovered fuels to be used for establishing a classification system'[1] and 'Refuse Derived Fuel, Current Practice and Perspectives', European Commission, 2003 [23] shows that the following WDF fall into this category:

   a. RDF pellets;

   b. SRF derived from polymers/polymer resins; and

   c. SRF derived from waste wood, filter cake, aluminium hydroxide sludge and spent activated carbon.

2. The moisture content thresholds in Classes 2, 3 and 4 resulted from a review of data on the moisture content of various SRFs and RDFs in CEN/TR 15508: 2006, 'Key properties on solid recovered fuels to be used for establishing a classification system'[1] and 'Refuse Derived Fuel, Current Practice and Perspectives', European Commission, 2003 [23]

3. The moisture content threshold of 40% wt/wt for Class 5 is based on a review of the data collected in CEN/TR 15508:2006[1] and 'Refuse Derived Fuel, Current Practice and Perspectives', European Commission, 2003 [23]. WDF with a moisture content higher than 40% would have a very low NCV (typically around 3MJ/kg) and would not be suitable for combustion in small scale EfW plants.

Notes on chlorine content classification:

1. The chlorine content thresholds for Class 1 and Class 2 are taken from BS EN 15359: 2011 'Solid recovered fuels – Specifications and classes' [9]. This is appropriate for small scale EfW facilities as it is within the normal tolerance range;

2. The threshold for 0.8% wt/wt (dry) for Class 3 is lower than the Class 3 threshold set out in BS EN 15359: 2011 of 1%, as plants treating wastes with more than 1% wt/wt (dry) chlorine content require chlorine bypass and other abatement systems to reduce the formation of PCDD/PCDF. The financial viability of implementing a similar chlorine removal system in a small scale EfW facility is questionable and therefore, a maximum tolerance limit of 0.8% (wt/wt) is used.

3. The chlorine content thresholds for Class 4 (↖1.5% wt/wt (dry)) and class 5 (↖3.0 wt/wt (dry)) as set out in BS EN 15359: 2011 are not considered appropriate for small scale EfW plants because of the increased cost of air emission abatement equipment that would be required.

Notes on ash content classification:

1. The ash content threshold for Class 1 is appropriate for WDF of biomass origin which is free from contamination. A review of ash content of biomass showed it is typically below 10% (S.V. Vassilev et al., 2010 [28]; Masia et al., 2007 [26]).

2. The ash content threshold for Classes 2, 3 and Class 4 were determined through a review of existing data on the ash content of SRF and RDF in CEN/TR 15508: 2006, 'Key properties on solid recovered fuels to be used for establishing a classification system'[1] and 'Refuse Derived Fuel, Current Practice and Perspectives', European Commission, 2003 [23].

3. WDF with ash content less than 50% will fall into Class 5. This value is set upon review of the data collected in CEN/TR 15508: 2006, 'Key properties on solid recovered fuels to be used for establishing a classification system' [1] and 'Refuse Derived Fuel, Current Practice and Perspectives', European Commission, 2003 [23] which showed that WDF with an ash content higher than 50% has an NCV (as received) lower than 6.5 MJ/kg and is therefore not suitable for small scale EfW.

Notes on bulk density classification:

1. Bulk density is applicable only for solid fuels.

2. The bulk density threshold for Class 1 is appropriate for solid biofuels in the form of briquettes and pellets.

3. The bulk density thresholds for Classes 2, 3 and 4 were determined through a review of data on bulk density of solid biofuels available in BS EN 14961-1: 2010, 'Solid biofuels – Fuel specification and classes – Part 1: General requirements'[3].

4. The bulk density threshold for Class 5 is taken from the results of inter-laboratory testing carried out by the Quality management, organisation, validation of standards, developments and inquiries for SRF (QUOVADIS). The results showed the bulk density of SRF to be typically above 100 kg/m3. For example, the bulk density of mixed SRF, wood containing SRF and plastic containing SRF is found to be above 100kg/m3.

Notes on mercury content classification:

1. The mercury threshold for Classes 1 and 2 are taken from BS EN 15359: 2011 'Solid recovered fuels – Specifications and classes'[9] and are appropriate for small scale EfW facilities as they fall within the normal design tolerance.

2. The 80th percentile mercury threshold for Class 3 is calculated using the methodology set out in Appendix 2. The threshold represents the maximum limit value (80th percentile) for mercury that could be present in a WDF with a NCV of 6.5MJ/kg (the lowest class) to enable the facility to still operate within the normal design tolerance, i.e. the WID emission limit for mercury would not be exceeded. The median value for Class 3 is calculated using the ratio of the median to the 80th percentile taken from the data collected by the technical committee for CEN 343 on the characteristics of SRF and set out in BS EN 15359: 2011[9].

3. The mercury threshold for Class 4 and Class 5 in BS EN 15359: 2011[9] fall outside the maximum limit value of mercury suitable for a small scale EfW facility and are therefore not included within this classification. The maximum

limit value of Class 5 (1mg/MJ) in the BS EN 15359: 2011 was determined by taking into consideration the lowest NCV (assumed to be 3MJ/kg as received) and the maximum for blending Hg containing wastes which was assumed to be 5mg/kg to 10mg/kg (as received). This class within BS EN 15359: 2011[9] represents SRF with high ash content that can be used as a raw material substitute in clinker production.

Notes on cadmium content classification:

1. The cadmium threshold for Class 5 value is calculated using the same equation as was applied for determining the maximum mercury limit value as shown in Appendix 2. The minimum NCV was assumed to be 6.5 MJ/kg and the maximum for blending Cd containing wastes was assumed to be same as that provided in BS EN 15359: 2011 'Solid recovered fuels – Specifications and classes'[9] (100mg/kg dry basis). This is considered a conservative approach as lower amounts of pollutants would be released per unit MJ because of the higher CV of the material.
2. The median value is calculated using the ratio of the median to the 80th percentile from the data collected by the technical committee for CEN 343 on the characteristics of SRF. CEN/TR 15508:2006, 'Key properties on solid recovered fuels to be used for establishing a classification system' [1] considered a ratio of 0.5 and the same ratio was applied to calculate the median value for each class.

Notes on 'other heavy metal' content classification:

1. The heavy metal threshold for Classes 1, 2, 3 and 4 were determined through a review of data on the heavy metals (mg/MJ as received) in SRF from a number of sources as provided in CEN/TR 15508:2006, 'Key properties on solid recovered fuels to be used for establishing a classification system'[1]. The ratio of median to 80th percentile is the same as mercury and cadmium.
2. The heavy metal threshold for Class 5 is calculated using the same equation applied for calculating the maximum limit value for mercury and cadmium as shown in Appendix 2. The maximum allowable content of heavy metals is set at 2,500 mg/kg as this is the threshold above which WDF would be classified as hazardous waste with the hazard code H14 for ecotoxicity.

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