Material change for a better environment

Environment Agency

Waste Protocols Project

Pulverised fuel ash and furnace bottom ash

A technical report on the manufacture of products from pulverised fuel ash (PFA) and furnace bottom ash (FBA)

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Background

The Waste Protocols Project is a joint Environment Agency and WRAP (Waste & Resources Action Programme) initiative in collaboration with industry, funded by the Department for Environment, Food and Rural Affairs (Defra) as a business resource efficiency activity.

The aim of the Waste Protocols Project is to provide guidance to business on a number of waste streams that will:

- define the point of full recovery from a waste back into a product or material that can be reused by the business or industry or sold into other markets; or
- confirm to the business community what legal obligations remain to control the reuse of the treated waste material.

Pulverised fuel ash (PFA) arising from the combustion of coal for energy was chosen as one of the waste streams to be addressed by the Waste Protocols Project. A Technical Advisory Group (TAG) was set up to bring together representatives from the Environment Agency, WRAP and industry.

The TAG subsequently agreed that they would evaluate furnace bottom ash (FBA) in addition to PFA and cenospheres (a type of PFA) from the combustion of coal both with and without the use of co-combustion materials. For the purposes of this document, the definition of PFA includes cenospheres.

Methodology

The TAG set out to:

- identify the major applications and thus appropriate end uses for PFA and FBA;
- identify the current legislative framework;
- consider standards or specifications appropriate for PFA and FBA;
- propose terminology that can be used consistently;
- identify and subjectively quantify the relative risk to human health and the environment from the use of PFA and FBA; and
- suggest the way forward for each of the major markets so that certain end uses may be regarded as fully recovered when strictly defined conditions are met.

Findings

The purpose of this report is to identify the point at which PFA (including cenospheres) and FBA may cease to be a waste. In order for their waste classification to be removed and no further waste management controls required, PFA and FBA must:

- have a market and certainty of use;
- meet an appropriate publicly available standard (e.g. an identified specification) requiring no further processing before being used; and
- be capable of being used without undermining the aims of the Waste Framework Directive and the Water Framework Directive of protecting human health and the environment.

The TAG concluded that there is sufficient evidence to support the use of products from PFA, FBA and cenospheres without waste management controls. Its findings are summarised below:

Has a market and certainty of use

There are a number of potential uses for PFA, FBA and cenospheres. These can be split into three main broad categories:

- bound applications – used as an ingredient/component within another product and is fully bound within that product;
- unbound applications – used without any binding agent; and
- grouts – where the material is hydraulically pumped or injected into the ground to fill void space.

Approximately 6 million tonnes of PFA and 1 million tonnes of FBA are produced annually by UK coal-fired power stations. Virtually all FBA is used in lightweight concrete block manufacture but approximately 50 per cent of the PFA is sent to landfill.

The designation of PFA as waste is limiting the use of PFA in some applications. The removal of this waste stigma is expected to increase the use of PFA in many applications and therefore reduce the amount being landfilled.

Meets a standard and requires no further processing

A number of British and European standards could be applied to PFA and FBA destined for use in most applications. These standards give the required engineering specification of the material and detail any necessary testing to demonstrate compliance.

There are no specified standards for the use of cenospheres in paint and plastics, or PFA in ceramic tiles and bricks. However, these are extremely specialised applications and the use of a customer specification should be appropriate to ensure certainty of use and no further processing.

Does not cause harm to human health or the environment

The risk assessment concluded that, overall, the use of products from PFA and FBA pose a low risk to human health and the environment provided a number of simple good practice measures are followed.

The use of PFA and FBA in bound applications has been shown through historical testing and reporting by the Department of the Environment, Transport and the Regions (DETR), the Drinking Water Inspectorate (DWI) and British Standards Institution (BSI) to be acceptable for use in contact with water without resulting in unacceptable impacts on water quality provided recommendations contained in DWI Advice Sheet 7 and the requirements of BS EN450-1: 2005 are followed.

There are concerns about the use of PFA in unbound and grout applications due to the potential release of cadmium and mercury (List I substances) to groundwater.

This potential risk would be sufficiently mitigated provided the United Kingdom Quality Ash Association (UKQAA) code of practice for the sale and use of PFA [13] and Building Research Establishment (BRE) *Stabilising mine workings with PFA grouts: environmental code of practice* [19] are followed.

Because the Groundwater Directive does not allow List I substances to come into contact with groundwater, the Environment Agency suggests that both codes of practice should be updated to include the following additional controls:

- the use of unbound applications and grouts should be prohibited in Source Protection Zone (SPZ)1[1];
- grouts should not be used below the water table without an appropriate site-specific risk assessment;
- a site-specific risk assessment should be completed for extensive uses (i.e. applications using a surface area >150m^2) of unbound applications and grout in SPZ2 and SPZ3, and above the water table; and
- a risk screening approach should be adopted for developments that may affect groundwater.

Any site-specific risk assessment completed should follow the guidelines set out in the DETR guidelines for environmental risk assessment and management.

The TAG recommends these major changes should be incorporated into the Quality Protocol (if produced) with the intention to update the codes of practice in due course.

In addition to these changes, it was suggested that the BRE code of practice should be revised to update legislation and terminology. The TAG recommends these minor changes should be detailed during the Quality Protocol consultation period.

To ensure the protection of surface water, the following regional surface area limits for unbound applications should be followed:

- Wales region – 250,000m^2.
- Northwest and Southern region – 500,000m^2.
- South West region – 750,000m^2.

Surface areas of up to 1 million m^2 would be acceptable in all other regions.

1 See Appendix G for further information on 'Source Protection Zones'

It has been suggested that the use of co-combustion materials may affect the chemical composition of PFA and FBA. In order to limit this affect the TAG recommend that the Quality Protocol ensures that if the co-combustion materials change, the PFA and FBA is tested to ensure it does not significantly exceed the parameters used by the risk assessment and detailed in Appendix F.

Conclusions

PFA and FBA currently have end markets that will be further stimulated if their classification as a waste is removed.

Producers must ensure that products from PFA and FBA meet the appropriate standards identified in this report.

With the appropriate use of good practice guidance, if the chemical composition does not significantly exceed the parameters used in the risk assessment and listed in Appendix F, the risk of harm to human health and the environment from the use of products from PFA and FBA is low.

Recommendations

The information gathered by the TAG in the preparation of this report supports the adoption of a Quality Protocol for the use of PFA and FBA in bound, unbound and grout applications.

With regard to the protection of human health, the TAG recommends the Quality Protocol states that the following good practice is adhered to:

- avoid creating airborne dust wherever possible;
- where dust is generated, consider engineering control measures (water sprays) to keep the airborne dust concentrations as low as reasonably practicable;
- avoid prolonged skin contact especially where the product is dampened;
- wear appropriate protective clothing (e.g. goggles, gloves, overalls and boots);
- change heavily contaminated clothing as soon as possible and launder it before reuse;
- maintain good housekeeping practices and high standards of personal hygiene; and
- use respiratory equipment strictly in accordance with the manufacturer's recommendations and follow any statutory requirements governing its selection and use.

The TAG identified a number of existing standards that can be applied to most of the PFA and FBA applications. Where a standard is not listed, the TAG recommends asking industry during the consultation if there is a need for one or whether a customer specification is appropriate.

It has been suggested that the use of co-combustion materials may affect the chemical composition of PFA and FBA. In order to limit this effect the TAG recommend that the Quality Protocol ensures that if the co-combustion materials change, the PFA and FBA is tested to ensure it does not significantly exceed the parameters used by the risk assessment and detailed in Appendix F.

The risk assessment resulted in a number of recommendations for use of standard good practice in all applications (e.g. UKQAA and BRE codes of practice). The TAG recommends this guidance is listed in the Quality Protocol and adhered to by users of PFA and FBA.

The Environment Agency recommends that the following additional controls are included in the Quality Protocol with the intention to update the codes of practices in due course:

- both unbound applications and grouts should be prohibited in areas designated SPZ1;
- grouts should not be used below the water table without an appropriate site-specific risk assessment;
- a site-specific risk assessment should be completed for extensive uses (i.e. applications using a surface area >150m^2) of unbound applications and grout in SPZ2 and SPZ3, and above the water table; and
- a risk screening approach should be adopted for developments that may affect groundwater.

Any site-specific risk assessment completed should follow the guidelines set out in the DETR guidelines for environmental risk assessment and management.

It is also suggested that in order to help characterise a site and locate aquifers, the Quality Protocol should refer to the use of the map contained in Groundwater protection: policy and practice. Part 4: Legislation and policies, issued by the Environment Agency for public consultation in June 2007.

In addition to these major changes, the Environment Agency suggests that the BRE code of practice should be revised to update legislation and terminology. The TAG recommends these minor changes should be detailed during the consultation period.

The risk assessment was based on worst case scenarios for the use of PFA and FBA. In order to evaluate the risks in more realistic scenarios, the risk assessment recommends:

- reviewing further test data from other power stations in England and Wales to refine information on the early leaching behaviour of soluble determinands;
- examining the effects of environmental weathering during storage on the dilution of List I substances and other metals; and
- studying the pozzolanic effects as these tend to limit permeability and leachate generation.

The TAG also recommends the Quality Protocol be reviewed and updated if coal combustion practices in the UK change significantly; for example, any change which results in the composition of PFA and FBA altering from that considered in the risk assessment and as detailed in Appendix F of this report.

1. Introduction

1.1 The Waste Protocols Project is a joint Environment Agency and WRAP (Waste & Resources Action Programme) initiative in collaboration with industry, funded by the Department for Environment, Food and Rural Affairs (Defra) as a business resource efficiency activity.[2]

1.2 Uncertainty over the point at which waste has been fully recovered and ceases to be waste within the meaning of Article 1(1)(a) of the EU Waste Framework Directive 2006/12/EC has inhibited the development and marketing of materials produced from waste which could be used beneficially without damaging human health and the environment. In some cases, this uncertainty has also inhibited the recovery and recycling of waste and its diversion from landfill.

1.3 Interpretation of EU legislation is ultimately a matter for the European Court of Justice and there is now a substantial body of case law on the interpretation of the definition of waste in Article 1(1)(a) of the Waste Framework Directive. Drawing on the principles established in this case law, it is possible to identify the point at which certain wastes cease to be waste and thus when the Waste Framework Directive's waste management controls no longer apply. This identification is the purpose of the Waste Protocols Project.

1.4 More specifically, depending on the circumstances of each waste stream concerned, the project seeks to achieve the following outcomes:

- to produce a Quality Protocol identifying the point at which waste, having been the subject of a complete recovery operation, may become a non-waste product or material that can be either reused by business or industry, or supplied into other markets, enabling such fully recovered products to be used without the need for waste management controls; and
- to produce a statement that confirms to the business community what legal obligations they must comply with to use the treated waste material.

1.5 Pulverised fuel ash (PFA) from the combustion of coal for energy was one of the waste streams identified for further research by the Waste Protocols Project. A Technical Advisory Group (TAG) was set up to bring together representatives from the Environment Agency, WRAP and industry. Appendix A contains a list of TAG members and Appendix B gives its terms of reference.

1.6 TAG members subsequently agreed that they would evaluate furnace bottom ash (FBA) in addition to PFA and cenospheres (a type of PFA) from the combustion of coal with and without the use of co-combustion materials. For the purposes of this document, the definition of PFA includes cenospheres.

1.7 For PFA and FBA to be considered as having ceased to be waste, it is necessary to demonstrate that the material has been fully recovered and that there is no further need for waste management controls.

1.8 To investigate this, the TAG considered in particular whether the waste has been made into a distinct product:

- having a market and certainty of use;
- meeting an appropriate publicly available standard (e.g. an identified specification) requiring no further processing before being used; and
- capable of being used without undermining the aims of the Waste Framework Directive and the Water Framework Directive of protecting human health and the environment.

1.9 The objectives of this report are to:

- describe the progress of the TAG on this topic;
- set out the TAG's findings; and
- provide recommendations to the Project Board and the Environment Agency on what steps are needed to meet one of the project outcomes as stated in paragraph 1.4.

2 The Waste Protocols Project was formerly funded by Defra's BREW (Business Resource Efficiency and Waste) Programme

1.10 The TAG set out to:

- identify the major markets and thus appropriate end uses for PFA and FBA;
- identify the current legislative framework;
- consider standards or specifications appropriate for PFA and FBA;
- propose terminology that can be used consistently;
- identify and subjectively quantify the relative risk to human health and the environment from the use of products from PFA and FBA; and
- suggest the way forward for each of the major markets so that certain end uses may be regarded as fully recovered when strictly defined conditions are met.

1.11 The information contained in this report has been provided by representatives of the TAG, unless otherwise referenced.

1.12 The TAG would particularly like to acknowledge the inputs and support received from the United Kingdom Quality Ash Association (UKQAA), Joint Environmental Programme (JEP) and Association of Electricity Producers (AEP). These bodies are represented on the group but have played a critical role during the extended data collection process.

2. How PFA and FBA are produced

2.1 The generation of electricity from coal-fired power stations results in the production of two forms of ash:
- furnace bottom ash (FBA); and
- pulverised fuel ash (PFA).

2.2 FBA is collected from the bottom of the furnace and accounts for 10–20 per cent of the ash produced.

2.3 PFA is a fine powder made up of individual fused ash spheres with a typical median diameter of about 10–15µm [1]. A certain proportion of PFA is formed as cenospheres, which are hollow glass spheres. These are described and handled as PFA until the lagoon stage of processing (lagooning), when they are separated.

2.4 Inputs

2.4.1 Co-combustion materials are increasingly being utilised by UK coal-fired power stations. These materials include petcoke (petroleum coke) and some types of biomass (e.g. derived from olive, wood, palm kernel and cereal) [1].

2.4.2 The use of co-combustion materials may affect the chemical composition of the resulting PFA and FBA. However, the risk assessment has shown that, at the levels burned in the UK (typically <6 per cent), there is no significant effect on the chemical composition of PFA or FBA. A trial programme has begun to examine the impact of changes in co-combustion materials on both the combustion process and the quality of PFA and FBA produced.

2.4.3 In order to limit this affect the TAG recommend that the Quality Protocol ensures that if the co-combustion materials change, the PFA and FBA is tested to ensure it does not significantly exceed the parameters used by the risk assessment and detailed in Appendix F.

2.5 Combustion process

2.5.1 Figures 2.1 and 2.2 contain flow charts showing how PFA, cenospheres and FBA are produced.

2.5.2 At the power station, the coal is ground to a fineness similar to cement and then blown into the boiler furnace with air. The coal burns within 3–4 seconds [2], leaving the fine ash as molten beads within the furnace exhaust gas stream.

2.5.3 In recent years, low nitrogen oxide (NO_X) burners have been introduced to reduce emissions of oxides of nitrogen [3]. As a result there is a tendency for ashes to have higher levels of unburnt carbon. Other NO_X control measures such as over fire air (OFA) are being introduced which could also increase unburnt carbon in the ashes [4].

2.5.4 The PFA and cenospheres pass out of the furnace area with the flue gas. As they do so they cool such that they are below their melting temperature when the gas leaves the furnace.

2.5.5 As a consequence of how they are formed, ash particles – particularly those below 50µm in diameter – are spherical in shape. The rapid cooling experienced by the ash particles as they pass out of the furnace causes them to solidify to form an amorphous, glassy material.

2.5.6 A certain amount of PFA is formed as cenospheres, which are hollow glass spheres often containing other PFA particles. This is a result of the trapping of a bubble of furnace gas in the molten PFA particles at the high temperatures involved. Cenospheres are used in applications where their lightweight, low density, alumino-silicate microspherical properties are critical to performance. They thus have a high financial value. Cenospheres account for <1 per cent of PFA production.

2.5.7 Some ash in a molten state adheres to the boiler tubes within the furnace. When its weight exceeds that which can be maintained on the tubes, this ash falls to the bottom of the furnace. Here the ash is cooled using high-pressure water jets and flushed from the bottom of the furnace. This material is FBA.

2.5.8 PFA particles leaving the furnace are captured from the flue gas by electrostatic precipitators (ESPs). PFA is held temporarily in hoppers beneath the precipitators.

2.5.9 As regulatory pressure to reduce sulphur dioxide (SO_2) emissions has increased, electricity generators have increasingly opted to burn imported coals with a low sulphur content. However, electrostatic precipitator performance is optimised with a high level of sulphur content in the flue gas. Some operators have introduced sulphur trioxide (SO_3) injection to offset the reduction in sulphur to maintain good ESP performance and thus minimise dust emissions.

2.5.10 One UK coal-fired power station injects lime into the flue gas stream to reduce sulphur dioxide emissions and uses bag filters instead of ESPs to remove PFA. The lime is injected upstream of the bag filters and effectively results in the production of calcareous PFA due to the presence of lime and gypsum.

2.6 PFA and FBA handling

2.6.1 Collected PFA is handled depending on the intended end use. The three main ways are as follows:

- dry – for use in cementitious applications, grouts and foamed bitumen;
- conditioned – where water is added to prevent dust issues; and
- slurried – where ash is transported to settlement lagoons.

2.6.2 PFA intended for use in cement and concrete production is normally used dry and is tested for Loss on Ignition (LOI) and/or fineness. LOI determines the amount of unburnt carbon in PFA; as explained above, levels of unburnt carbon have increased in recent years due to NO_X control methods. The UK standard specification for concrete, BS 8500 [5], currently has a limit of 7.0 per cent maximum LOI in the specification for concrete though BS EN 450-1 [6] permits PFA with up to 9.0 per cent LOI.

2.6.3 There is nothing technically wrong with PFA with a high LOI. A LOI limit is placed on PFA for its use in concrete because of the impact unburnt carbon has on the effectiveness of admixtures, that are used to improve concrete performance, and the quantity required. LOI is less important in other applications as they rarely contain admixtures. If the LOI is kept consistent, the dosages of admixtures can be adjusted to compensate for any effects on quality.

2.6.4 LOI is monitored continually at power stations to check the efficiency of the boilers. The LOI information is then used to decide which end uses the PFA is suitable for.

2.6.5 PFA with a low LOI (<7 per cent) can be used in concrete straight from the power station. Alternatively it can be passed through air-swept classifiers to produce a finer, water-reducing and therefore more reactive 'Class S' material. This further processing is permitted under BS EN 450.

2.6.6 PFA with a high LOI (>7 per cent) can be passed through a carbon separator system to separate it into high and low carbon fractions. The high carbon PFA from this process can be mixed with pulverised coal and returned to the furnace.

2.6.7 PFA that does not meet the relevant quality for use to BS EN 450 may be used for other dry applications such as grouts or foamed bitumen, but is usually conditioned for use in other applications that require PFA in the form of a wet ash. Alternatively, the PFA may be slurried for storage or disposal in mounds or lagoons.

2.6.8 Conditioners are large mixers that simply mix PFA with ≥25 per cent water (depending on the application) to produce conditioned ash. In this semi-dry form, the PFA is similar to a silt soil and can be:

- easily transported in normal tipping vehicles to a variety of uses;
- stored awaiting use; and
- sent to a disposal site if surplus to requirements.

2.6.9 Excess ash may be mixed with water until it has a water content >60 per cent for pumping using slurry pumps to lagoons. Here the excess water drains, returning to a river or the sea – often via a water treatment process. The PFA may be harvested from the lagoons and allowed to drain before being sold. Despite storage and exposure to the elements for many years, 'lagooned' PFA retains similar properties to those of 'run-of-station' PFA [7].

2.6.10 The hollow PFA particles (cenospheres) float to the surface of the lagoons. The cenospheres have the potential to become a significant dust problem if they are allowed to dry out so are removed regularly to be sold as lightweight filler.

2.6.11 FBA is collected from the bottom of the furnace, quenched with water, crushed and transported hydraulically to pits where it is drained. Once drained, it is removed and may be crushed and screened into coarse and fine fractions.

2.7 Outputs and applications

2.7.1 PFA can be supplied in various forms:

- Dry ash. This is supplied in tankers and is used as a concrete addition, for aerated block manufacture, mixed and pre-cast concrete products and grouts. Though it can be classified to remove the coarser particles to enhance reactivity, the majority is not.
- Conditioned ash. This is PFA that is mixed with an appropriate percentage of water. It is supplied in tipping vehicles and is used for block manufacture, grout, load-bearing fill and landscaping. Conditioned PFA may also be recovered from lagoons after they have been drained.
- Cenospheres. These unique free-flowing powders composed of shelled, hollow minute spheres are generally used as inert filler in industrial applications. Cenospheres may also be used in paint, varnish and plastics.

2.7.2 FBA is supplied as 'all in aggregate' or occasionally as separate 'coarse and fine aggregate'. It can be used in block manufacture or as a sub-base in road construction or in temporary roads.

2.7.3 Section 3 provides more detail on the main markets and applications for PFA and FBA.

Figure 2.1: Production and processing of PFA and cenospheres

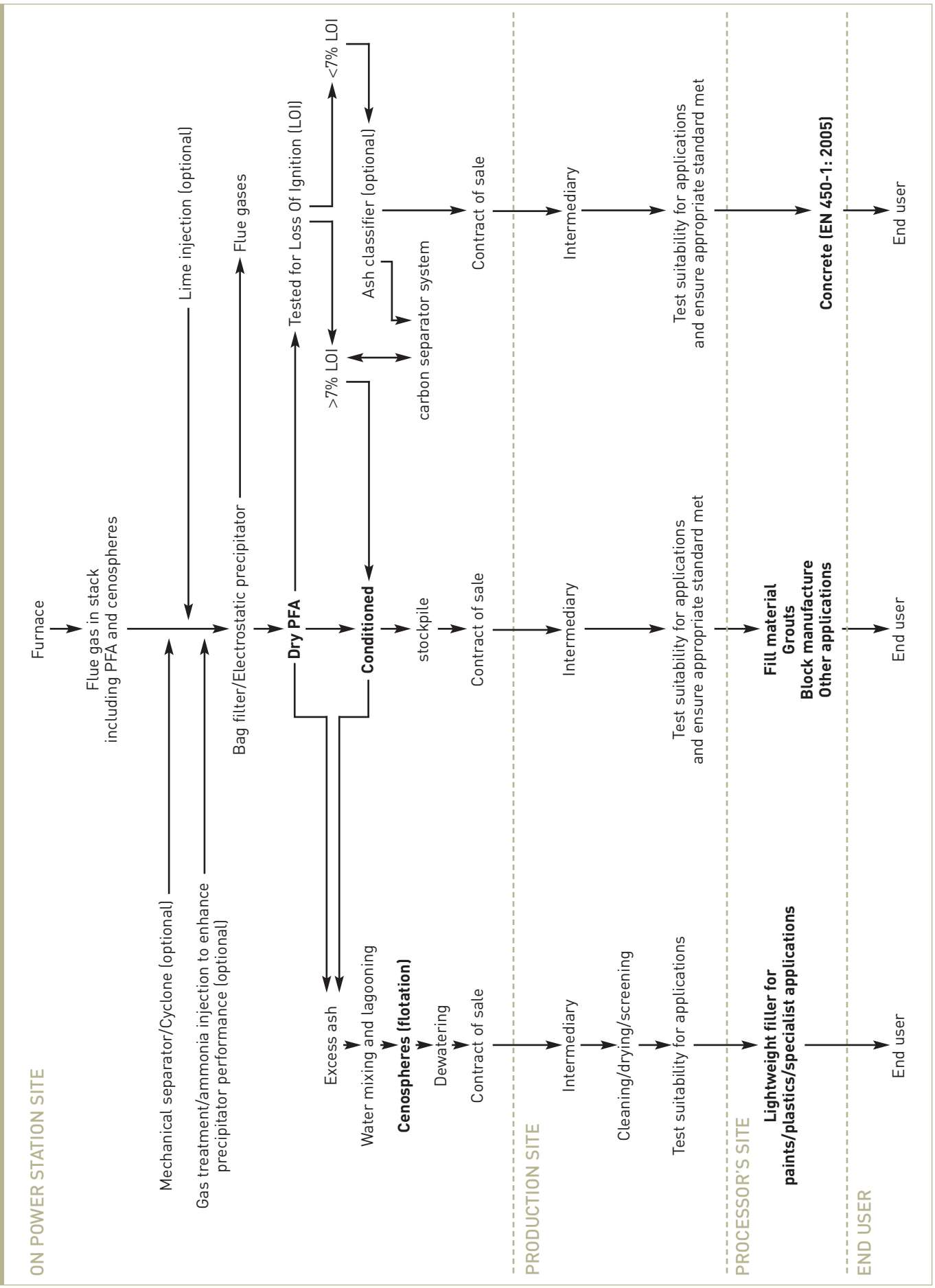
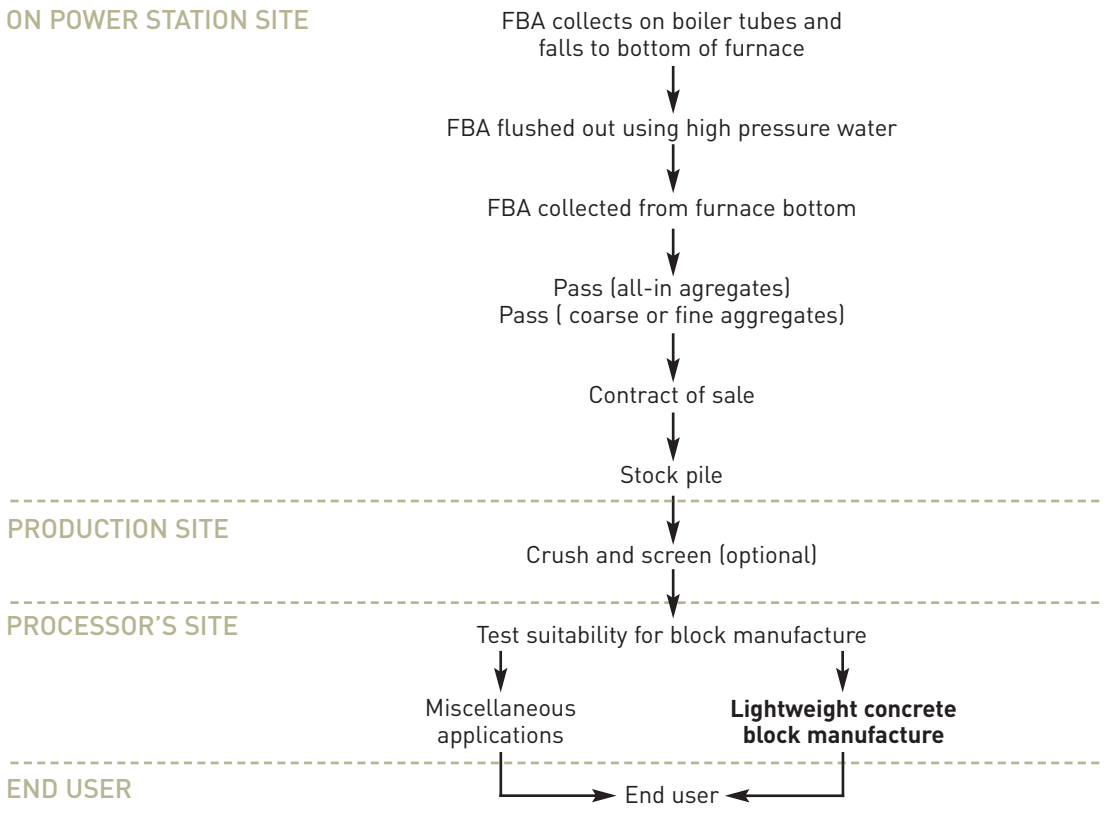


Figure 2.2: Production and processing of FBA



3. Key markets for PFA and FBA

3.1 There are a number of potential uses for PFA, FBA and cenospheres. The TAG agreed that, for the purposes of this technical report, the potential uses can be split into three main broad categories:

- bound applications – used as an ingredient/component within another product and is fully bound within that product. Examples include concrete, asphalt, hydraulically bound mixtures, ground stabilisation, plastics and rubber;
- unbound applications – used without any binding agent. Examples include as a fill material in embankments and as capping layers; and
- grouts – where the material is hydraulically pumped or injected into the ground to fill void space. The material sets gradually. Setting time is dependant on the mixture design, water content and ground conditions.

3.2 PFA is primarily used in the construction market. Table 3.1 and Figure 3.1 summarise the detailed uses of PFA, FBA and cenospheres.

Table 3.1: Summary of uses for PFA, FBA and cenospheres

Broad category	Product	Details	Estimated ash use in 2006 (tonnes)	Proportion of total sales (PFA and FBA)
Bound applications	Aerated concrete blocks	PFA used as filler aggregate. Bound with cement and/or lime pozzolanic reaction.	787,447	20.5%
	Lightweight concrete blocks	FBA used as an aggregate. Bound with cement.	1,010,981	26.3%
	Cement manufacture – raw material	PFA added as raw material into kiln feed. Bound chemically in kiln.	423,588	11.0%
	Cement manufacture – blended cement	PFA added to Portland cement. Extends Portland cement and enhances technical performance.	88,384	2.3%
	Ready-mixed and pre-cast concrete	PFA used as an addition to concrete with the Portland cement to enhance technical properties. May also be added as filler aggregate. Bound by Portland cement.	548,218	14.3%
	Ceramic tiles and brick making	PFA mixed with clay and heated in kiln to vitrification.	Not collected*	
	Sintered lightweight aggregate (Lytag)	PFA is partially melted and formed into spherical lightweight aggregate for use in screeds, concrete or as aggregate for block making. Bound by cement.	62,529	1.6%
	Paints, plastics, rubber and similar	Cenospheres and PFA are used as filler aggregate to extend the medium, e.g. paint, rubber, plastic. They are bound by the medium they are included in.	1,522	0.04%
	Asphalt	PFA as filler in foamed bitumen and some asphalt mixtures to enhance technical properties. Bound by bitumen.	Not collected*	

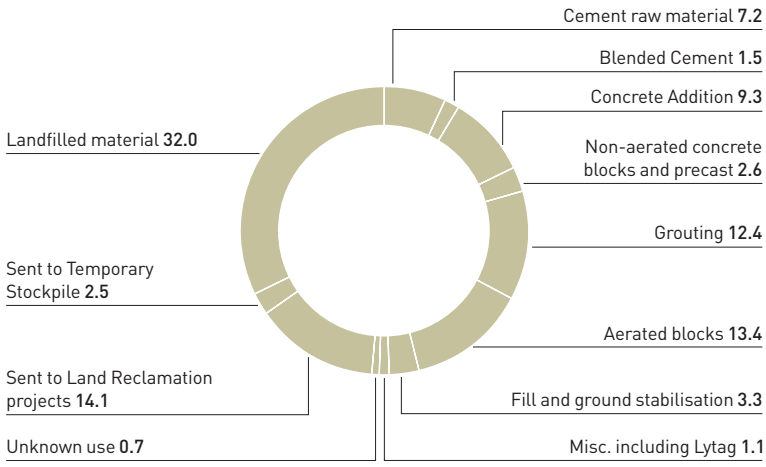
* The UKQAA does not collect statistics for smaller applications. These are included in the miscellaneous category.
Source: LKA Sear, UKQAA.

Table 3.1: Summary of uses for PFA, FBA and cenospheres continued

Broad category	Product	Details	Estimated ash use in 2006 (tonnes)	Proportion of total sales (PFA and FBA)
Unbound applications	Fill material	PFA used to create embankments, raise levels for construction sites, cap contaminated land, etc.	191,648	5.0%
	Horse ménages, capping layers	FBA used as a free draining material which is lightweight and yet friable.	Not collected*	
	Sintered lightweight aggregate (Lytag)	Used as horticultural growing medium (Hortag), for vehicle arrestors, lightweight fill material (roof car parks).	Not collected*	
Grouts	PFA grouting	PFA used as the aggregate in producing Portland cement; PFA grouts for cavern, mine filling.	728,650**	19.0%
		Total FBA and PFA sales	**3,841,475**	

* The UKQAA does not collect statistics for smaller applications. These are included in the miscellaneous category.
Source: LKA Sear, UKQAA.
** Includes Northwich mines – a 1 million tonne contract.

Figure 3.1: Utilisation of UK produced PFA in 2006 (%)



3.3 Appendix C provides a more detailed market analysis of PFA.

3.4 Approximately 50 per cent of PFA produced in the UK enters the markets shown in Table 3.1 and Figure 3.1.

3.5 There are a number of advantages of using PFA in place of virgin materials for these market applications. These include:

- displacing the need for raw material extraction;
- avoided landfilling of PFA; and
- carbon savings.

3.6 On a weight-by-weight basis and in comparison with natural aggregates, the overall carbon dioxide (CO_2) savings of using PFA have been estimated to be up to 153,000 tonnes over 10 years [8]. This calculation assumes that, if 1 tonne of PFA is replaced by sand in grouting, then the extra CO_2 emissions would be 0.05 tonnes. The benefits from replacing aggregates with PFA in cement are around 0.8 tonne CO_2 per tonne cement.

3.7 The remaining 50 per cent of PFA produced in the UK is normally landfilled as conditioned ash in either a monofill or a lagoon.

3.8 Ground stabilisation is a process used in the construction of road and paved areas which allows the use of unsuitable in situ materials through the addition of binders to the soil. One such binder is PFA – as described in BS EN 14227-14 [9]. The process eliminates the import of virgin aggregates, vehicle movements, etc. and creates a suitable working platform and sub-grade and/or sub-base for subsequent construction activities.

3.9 Products such as sintered lightweight aggregate (Lytag) and horticultural growing medium (Hortag) are not currently produced in the UK. The TAG therefore agreed it would not consider these applications further in this report.

3.10 The TAG also agreed that the horse ménage application is currently a very small market and therefore should also not be considered further in this report.

3.11 If these markets develop further, the TAG recommends that a risk assessment is carried out so that they can be considered in reviews of the Quality Protocol.

3.12 The use of PFA in the remediation of contaminated land (ground remediation) is also not considered further in this document. The treatment of contaminated land is considered a waste activity and is therefore controlled by waste management controls.

4. Current legislative position

4.1 There has been considerable debate between industry and the Environment Agency over whether PFA should be classified as a waste or a by-product. The Environment Agency classifies PFA and FBA, in all circumstances, as a waste. The industry considers that PFA and FBA arising from coal-fired power stations that is used directly for another purpose should not be classified as a waste. The industry agrees that PFA that is discarded (into a PFA monofill) is classified as a waste.

4.2 Table 4.1 summarises the Environment Agency's interpretation of the current legislation and its regulatory approach.

Table 4.1: Summary of waste management controls on PFA and FBA

Activity	Current legislative control	Current approach
Formation of PFA and FBA from combustion of coal with or without the use of co-combustion materials.	All combustion processes >50 MW require a permit under the Environmental Permitting Regulations (England and Wales) 2007 (EPR).	Normal regulatory controls apply
Storage of PFA and FBA	Any material stored within the installation boundary must be stored in accordance with the site's permit. No additional permit is required. If stored off-site (i.e. outside the installation boundary), storage will require an environmental permit under the Environmental Protection Act 1990 unless the storage is exempt from licensing under one of the paragraphs in Schedule 3 of the EPR. Paragraph 19 of Schedule 3 of the EPR is one exemption that might apply if the PFA or FBA is to be stored on a site where relevant construction works will be carried out. If ≤20,000 tonnes of PFA or FBA are stored at a place where blocks are to be manufactured, the storage will also be exempt from licensing under paragraph 13 of the EPR. Exemptions must be registered with the Environment Agency.	Normal regulatory controls apply
Processing of PFA and FBA for end use	An environmental permit is required under the Environmental Protection Act 1990 unless the activity is exempt from licensing under one of the paragraphs in Schedule 3 of the EPR. Paragraph 13 is an exemption which might apply if the particular conditions of that paragraph are met. The manufacture of blocks from PFA and FBA can be carried out under this exemption. Exemptions must be registered with the Environment Agency.	Normal regulatory controls apply
Delivery of PFA and FBA to end user (consumer)	PFA and FBA must be handled according to the Environmental Protection (Duty of Care) Regulations 1991. The materials must be transported by a person who is registered as a waste carrier.	Normal regulatory controls apply
Use of PFA and FBA by the consumer	PFA and FBA are normally viewed as waste unless, and until, they are incorporated, for example, into a block or structure. The use of PFA or FBA will normally require an environmental permit under the Environmental Protection Act 1990 unless the activity is exempt from licensing under the EPR. PFA and FBA may be used for certain construction works under the exemption from permitting in paragraph 19 of Schedule 3 EPR. The storage of ash to be used for these works may also be exempt, subject to the conditions in paragraph 19.	Normal regulatory controls apply

4.3 In addition to waste management controls, the use of PFA and FBA is covered by other legislation such as:

- Groundwater Regulations 1998;
- Water Resources Act 1991 as amended by Water Act 2006;
- Water Framework Directive and associated Groundwater Daughter Directive (European Community directive on groundwater 80/68/EEC);
- The Town and Country Planning (Local Development) (England) Regulations 2004;
- Construction Products Directive 89/106; and
- drinking water standards imposed by the Drinking Water Inspectorate (DWI).

4.4 To protect groundwater the use of PFA and FBA can be controlled using a number of methods. The use can be prohibited or controlled using a Groundwater Regulations Regulation 19 notice. A Works Notice under the Water Resources Act 1991 can be used to forestall or mitigate pollution of controlled waters. The revised Groundwater Regulations are under consultation by Government at present.

4.5 The REACH Regulation

4.5.1 The REACH (Registration, Evaluation, Authorisation and Restrictions of Chemicals) Regulation [10] came into force in the EU in June 2007. It aims to improve protection of human health and the environment by making more information available about materials and products.

4.5.2 The Regulation applies to 'substances', 'preparations' (mixtures of substances), and 'articles'. These are defined in Articles 3(1), (2) and (3) of the Regulation as:

'1) Substance: means a chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition;

2) Preparation: means a mixture or solution composed of two or more substances;

3) Article: means an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition;'

4.5.3 All these exclude waste as defined in the Waste Framework Directive. It follows that compliance with a Quality Protocol, while resulting in the removal of the need to apply waste management controls, could bring the material or product concerned within the scope of the REACH Regulation.

4.5.4 The main effect is that, unless the material is specifically exempted from REACH, it will need to be registered by its manufacturer or importer or else it will no longer be able to be marketed in the EU. Certain substances are eligible for phased registration over an 11-year period (i.e. if they were on the market prior to 1981) but, to qualify, they must be pre-registered with the new European Chemicals Agency between 1 June and 1 December 2008. Otherwise, substances new to the market will be required to be registered after 1 June 2008.

4.5.5 It is the industry's interpretation that recovered materials or by-products will require registration. In conjunction with the European Coal Combustion Products Association (ECOBA), UKQAA members intend to:

- pre-register PFA and FBA; and
- form a Substance Information Exchange Forum (SIEF) to prepare a full chemical report.

4.5.6 Coal-fired power station ash products already have EINECS (European Inventory of Existing Commercial Chemical Substances) and CAS (Chemical Abstracts Service) numbers and will be registered under these.

4.5.7 Further information on this and other processes relating to REACH is available from the UK REACH Competent Authority website (http://www.hse.gov.uk/reach). Specific advice may be available from the Competent Authority Helpdesk on 0845 408 9575 or email ukreachca@hse.gov.uk

5. Standards and specifications

5.1 To ensure that products made from PFA or FBA are fit-for-purpose, the requirements of the standards outlined in Table 5.1 must be met. If the products do not meet the requirements of these standards, they will be unsuitable for use in the relevant applications.

5.2 European standards use the term 'fly ash' as being the accepted EU wide phraseology for PFA. These terms are synonymous. The term 'fly ash' is not to be confused with 'incinerator fly ash' which is produced from the incineration of municipal solid waste.

Table 5.1: Summary of standards, specifications and good practice documents

	Product	Standard	Use and associated standards	Quality controls
1	Engineering fill	Design Manual for Roads and Bridges (DMRB) Volume 7 [11] Specification for Highway Works (SHW) 600 series [12]	Embankments, raising ground levels.	UKQAA Environmental Code of Practice [13] and the SHW recommendations are that PFA fill is isolated from capillary action from subsoil and should be fully protected to prevent dust blow.
2	Fly ash for hydraulic bound mixtures in road construction	BS EN 14227-4 [14] DMRB/SHW	Capping, sub-base and road base in road construction. BS EN 14227-3 [15] covers fly ash bound mixtures. BS EN 14227-14 [9] covers soil treated by fly ash. pr EN 13282-1 and pr EN 13282-2 [16] cover factory-made hydraulic road binder cements. Use is governed by DMRB and SHW.	As required by SHW. DMRB sets out UK practice on road design (BS EN standards are not harmonised).
3	Type II addition in concrete	BS EN 450-1 and 2 [6]	Cementitious component in concrete. BS EN 206 [17] governs the use of Type II additions. BS 8500 is the UK complementary standard [5] and includes UK rules for the use of Type II additions. BS EN 12715 [18] permits the use of PFA as a cementitious component in grout.	Level 1+ attestation and CE marking An Annex to BS 8500 details the additional requirements in the UK that permit PFA to count fully towards the cementitious content of concrete as a Type II addition. This standard is required, as BS EN 206 is not a harmonised standard and as such there are no Europe-wide requirements on the use of additions. BRE Environmental Code of Practice for PFA grouts [19] contains a series of recommendations for protecting the environment.

Table 5.1: Summary of standards, specifications and good practice documents continued

Product	Standard	Use and associated standards	Quality controls
4.1 Filler aggregate (Type I addition in concrete)	BS EN 12620 [20]	Inert filler in concrete. BS EN 206 [17] governs the use of Type I additions. BS 8500 is the UK complementary standard [5] includes UK rules for the use of Type I additions.	Level 4 attestation and CE marking
4.2 Lightweight filler aggregate (Type I addition in concrete)	BS EN 13055-1 [21]	Inert filler in concrete and mortar including aerated concrete. BS EN 206 [17] governs the use of Type I additions. BS 8500 is the UK complementary standard [5] includes UK rules for the use of Type I additions. BS EN 771-3 and BS EN 771-4 [22] cover concrete masonry units including aerated concrete. BS EN 998-1 and BS EN 998-2 [23] cover mortars for rendering and plastering and for masonry uses.	Level 4 attestation and CE marking
5 Cementitious component in cement manufacture	BS EN 197-1 [24] for common cements BS EN 413-1 [25] for use in masonry cements BS EN 14216 [26] for use in very low heat special cements BS EN15368 [27] – for use in non structural applications prEN 13282-1 [16] – rapid setting road binder prEN13282-2 [16] – normal setting road binder	Component in cement manufacture. BS EN 206 [17] and BS 8500 [5] cover the use of cement types for use in concrete. BS EN 14227-1 [28] covers cement bound mixtures that may contain fly ash.	Controls are required on influential components such as LOI, alkalis and chemical constituents. The cements are required to have Level 1+ attestation and CE marking. Cement manufacturers may specify additional requests to these standards in order to balance the chemistry (e.g. silica and alkalis) in raw feed materials for cement clinker manufacture.

Table 5.1: Summary of standards, specifications and good practice documents continued

Product	Standard	Use and associated standards	Quality controls
6 Lightweight filler aggregate for use in grouts	BS EN 13055-1 [21]	BS EN 12715 [18] permits the use of PFA as an inert filler in grout.	Level 4 attestation and CE marking BRE Environmental Code of Practice for PFA grouts [18] contains a series of recommendations for protecting the environment.
7 Lightweight filler in bitumen-bound materials	BS EN 13055-2 [21]	Bitumen-bound road materials including foamed bitumen.	Level 4 attestation and CE marking
8.1 Mineral	Client specification dependent on balance of other raw materials	Ceramic tiles and brick manufacturing.	Material safety data sheet
8.2 Mineral	Client specification	Component in manufacture of lightweight aggregate (e.g. Lytag). BS EN 13055-1 and BS EN 13055-2 [21] cover the use of lightweight aggregates in cementitious and bitumen bound materials.	Material safety data sheet Aggregates require Level 4 attestation and CE marking.
9 Filler	Client specification	Paints, plastics rubber, etc.	Material safety data sheet
10 FBA as a lightweight aggregate in concrete	BS EN 13055-1 [21]	BS EN 206 [17] governs the use of Type I additions. BS 8500 is the UK complementary standard [5] includes UK rules for the use of Type I additions. BS EN 771-3 and BS EN 771-4 [22] cover concrete masonry units including aerated concrete. BS EN 998-1 and BS EN 998-2 [23] cover mortars for rendering and plastering and for masonry uses.	Level 4 attestation and CE marking
11 FBA as an aggregate in road construction	Sub-base and capping in road construction BS EN 13242 [29] for unbound road mixtures	DMRB/SHW set out requirements for capping (600 series) and sub-base (800 series) [30].	Material safety data sheet SHW contains guidelines on controls.

DMRB = Design Manual for Roads and Bridges
SHW = Specification for Highway Works

5.3 CE marking and levels of attestation

5.3.1 CE marking can be applied only to products meeting attestation and harmonised standards. These are standards that CEN (Comité Européen de Normalisation) has decided are necessary to allow trade across the EU in line with the requirements of the Construction Products Directive. Some standards (e.g. BS EN 14227 and BS EN 206) are not harmonised as there is deemed to be little cross-border trade in the products defined by the standards. These products cannot therefore use the CE marking.

5.3.2 The various European standards in Table 5.1 have differing levels of testing and compliance. These are known as 'levels of attestation' – the highest being 1+ and the lowest 4. The level of attestation reflects the degree of importance the product has to the satisfactory performance of the resulting structure.

5.3.3 The cement and cementitious additions to concrete require attestation at Level 1+. As such, anyone supplying to these standards is required to have third party accreditation and factory production control systems in place. Compliance is assessed at least annually and the third party accreditation body – such as BSI [31] or Construction Products Certification – QSRMC [32] – has to take independent samples of the materials for testing and comparison with the manufacturer's data.

5.3.4 The approach taken by third party accreditation bodies is harmonised across Europe through a body called Sector Group 2. This publishes 'position papers' [33],[34] for each standard to harmonise the accreditation of the various producers. These papers are available only to third party accreditation bodies.

5.3.5 Manufacturers are only permitted to use the CE mark on their products when they have been assessed and deemed compliant with the requirements of Annex ZA within a standard. Appendix E shows an example of a CE mark for EN450-1 PFA for concrete.

5.3.6 CEN may also publish guidance [35] designed to prevent third party accreditation bodies from interpreting a standard incorrectly. These documents are available through BSI.

5.3.7 Other EN standards require a lesser level of attestation. For example, BS EN 13055-1 [21] is Level 4 attestation, which is effectively self-certification by the supplier. Guidance on this is given in the standard.

5.3.8 The TAG agreed that, if a Quality Protocol was produced, there would be no need for any independent certification to accompany it as the industry already has a form of certification incorporated into the standards.

6. Material composition

6.1 Variations in the physical and chemical composition of PFA and FBA can be caused by a number of factors:

- type of coal and co-combustion materials used;
- crushed particle size of the coal;
- boiler unit design and firing technique;
- how the ash is stored and handled prior to reuse;
- distance travelled in the flue stream;
- milling and combustion conditions; and
- ash storage and conditioning.

6.2 Appendix F shows the typical chemical composition of PFA and FBA produced in the UK from the combustion of coal both with and without the use of co-combustion materials.

6.3 PFA

6.3.1 Approximately 60–90 per cent of PFA is amorphous glass spheres, rich in aluminium and silicon.

6.3.2 The surface layer of a PFA particle is likely to be enriched in sulphate, sodium, potassium, iron, calcium and magnesium to a depth of approximately 0.003 µm. Approximately 2 per cent of PFA is typically soluble in water [36].

6.3.3 Polycyclic aromatic hydrocarbons (PAHs) can arise from a wide range of combustion processes. However, the furnace temperatures in a coal-fired power station are so high that relatively low PAH levels are found. The leachate from PFA contains very small amounts of PAHs [37].

6.3.4 Dioxins are formed when chlorine is present in furnaces. There is little chlorine in coals used in the UK and the furnace temperatures are so high that dioxins cannot form. Dioxin levels of less than 10 ng/kg have typically been found in ashes [38].

6.3.5 Some co-combustion materials may affect the composition of PFA. Biomass tends to have lower concentrations of the majority of trace elements (cadmium, mercury, lead, arsenic) and the major elements (aluminium, silicon, iron). However, the concentrations of trace elements manganese and zinc in biomass may be equivalent to or higher than those in coal. The major elements (phosphorus, sodium, calcium and potassium) tend to be higher in biomass than in coal.

6.3.6 The main inorganic constituents in petcoke are vanadium (V) and nickel (Ni). At current levels of petcoke burn, Ni and V have not been shown to cause a problem (see Section 7).

6.3.7 As PFA is derived from natural fossil fuel, it contains small amounts of naturally occurring radionuclides.

6.3.8 PFA is able to undergo a pozzolanic reaction in the presence of moisture and lime. Because PFA contains a small quantity of lime, it will harden to some extent on contact with water and is therefore naturally pozzolanic. Lime is needed to promote the pozzolanic reaction and results in stabilisation/solidification of the material.

6.3.9 The stabilisation of PFA relies on the formation of calcium silicate gels which harden gradually over a long period of time to form a stable material. The pozzolanic reaction results in the production of a chemical and physical barrier to metal ion migration [39].

6.3.10 The resulting material is a less porous, impermeable material and may form a weathered crust over a PFA mound.

6.3.11 The rate of the pozzolanic reaction and subsequent formation of a cementitious crust depends on a range of variables such as:

- surface area of the particles;
- chemistry of the solids and fluids; and
- environmental factors such as temperature.

6.3.12 Due to lack of information, the TAG did not consider further the pozzolanic reaction and its affect on the potential to reduce leaching.

6.4 Weathered/conditioned PFA

6.4.1 The mineralogy of PFA alters following chemical interactions with water and natural strata. Weathered ash has been found to contain more potassium and sodium and less calcium, magnesium and iron than newly produced ash. Concentrations of barium, beryllium, lithium, strontium, vanadium, copper and zinc were also found to be less in weathered PFA [40].

6.4.2 The sulphate level in lagoon PFA is usually very low because the water/solids ratio used to slurry the PFA means the majority of the sulphate is washed out during the lagooning process. Excess water from lagoons is returned to the river/sea as appropriate, though it may be treated. These processes are all governed by the power station's environmental permit.

6.5 FBA

6.5.1 The composition of FBA is very similar to that of PFA, with oxides of the predominant elements aluminium, iron and silicon representing 80 per cent of the solid material. Compared to PFA, FBA contains less of the volatile elements but more of the refractory elements chromium, iron, manganese and nickel. Less than 1 per cent by weight of FBA is soluble in water.

6.5.2 FBA does not have the 'surface layer' effect observed with PFA.

6.5.3 The use of co-combustion materials will generally have the same effect on FBA as PFA.

6.5.4 Both dioxin and PAH levels have been found to be low in FBA [38].

6.6 Implications of material composition in relation to end use

6.6.1 The ash from power stations which inject lime into the flue gas stream has a relatively high lime and gypsum content and is known technically as a calcareous fly ash. Due to pozzolanic and gypsum reactions, this ash becomes self-setting on contact with water. This makes the PFA unsuitable for use in concrete and cement and unable to comply with BS EN 450-1 [6]. However, it has considerable benefits in some applications such as road sub-base construction where self-setting is beneficial.

6.6.2 Ash produced in recent years from combustion processes fitted with low NO_X burners has a tendency to contain more unburnt carbon. This ash is still suitable for use in cement and concrete production if its LOI is below the limit of 7.0 per cent specified in BS 8500 [5] or 9.0 per cent specified in BS EN 450-1 [6].

6.6.3 Ammonia may be injected into the gas stream to improve the efficiency of electrostatic precipitators. A stoichiometric amount of ammonia reacts with compounds in the gas stream to form various salts. If excess ammonia is injected, the excess is absorbed into the ash particles. However, it may be released on contact of the ash with an alkaline material such as Portland cement. This problem is known as ammonia slip and makes it difficult to use such ash in the concrete industry. Even small amounts of ammonia are detectable by smell (<10 ppm by volume in air).

6.6.4 The TAG confirmed that SO_3 injection (see paragraph 2.16) has no impact on overall PFA and FBA quality. It is undertaken simply to boost SO_3 levels in flue gas from low sulphur coals to optimise ESP performance.

6.7 To assess the perceived risks that PFA and FBA leachate causes harm to human health and the environment, a risk assessment was commissioned to:

- determine the generic properties of PFA and FBA; and
- ascertain whether certain proposed end uses could present unacceptable risks to human health or the wider water environment (surface water and groundwater).

7. Risk assessment

7.1 The aims of the risk assessment [41] were to:
- assess PFA and FBA sources and leaching characteristics;
- assess the risk to controlled waters (groundwater and surface water);
- assess the risk to human health; and
- suggest ways in which perceived risks to human health and the environment might be mitigated and managed.

7.2 The generic risk assessment was undertaken to review such risks in the context of typical PFA applications. The uses assessed were:
- bound concrete;
- unbound embankments and made ground construction caps; and
- grouts.

7.3 The risk assessment is based on solid and leachate test data provided by the power-producing companies, i.e. it is representative of the PFA and FBA produced in England and Wales. Leaching data for PFA and FBA co-fired with petcoke and biomass were assessed together as no significant variation in composition was identified.

7.4 As a result of this risk assessment and further discussion with the Environment Agency, it was concluded that, as flood waters are themselves highly contaminated, the risk of any potential leachate from unbound applications in the flood plain would be negligible.

7.5 The conclusions from the risk assessment are set out below.

7.6 Human health

7.6.1 A quantitative human health risk assessment was undertaken with the aim of identifying the level of risks to construction workers and adjoining site users from exposure to PFA and FBA dust during a construction project.

7.6.2 The concentrations of metals in the air were calculated on the basis that the dust is made up entirely of PFA or FBA. This therefore represents a worst case scenario.

7.6.3 To assess the risk to local residents, the calculated off-site dust concentrations were compared with short-term and long-term Environmental Assessment Levels (EALs). The assessment concluded that no EALs were exceeded.

7.6.4 To assess the risk to construction workers, the maximum potential concentrations in the air – of individual substances with assigned Workplace Exposure Limit (WEL) – were calculated on the basis that the maximum dust levels allowed by the Control of Substances Hazardous to Health (COSHH) Regulations are adhered to. The assessment concluded that, provided good practice dust control measures were followed:
- exposure would remain below the dust levels allowed; and
- concentrations would be below the lowest applicable WEL.

7.6.5 The following good occupational hygiene and safety practices were recommended:
- avoid creating airborne dust wherever possible;
- where dust is generated, consider engineering control measures (water sprays) to maintain the airborne dust concentrations as low as reasonably practicable;
- avoid prolonged skin contact especially where the product is dampened;
- wear appropriate protective clothing (e.g. goggles, gloves, overalls and boots);
- change heavily contaminated clothing as soon as possible and launder before reuse;
- maintain good housekeeping practices and high standards of personal hygiene; and
- use respiratory equipment strictly in accordance with the manufacturer's recommendations and follow any statutory requirements governing its selection and use.

7.6.6 TAG members confirmed that industry is already using these good occupational hygiene and safety practices.

7.6.7 The human health risk assessment also looked at the perceived risk of radiation from the use of PFA. PFA is derived from a natural fossil fuel and therefore contains small amounts of naturally occurring radionuclides. The risk assessment reviewed a standalone radiological risk assessment for PFA carried out by the Health Protection Agency (HPA) [42].

7.6.8 The conclusion from these studies was that the radiological impact on workers and members of the public from the use of PFA in building material was negligible.

7.6.9 In terms of potential exposure through the use of PFA as a general fill, the HPA confirmed that the testing performed on PFA is also applicable to unbound ash applications given that there is a protective layer of concrete over any fill materials used to level the ground. The low exposure duration and frequency would also limit the public to the radiation in applications such as embankments.

7.6.10 The human health risk assessment therefore concluded that, provided good practice was followed, there would be no risk of harm to human health from the use of PFA and FBA in bound, unbound or grout applications.

7.7 Controlled water

7.7.1 The aim of the risk assessments for controlled water was to determine whether the eluate produced by an end use PFA could have an unacceptable impact on surface water and/or groundwater.

7.7.2 For bound applications and grouts, the risk assessment drew conclusions on the risks to controlled waters from historical testing and reporting by the Department of Environment, Transport and the Regions (DETR),[3] and the Drinking Water Inspectorate (DWI) [43].

7.7.3 A quantitative risk assessment was applied to determine the risks to surface water and groundwater of using PFA and FBA in unbound applications.

7.7.4 Unbound applications – surface water

7.7.5 To calculate generic likely dilution factors in surface waters, flow statistics were collated from raw data provided by the Centre of Ecology and Hydrology (CEH). Regionally representative flow rates were then calculated.

7.7.6 Chromium was identified as the highest potential contaminant with respect to its theoretical leachate and surface water background concentrations. It was therefore used as the risk driver for determining impacts on surface watercourses.

7.7.7 Regional-specific background concentrations were used to calculate dilution factors for chromium in a number of infiltration zones.

7.7.8 The conceptual model used for the surface water assessment is shown in Figure 7.1.

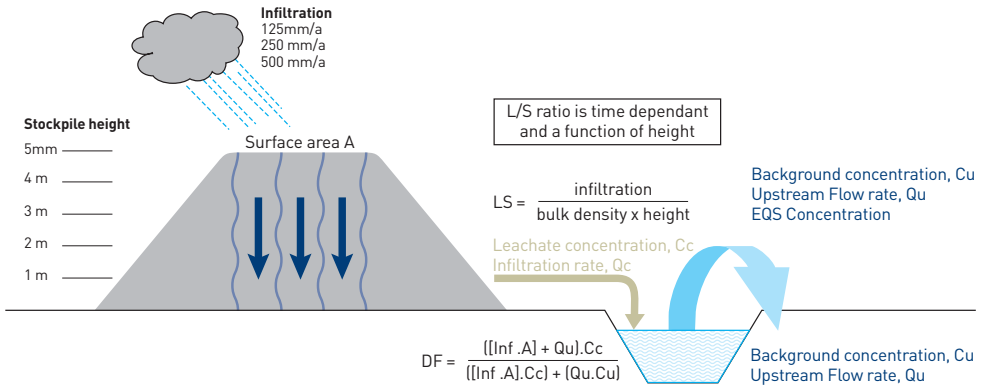
7.7.9 Environment Agency risk assessment guidance recommends use of a dilution factor of 10 per cent of the available Environmental Quality Standards (EQS) concentration above background levels where background concentrations and low watercourse flow conditions have not been taken into account.

7.7.10 As the risk assessment was representative of both regional-specific background concentrations and watercourse flows, the TAG agreed that a higher value of 50 per cent dilution of the EQS should be used.

7.7.11 A maximum generic PFA surface area (i.e. acceptable for all combinations of river flow rates, infiltration rates and PFA heights) was calculated. This gave the maximum area above which no further assessment was needed.

3 Predecessor to Defra.

Figure 7.1: Surface water conceptual model



*Cu represents background concentration, Qu represents upstream flow rate.

7.7.12 The results show that, for PFA embankments and capping layers up to 10 metres in height, draining to a surface watercourse is acceptable for proposed surface areas of 250,000–750,000m^2 (depending on the region) for 10 per cent dilution of the EQS. For 50 per cent dilution, areas of up to 1 million m^2 would be acceptable.

7.7.13 Wales region would require a surface area limit of 250,000m^2, Northwest and Southern regions would require a limit of 500,000m^2 and Southwest region would require a limit of 750,000m^2 in order to protect surface water quality.

7.7.14 The TAG agreed that these areas are likely to cover most applications of PFA and demonstrate a low risk of impact to surface water quality but it is recommended that this is added into the Quality Protocol, if produced, to provide clarity.

7.7.15 Unbound applications – groundwater

7.7.16 To assess risk to groundwater, the concentration of each determinand in the representative leachate was compared with its drinking water standard (DWS) to establish which determinands have the potential to present a risk to groundwater as a potable resource.

7.7.17 However, use of DWS is only appropriate as an indication of the potential pollutant load. Pollution may occur at levels significantly below DWS depending on the receptor or the use of groundwater. There must be no entry of List 1 to groundwater so comparison against DWS gives only an indication that an unacceptable discharge is occurring. Therefore entry to groundwater was compared against minimum reporting values (MRV). Any site-specific risk assessment undertaken should also compare against MRV.

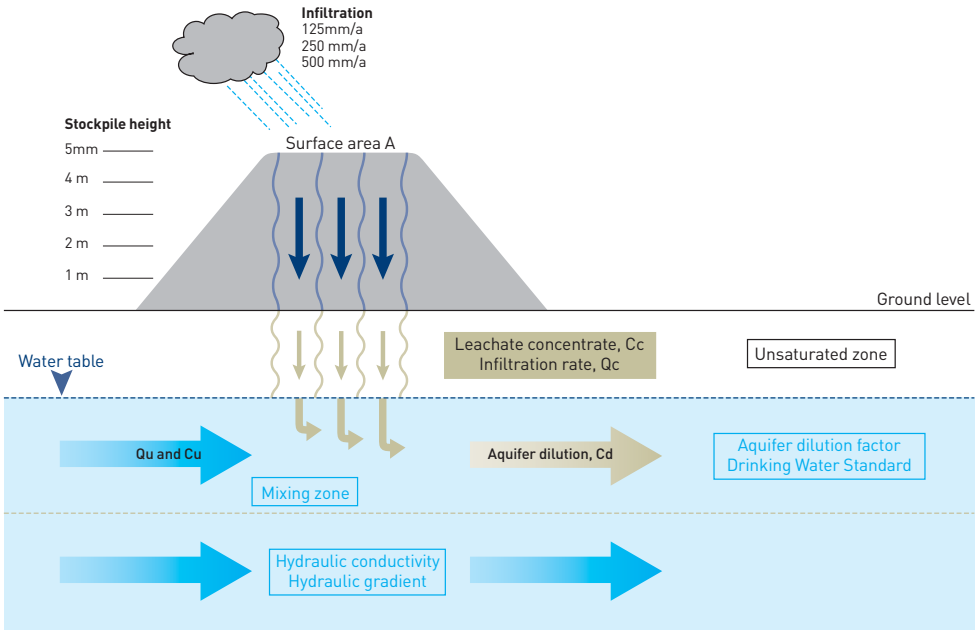
7.7.18 The conceptual model used for the groundwater assessment is shown in Figure 7.2.

7.7.19 The results showed that there is a potential for List I and II substances to enter groundwater from unbound applications of PFA.

7.7.20 Both cadmium and mercury (List I substances) significantly exceed the MRV demonstrating non-compliance of the Groundwater Directive. Dilution factors were therefore not applied to List I substances in the risk assessment.

7.7.21 The effect of dilution of List II substances within an aquifer was assessed. As with the surface water assessment, chromium was used as a representative List II substance (the risk driver) and a model was run using infiltration rates common to aquifers in England and Wales.

Figure 7.2: Groundwater conceptual model



*Cu represents background concentration, Qu represents upstream flow rate.

7.7.22 The model concluded that the median time to breakthrough above the DWS in each of the aquifers modelled ranged from zero (for chalk, limestone and sandstone aquifers that exhibit significant secondary porosity within the unsaturated zone) to over 20,000 years for three aquifers with lower hydraulic permeability. The large majority of the aquifers exhibited non-compliance after between 10 and 2,750 years, with an average of 500 years.

7.7.23 This shows that the bulk of aquifers in England and Wales would not dilute PFA leachate to below the DWS following mixing. The breakthrough time above the DWS is strongly affected by the thickness of the unsaturated zone; a thickness >1 metre is likely to delay the onset of non-compliance but not prevent it. In addition, aquifers displaying significant fracturing or karstic development are at high risk from impact due to the efficient flow of leachate to the saturated zone.

7.7.24 To permit the location of an unbound PFA stockpile on an outcrop of aquifer, a drained capillary layer would be required to prevent infiltration to the unsaturated zone. This is as recommended by the UKQAA code of practice for the sale and use of PFA [13]. This guidance is subsequently referred to in this technical report as the 'UKQAA code of practice'.

7.7.25 The TAG discussed the use of the UKQAA code of practice to manage the potential risk of List I and II substances being released to groundwater from the use of PFA in unbound applications (see Section 8).

7.7.26 Bound applications

7.7.27 Data from 28-day immersion tests on test samples of Portland cement concrete containing PFA are given in a DETR/DWI report published in 1998 [43]. The results showed that only aluminium was detected at levels above the DWS. The concentration of the other metals was mostly less than 10 per cent of the appropriate DWS. DWI therefore concluded that:

- the concentration of the specified metals was not of concern;
- actual testing of 'admixture-free' concretes was unlikely to be required to obtain authorisation to water supply pipes, service reservoirs and water towers containing PFA.

7.7.28 In addition, the use of PFA within concrete is controlled by a number of standards. In terms of risk to controlled waters, BS EN 450-1: 2005 [6] states in Annex ZA Note 1:

'In addition to any specific clauses relating to dangerous substances contained in this standard, there may be other requirements applicable to the products falling within its scope (e.g. transposed European legislation and national laws, regulations and administrative provisions). In order to meet the provisions of the EU Construction Products Directive, these requirements need to be complied with when and where they apply.'

7.7.29 DWI Advice Sheet 7 [44] gives guidance on the approval of products for use with drinking water. Specifically for cement-based products, the advice given is as follows:

'Water undertakers or their appointed agents must obtain a declaration for all cement admixtures proposed for use in a concrete mix. The declaration must confirm that the admixture does not contain chemicals other than those given in the 'List of Authorised Cement Admixture Components' and that the admixture conforms to relevant European Standards (ENs). If no admixtures are used, then this should be confirmed in writing.'

7.7.30 No further testing is needed and no approval needs to be issued for products meeting the requirements set out in Advice Sheet 7. For products not meeting these requirements, advice must be sought from DWI.

7.7.31 As the volumes of any potential leachate from bound applications are likely to be very small and take a long time to emerge, the TAG concluded that the use of bound applications is acceptable provided:

- the recommendations given in DWI Advice Sheet 7 [44] are followed;
- the requirements of BS EN 450-1: 2005 [6] are met.

7.7.32 Grout

7.7.33 An extensive trial of leaching behaviour from PFA grout has been undertaken by BRE [45]. The results showed that:

- aluminium in leachates exceeded the DWS; and
- cadmium was present in leachates above the minimum reporting value (MRV).

7.7.34 The presence of cadmium – a List I substance – was taken by the TAG as evidence that controls are required if PFA grout is used in contact with or where it can drain to groundwater.

7.7.35 There are three potential mechanisms by which the use of PFA grout could pollute groundwater [16]:

- release of bleed water upon emplacement;
- initial mixing of the grout with mine water when pumped into water-filled mines; and
- leaching of contaminants once set.

7.7.36 All these potential avenues for polluting groundwater are covered by the BRE publication, *Stabilising mine workings with PFA grouts: environmental code of practice*, [19] – subsequently referred to in this report as the 'BRE code of practice'.

7.8 The TAG discussed the possibility of using the BRE code of practice to manage the risk of potential pollution to groundwater from the use of PFA in grout applications (see Section 8).

7.9 Conclusions

7.9.1 The risk assessment concluded that all applications present an acceptable risk to human health.

7.9.2 Bound applications are acceptable for use in contact with water without resulting in unacceptable impacts on water quality provided the recommendations in DWI Advice Sheet 7 [44] and the requirements of BS EN 450-1: 2005 [6] are followed.

7.9.3 BRE has shown that:

- leachates in aluminium exceed the DWS; and
- cadmium is present in leachates above the MRV.

7.9.4 The quantitative controlled risk assessment demonstrated that the use of unbound PFA within embankments or as a capping material has the potential to pollute groundwater.

7.9.5 The release of the List I substances, mercury and cadmium, at concentrations above the MRV laid down by the Environment Agency suggests that the use of unbound PFA above major or minor aquifers presents an unacceptable theoretical risk to groundwater resources.

7.9.6 The surface water risk assessment concluded that unbound uses of PFA and FBA do not present unacceptable risks to surface waters where the total surface area does not exceed 250,000–1,000,000m^2 (depending on the region).

7.9.7 It is suggested that a site-specific risk assessment should be completed for the use of unbound products from PFA in the flood plain.

7.9.8 Section 8 describes in more detail how these risks can be managed.

8. Risk management

8.1 The main risks that need to be managed are:
- release of List I and II substances to groundwater from the use of unbound applications;
- release of List I and II substances to groundwater from use of grout applications;
- use of unbound applications in the flood plain; and
- protection of surface water where the total surface area exceeds 250,000–1,000,000m^2.

8.2 Bound applications are found to be acceptable for use in contact with water without resulting in unacceptable impacts on water quality provided the recommendations in DWI Advice Sheet 7 [44] and the requirements of BS EN 450-1: 2005 [6] are followed. FBA is only used in bound applications and is therefore not considered further in this section.

8.3 Any discharge of List I substances would not comply with the requirements of the Groundwater Directive 80/68/EEC, which states there should be no entry of List I and no pollution by List II substances. This stipulation is continued in the 'prevent and limit' requirements of the Water Framework Directive and associated Groundwater Daughter Directive.

8.4 Colleagues from the Environment Agency's groundwater policy team stated that other regulatory options (outside the waste regime) are in place to control the use of PFA and FBA in applications where there may be a risk to groundwater. These controls currently include notices under the Groundwater Regulations 1998 and Water Resources Act 1991 (as amended by the Water Act 2006).

8.5 The amount of harm that may occur from the release of List I substances is site-specific. For example, the extent of any pollution will depend on the hydrogeology and size of the site. As described in the Environment Agency's groundwater protection policy [46], a site's vulnerability is estimated from:
- soil type;
- thickness of the unsaturated zone; and
- aquifer type.

8.6 Groundwater source catchments can be divided into four zones depending on their sensitivity (see Appendix G). Zone 1 is the most sensitive.

8.7 A number of codes of practice are well-known in the industry and are currently used as existing good practice guidance. These are available to ensure a risk assessment is made before PFA is used in unbound and grout applications.

8.8 Unbound applications

8.8.1 The TAG agreed that the UKQAA code of practice [13] should be followed when using PFA in unbound applications.

8.8.2 The UKQAA code of practice is based on generic physical and chemical properties of PFA. It was developed to provide a framework for design engineers to ensure a proper assessment is made of possible effects to the environment.

8.8.3 The UKQAA code of practice takes into account the use of PFA and FBA in bound and unbound applications such as road embankments.

8.8.4 The code states that when constructing a road embankment, the following measures should be taken:
- place a drainage layer beneath the PFA to prevent capillary rise;
- protect side slopes with topsoil or vegetation and a road built on top to isolate PFA from the surrounding environment; and
- provide a method statement for handling material.

8.8.5 In other types of fill structures where the PFA cannot be protected to the same extent, the code recommends an environmental impact assessment is completed taking into account the low permeability of the PFA.

8.8.6 The TAG believes that use of the UKQAA code of practice will ensure adequate protection against the possible release of List I and II substances to groundwater.

8.8.7 But although this code of practice presumes against the use of unbound applications in Source Protection Zone 1 (SPZ 1), groundwater specialists in the Environment Agency recommended that, because of the presence of List I substances, the code of practice be updated to explicitly state that the use of unbound applications in SPZ 1 is prohibited. This includes a minimum set-off distance of 50 metres from any groundwater source supplying water intended for human consumption.

8.8.8 Environment Agency groundwater experts suggested that controls on the use of unbound applications outside SPZ1 and above the water table would only be needed for extensive use i.e. placement of >150m^2 surface area. Below the water table, any use of unbound applications would require an appropriate risk assessment, determined by following the DETR guidelines for environmental risk assessment and management [47], and necessary mitigation.

8.8.9 Environment Agency scientists felt that use of unbound applications in the flood plain had essentially the same risks as associated with unbound use. Therefore, they initially recommended a site-specific risk assessment to allow measures to be put in place to manage any potential risks to water quality. But discussions with flood risk management colleagues suggested that, because flood waters are themselves highly contaminated, the risk of any potential leachate from unbound applications in the flood plain would be negligible. It was therefore concluded that no additional site-specific assessment is necessary in the flood plain.

8.8.10 Other updates to the UKQAA code of practice that are deemed necessary include:

- inclusion of a risk screening approach as normal practice for developments that may affect groundwater;
- need to address risk to groundwater-fed potable water supplies;
- include reference to Source Protection Zones;
- a ban on the use of unbound applications and grout in an area designated SPZ1;
- include details of the risk assessment and mitigation necessary to permit use below the water table; and
- reference to the need for some risk assessment before the use of PFA.

8.8.11 The TAG recommends these major changes should be incorporated into the Quality Protocol (if produced) with the intention to update the code of practice in due course.

8.8.12 In addition to these changes, it was suggested that the UKQAA code of practice should be revised to update legislation and terminology. The TAG recommends these minor changes should be detailed during the consultation period.

8.8.13 Provided these amendments are made, the Environment Agency groundwater and science teams are happy to recommend that the potential risk can be managed through the use of the UKQAA code of practice.

8.9 Grout applications

8.9.1 The Environment Agency have policies for the protection of groundwater in the Groundwater Protection: Policy and Practice (GP3) Part 4 – Legislation and Policies document [46]. Policy P1-10 'Influencing' states:

'We expect best practice regarding the backfilling of any abandoned shaft, well, borehole, tunnel or adit in order to prevent pollution or loss of water resources.'

8.9.2 The BRE code of practice [19] seeks to address concerns over the potential contamination of groundwater by bleed water and leachate released from PFA grout. It provides guidance on:

- the selection of environmentally compatible and cost-effective materials;
- techniques for stabilisation of underground cavities; and
- good practice.

8.9.3 The BRE code of practice suggests that the risk of contaminating groundwater through the use of PFA grout can be reduced through:

- appropriate materials selection;
- appropriate design of the PFA grout; and
- measures such as controlling the groundwater regime and using engineered barriers.

Guidance is given on how to characterise the site and the materials being considered, and on appropriate measures for safe filling.

8.9.4 The TAG feels that following the BRE code of practice would provide sufficient mitigation against the potential risk from the release of List I and II substances to groundwater from the use of PFA grouts.

8.9.5 However, Environment Agency groundwater specialists advised that the BRE code of practice needs to be updated to include an explicit statement that the presence of List I substances means that PFA grouts should not be used in an area designated SPZ1. This zone sets a minimum set-off distance of 50 metres from any groundwater source supplying water intended for human consumption.

8.9.6 Environment Agency groundwater specialists also suggest that controls on the use of grout outside SPZ1 and above the water table. These should follow the DETR guidelines for environmental risk assessment and management [47]. This suggests a desk top study in all instances leading to a potential full site-specific risk assessment for extensive use, i.e. placement of >150m^2 surface area. Also, any use of grout below the water table would require an appropriate risk assessment and necessary mitigation.

8.9.7 Other updates to the BRE code of practice deemed necessary include:

- inclusion of a risk screening approach as normal practice for developments that may affect groundwater;
- need to address risk to groundwater-fed potable water supplies;
- include reference to Source Protection Zones;
- a ban on the use of grout in an area designated SPZ1;
- include details of the risk assessment and mitigation necessary to permit use below the water table; and
- reference to the need for some risk assessment before the use of PFA.

8.9.8 As with the updates to the UKQAA code of practice, the TAG recommends these major changes should be incorporated into the Quality Protocol (if produced) with the intention to update the code of practice in due course.

8.9.9 In addition to these changes, it was suggested the BRE code of practice should be revised to update legislation and terminology. The TAG recommends that these minor changes should be detailed during the consultation period.

8.9.10 A map produced by the Environment Agency to support its groundwater protection policies shows the location of aquifers unprotected by low permeability cover and therefore vulnerable to the impact from pollution. Groundwater Source Protection Zones are also shown. This map is reproduced in *Ground water protection: policy and practice. Part 4: Legislation and policies*, issued by the Environment Agency for public consultation in June 2007 [46].

8.9.11 The TAG recommends this map is used when characterising a site and the potential effects of the use of PFA to the environment. However, this map only shows vulnerability of groundwater to activities on the surface. It is also a very small scale map and suitable for strategic screening assessment only. It is invalid for any operations in, rather than, on the ground.

8.10 Summary/conclusions

8.10.1 Table 8.1 summarises the controlled water risk assessment results within a risk decision matrix to ensure effective management of the use of PFA and FBA in bound, unbound and grout applications.

8.10.2 In addition to the controls set out in Table 8.1, the Environment Agency suggests:

- a site-specific risk assessment is completed for all uses below the water table;
- a site-specific risk assessment is completed for extensive uses in SPZ2 and SPZ3, and above the water table; and
- a risk screening approach is adopted for developments that may affect groundwater.

8.10.3 The TAG agreed these additional controls should be written into the Quality Protocol (if produced) with a view to updating the codes of practice in due course.

8.10.4 The risk assessment was based on worst case scenarios for the use of PFA and FBA. To assess the risks in more realistic scenarios and therefore possibly reduce these control measures, it is recommended that:

- further test data from other power stations in England and Wales should be reviewed to allow the early leaching behaviour of the soluble determinands to be refined further;
- the effects of environmental weathering during storage on the dilution of List I substances and other metals should be investigated; and
- the pozzolanic effects, which would tend to limit permeability and leachate generation, should be studied.

Table 8.1 Controlled water risk management matrix

	GROUNDWATER SOURCE PROTECTION		
Activity	Zone 1	Zone 2	Zone 3
Unbound PFA	Unacceptable	Acceptable subject to adoption of UKQAA code of practice* or further investigation into dilution of groundwater at the abstraction.	Acceptable subject to adoption of UKQAA code of practice or further investigation into dilution of groundwater at the abstraction.
PFA/FBA concrete	Acceptable following recommendations given in DWI Advice Sheet 7 and subject to the requirements of BS EN450-1: 2005.	Acceptable following recommendations given in DWI Advice Sheet 7 and subject to the requirements of BS EN450-1: 2005	Acceptable following recommendations given in DWI Advice Sheet 7 and subject to the requirements of BS EN450-1: 2005.
PFA grout	Unacceptable	Acceptable, subject to carrying out a site-specific risk assessment as per the BRE code of practice.**	Acceptable, subject to carrying out a site-specific risk assessment as per the BRE code of practice.

* Environmental code of practice for the sale and use of pulverised fuel ash (PFA), UKQAA, 2003.
** Stabilising mine workings with PFA grouts: environmental code of practice, BRE, 2006.

Table 8.1 Controlled water risk management matrix continued

	GROUNDWATER RESOURCE PROTECTION		
Activity	**Principal aquifer**	**Secondary aquifer**	**Unproductive strata**
Unbound PFA	Acceptable subject to adoption of UKQAA code of practice.	Acceptable subject to adoption of UKQAA code of practice	Acceptable
PFA concrete	Acceptable following recommendations given in DWI Advice Sheet 7 and subject to the requirements of BS EN450-1: 2005.	Acceptable following recommendations given in DWI Advice Sheet 7 and subject to the requirements of BS EN450-1: 2005.	Acceptable
PFA grout	Acceptable in situations, subject to compliance with BRE code of practice.	Acceptable in situations, subject to compliance with BRE code of practice.	Acceptable
	SURFACE WATER PROTECTION		
Activity	**Flood plain**	**Main river**	**Minor watercourse**
Unbound PFA	Acceptable, subject to adoption of UKQAA code of practice.	Acceptable subject to risk screening against region, infiltration zone, PFA thickness and river flow and subject to compliance with UKQAA best practice.	Acceptable subject to risk screening against region, infiltration zone, PFA thickness and river flow and subject to compliance with UKQAA best practice.
PFA concrete	Acceptable, subject to meeting the requirements of BS EN450-1: 2005.	Acceptable, subject to meeting the requirements of BS EN450-1: 2005.	Acceptable, subject to meeting the requirements of BS EN450-1: 2005.
PFA grout	Acceptable, subject to carrying out a site-specific risk assessment as per the BRE code of practice.	Acceptable, subject to carrying out a site-specific risk assessment as per the BRE code of practice.	Acceptable, subject to carrying out a site-specific risk assessment as per the BRE code of practice.

9. Findings

9.1 The purpose of this report is to identify the point at which PFA (including cenospheres) and FBA may cease to be a waste. In order for their waste classification to be removed and no further waste management controls required, PFA and FBA must:

- have a market and certainty of use;
- meet an appropriate publicly available standard (e.g. an identified specification) requiring no further processing before being used; and
- be capable of being used without undermining the aims of the Waste Framework Directive and the Water Framework Directive of protecting human health and the environment.

9.2 The TAG concluded that there is sufficient evidence to support the use of products from PFA, FBA and cenospheres without waste management controls. Its findings are summarised below.

9.3 Has a market and certainty of use

9.3.1 There are a number of potential uses for PFA, FBA and cenospheres. These can be split into three main broad categories:

- bound applications – used as an ingredient/component within another product and is fully bound within that product;
- unbound applications – used without any binding agent; and
- grouts – where the material is hydraulically pumped or injected into the ground to fill void space.

9.3.2 Approximately 6 million tonnes of PFA and 1 million tonnes of FBA are produced annually by UK coal-fired power stations. Virtually all FBA is used in lightweight concrete block manufacture but approximately 50 per cent of the PFA is landfilled.

9.3.3 The designation of PFA as waste is limiting the use of PFA is some applications. The removal of this waste stigma is expected to increase the use of PFA in many applications and therefore reduce the amount being landfilled.

9.4 Meets a standard and requires no further processing

9.4.1 A number of British and European standards could be applied to PFA and FBA destined for use in most applications. These standards give the required engineering specification of the material and detail any necessary testing to demonstrate compliance.

9.4.2 There are no specified standards for the use of cenospheres in paint and plastics or PFA in ceramic tiles and bricks. However, these are extremely specialised applications and the use of a customer specification would be appropriate to ensure certainty of use and no further processing.

9.5 Does not cause harm to human health or the environment

9.5.1 The risk assessment concluded that, overall, the use of products from PFA and FBA pose a low risk to human health and the environment provided a number of simple good practice measures are followed.

9.5.2 The use of PFA and FBA in bound applications has been shown through historical testing and reporting by the DETR, DWI and BSI to be acceptable for use in contact with water without resulting in unacceptable impacts on water quality provided recommendations contained in DWI Advice Sheet 7 [43] and the requirements of BS EN450-1: 2005 [6] are followed.

9.5.3 There are concerns about the use of PFA in unbound and grout applications due to the potential release of cadmium and mercury (List I substances) to groundwater.

9.5.4 However, this potential risk would be sufficiently mitigated provided the following two codes of practice are followed:

- UKQAA code of practice [13]; and
- BRE code of practice [19].

9.5.5 Because the Groundwater Directive does not allow List I substances to come into contact with groundwater, the Environment Agency suggests that both codes of practice should be updated to include the following additional controls:

- the use of unbound applications and grouts should be prohibited in SPZ1;
- grouts should not be used below the water table without an appropriate site-specific risk assessment;
- a site-specific risk assessment should be completed for extensive uses (i.e. applications using a surface area >150m^2) of unbound applications and grout in SPZ2 and SPZ3, and above the water table; and
- a risk screening approach should be adopted for developments that may affect groundwater.

9.5.6 Any site-specific risk assessment completed should follow the guidelines set out in the DETR guidelines for environmental risk assessment and management [47].

9.5.7 The TAG recommends these major changes should be incorporated into the Quality Protocol (if produced) with the intention to update the codes of practice in due course.

9.5.8 In addition to these changes, it was suggested that the BRE code of practice should be revised to update legislation and terminology. The TAG recommends these minor changes should be detailed during the Quality Protocol consultation period.

9.5.9 To ensure the protection of surface water, the following regional surface area limits for unbound applications should be followed:

- Wales region – 250,000m^2.
- Northwest and Southern region – 500,000m^2.
- South West region – 750,000m^2.

Surface areas of up to 1 million m^2 would be acceptable in all other regions.

9.5.10 It has been suggested that the use of co-combustion materials may affect the chemical composition of PFA and FBA. In order to limit this affect the TAG recommend that the Quality Protocol ensures that if the co-combustion materials change, the PFA and FBA is tested to ensure it does not significantly exceed the parameters used by the risk assessment and detailed in Appendix F.

9.6 Conclusions

9.6.1 PFA and FBA currently have end markets that will be further stimulated if their classification as a waste is removed.

9.6.2 Producers must ensure that the products from PFA and FBA meet the appropriate standards identified in this report.

9.6.3 With the appropriate use of good practice guidance, if the chemical composition does not significantly exceed the parameters used in the risk assessment and listed in appendix F, the risk of harm to human health and the environment from the use of products from PFA and FBA is low.

10. Recommendations

10.1 The information gathered by the TAG in the preparation of this report supports the adoption of a Quality Protocol for the use of PFA and FBA in bound, unbound and grout applications.

10.2 With regard to the protection of human health, the TAG recommends the Quality Protocol states that the following good practice is adhered to:

- avoid creating airborne dust wherever possible;
- where dust is generated, consider engineering control measures (water sprays) to maintain the airborne dust concentrations as low as reasonably practicable;
- avoid prolonged skin contact especially where the product is dampened;
- wear appropriate protective clothing (e.g. goggles, gloves, overalls and boots);
- change heavily contaminated clothing as soon as possible and launder before reuse;
- maintain good housekeeping practices and high standards of personal hygiene; and
- use respiratory equipment be strictly in accordance with the manufacturer's recommendations and follow any statutory requirements governing its selection and use.

10.3 The TAG identified a number of existing standards that can be applied to most of the PFA and FBA applications. Where a standard is not listed, the TAG recommends asking industry during the consultation if there is a need for one or whether a customer specification is appropriate.

10.4 It has been suggested that the use of co-combustion materials may affect the chemical composition of PFA and FBA. In order to limit this effect the TAG recommend that the Quality Protocol ensures that if the co-combustion materials change, the PFA and FBA is tested to ensure it does not significantly exceed the parameters used by the risk assessment and detailed in Appendix F.

10.5 The risk assessment resulted in a number of recommendations for use of standard good practice in all applications (e.g. UKQAA and BRE codes of practice). The TAG recommends this guidance is listed in the Quality Protocol and adhered to by users of PFA and FBA.

10.6 The Environment Agency recommends that the following additional controls are included in the Quality Protocol with the intention to update the codes of practices in due course:

- both unbound applications and grouts should be prohibited in areas designated SPZ1;
- grouts should not be used below the water table without an appropriate site-specific risk assessment;
- a site-specific risk assessment should be completed for extensive uses (i.e. applications using a surface area >150m^2) of unbound applications and grout in SPZ2 and SPZ3, and above the water table; and
- a risk screening approach should be adopted for developments that may affect groundwater.

10.7 Any site-specific risk assessment completed should follow the guidelines set out in the DETR guidelines for environmental risk assessment and management [47].

10.8 It is also suggested that in order to help characterise a site and locate aquifers, the Quality Protocol should refer to the use of the map contained in Groundwater protection: policy and practice. Part 4: Legislation and policies, issued by the Environment Agency for public consultation in June 2007 [46].

10.9 In addition to these changes, the Environment Agency suggests that the BRE code of practice should be revised to update legislation and terminology. The TAG recommends these minor changes should be detailed during the consultation period.

10.10 The risk assessment was based on worst case scenarios for the use of PFA and FBA. In order to evaluate the risks in more realistic scenarios, the risk assessment recommends:

- reviewing further test data from other power stations in England and Wales in order to refine the early leaching behaviour of soluble determinands;
- examining the effects of environmental weathering during storage on the dilution of List I substances and other metals; and
- studying the pozzolanic effects, which would tend to limit permeability and leachate generation.

10.11 The TAG also recommends the Quality Protocol be reviewed and updated if coal combustion practices in the UK change significantly; for example, any change which results in the composition of PFA and FBA altering from that considered in the risk assessment and detailed in Appendix F of this report.

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UKQAA publications

Most are available from: http://www.ukqaa.org.uk/Publications.html

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Best Practice Guide No. 2 *The placing and compaction of fly ash as structural fill: a guide for site foremen*.

The development of a code of practice for the environmental sound use of PFA as a fill. Paper presented to Wascon 2000 by R Coombs R and L K A Sear.

Assessment of the leaching risk to the environment from the use of pulverised fuel ash (PFA), January 2003 (http://www.ukqaa.org.uk/Environment/Environmental%20Risk%20Assessment%20January%202003.pdf)

Technical datasheets:

General Information	A six-sided general introduction to PFA/fly ash from coal-fired power stations
Datasheet 1.0	PFA/fly ash for concrete – explains why fly ash is beneficial in concrete.
Datasheet 1.1	Specifying PFA/fly ash in concrete to EN 206/BS 8500 – explains how to specify fly ash in your concrete using the current UK standard.
Datasheet 1.2	The relative performance of EN450 fly ashes to Category S and N
Datasheet 1.3	Applications for fly ash to EN450-1: 2005
Datasheet 2.0	PFA/fly ash as a fill material. Describes how PFA is used as a general and structural fill material.
Datasheet 3.0	PFA/fly ash for grouting applications – how PFA is used for grouting caverns, mines, redundant pipework, etc.
Datasheet 4.0	Sintered PFA lightweight aggregates. Describes how lightweight aggregate is made and the applications its use for.
Datasheet 5.0	Cenospheres – a unique filler. Describes what they are and some of the many applications for the material.
Datasheet 6.0	An overview of fly ash bound mixtures (FABM). Fly ash hydraulically bound mixtures are increasingly being specified for road construction because of their environmental credentials.
Datasheet 6.1	Lime fly ash granular material (GFA) – the most common fly ash based hydraulically bound mixture
Datasheet 6.2	Laboratory mix design for FABMs

Datasheet 6.3	GFA on the A52 in Staffs – a case study on one of the first uses of granular fly ash in the country
Datasheet 6.4	PFA in CBMs – cement bound mixtures are improved by the use of fly ash
Datasheet 6.5	Lime fly ash for capping and sub-base
Datasheet 6.6	The structural design of GFA pavements for roads. A detailed explanation how to design fly ash based hydraulically bound mixtures with fly ash to the Specification for Highways and using an alternative approach.
Datasheet 6.7	A draft specification for GFA – for specifiers to use within their own specification
Datasheet 6.8	Trench mix is a slow setting slow hardening recycled material purposely designed for trench reinstatements.
Datasheet 6.9	PFA in enhanced stabilised capping (ESC)
Datasheet 6.10	A draft specification for enhanced stabilised capping (ESC) that you can use as a template for your specification.
Datasheet 7.0	Furnace bottom ash in lightweight aggregate (LWA) concrete blocks
Datasheet 7.1	PFA in aerated concrete blocks
Datasheet 8.0	PFA and the environment
Datasheet 9.0	COSHH information about PFA

Appendix A Technical Advisory Group (TAG) membership

Organisation	Representative	Type of member
Association of Electricity Producers (AEP)	Andy Limbrick	Attending
Department for Business, Enterprise and Regulatory Reform (BERR)	Jonathan Thomas Kerry Vitalis	Attending Attending
Environment Agency	Scott McFarlane Andrew Hitchings	Attending Attending
Joint Environmental Programme (JEP)	Neil Bowmer Richard Busby	Attending Attending
National Industrial Symbiosis Programme (NISP)	Nizar Ghazireh	Attending
UK Quality Ash Association (UKQAA)	Lindon Sear	Attending
Waste Protocols Project Team	Suzanne Laidlaw Michelle Steer Hana Leithgoe Sarah Clayton Nicola Content Ahlim Hashm (RPS)	Attending Attending Attending Attending Attending Attending
WRAP (Waste & Resources Action Programme)	John Barritt	Attending
Aggregate Industries	Andrew Swain	Invited member
Ash Solutions Ltd	Les Drury	Invited member
Environment Agency	Clare McCallan Kathryn Harris	Corresponding Corresponding
Environment Agency Wales	Becky Favager	Corresponding
Scottish Environment Protection Agency (SEPA)	John Harris	Corresponding
Veolia	Sarah Moseley	Corresponding
Welsh Assembly Government (WAG)	Aoife O'Sullivan	Corresponding

Appendix B Terms of reference[4]

1. Mission statement

To produce a technical report, recognised by (and produced with the support of) industry, that defines when pulverised fuel ash (PFA), and pulverised fuel ash exhumed from landfill, has been reprocessed to such a level that it is considered to be fully recovered and no longer subject to the requirements of the regulatory waste regime.

If this is not achievable, the technical report will provide guidance to business that:

- defines when PFA is recovered to a state where the Environment Agency considers that its use is acceptable in accordance with its low risk regulatory principles; or
- confirms to the business community what legal obligations remain to control the reuse of the treated waste material.

2. Desired outcomes/outputs

The Technical Advisory Group (TAG) will produce a technical report that identifies and establishes:

- which end products the protocol should address;
- whether there are existing standards and specifications for each end product;
- whether the material can be collected and reprocessed to meet existing standards and specifications;
- where existing standards and specifications do not exist, to identify alternatives and/or to scope out a project for producing a new standard or specification;
- what the potential human health and environmental impacts are, and what mitigation methods may be used to maintain or reduce those impacts;
- the costs and benefits of the different end uses (with the aid of project economist);
- a standard terminology; and
- likely requirements under REACH.

3. Limitations

- The project is conducted without prejudice to the outcomes of the European Commission's revision of the Waste Framework Directive and Defra/Environment Agency consultations on exemptions from the Waste Management Licensing Regulations.
- In relation to the output of this TAG, the Environment Agency must be satisfied with the TAG's determination of the point at which pulverised fuel ash has been fully recovered.
- If the point of full recovery of PFA cannot be defined or agreed, the TAG will refer this matter to the Environment Agency for it to produce guidance on when waste regulatory controls apply.
- Where specifications and standards do not exist and are required, financial or time implications may delay the preparation of the technical report.

4 Agreed by TAG on 5 March 2007. Subsequently the TAG outputs were expanded to include furnace bottom ash (FBA). Please see report introduction.

Appendix C Market analysis

C.1 Production of PFA from coal burning

C.1.1 The definition of PFA for the purposes of this analysis is:

> '...the ash resulting from the burning of pulverised coal as fuel, both with and without co-combustion materials, within coal fired power stations. This ash is extracted from the furnace gas stream by electrostatic precipitators as a fine ash, known as 'fly ash' or PFA, that may contain hollow spherical ash particles, known as 'cenospheres'. The ash is also deposited on the boiler tubes, which subsequently falls to the bottom of the furnace where it is rapidly quenched, which is known as furnace bottom ash (FBA).'[5]

C.1.2 The coal-fired power stations in England are in the North West, Yorkshire and Humberside, West Midlands, East Midlands and the South East. The arisings of PFA and FBA are therefore heavily concentrated in these areas.

C.1.3 In 2006, UK power stations produced a total of approximately 5.9 million tonnes of PFA;[6] PFA arisings had risen from 4.4 million tonnes in 2001 as a result of greater use of coal-fired power stations following the increases in gas prices.[7] Production peaked in the 1970s with around 16 million tonnes per year.

C.1.4 Around 1 million tonnes of FBA are produced in the UK annually. Virtually all of this output is used in the manufacture of lightweight concrete blocks (99.9 per cent).[8] There are no significant stockpiles of FBA other than as short-term production stock. Only a few thousand tonnes of FBA are thought to go to landfill per year.

C.1.5 Cenosphere production in the UK is very low – 1,522 tonnes in 2006.

C.1.6 PFA can be supplied in various forms:

- dry ash. This is supplied in tankers and used as a concrete addition, for aerated block manufacture, mixed and pre-cast concrete products and grouts. It can be classified to remove the coarser particles to enhance reactivity, but the majority is not;
- conditioned ash. This is PFA mixed with an appropriate percentage of water. It is supplied in tipping vehicles and is used for block manufacture, grout, load-bearing fill and landscaping. Conditioned PFA may also be recovered from lagoons after they have been drained; and
- cenospheres. These unique, free-flowing powders composed of shelled, hollow, minute spheres are generally used as inert filler in industrial applications. Cenospheres may also be used in paint, varnish and plastics.

C.1.7 In addition, PFA is increasingly being processed to remove its excess carbon content.[9] The carbon content has increased recently due to the fitting of low NO_X burners at some coal-fired power stations to reduce emissions of nitrogen oxides (NO_X). A plant is also being built to remove the ammonia from PFA arising at power stations that have injected ammonia into their gas streams to improve the performance of their electrostatic precipitators.

C.1.8 Approximately half of PFA produced goes to end applications and the other half is landfilled (as conditioned ash in either a monofill or a lagoon containing only PFA waste) or sent to land reclamation sites (landfill tax is not paid for this). The monofills are often on the power station site. The power station pays the landfill tax and the costs of maintaining its landfill sites. The UK has a large stock of landfilled PFA (60 million tonnes[10]) which could be recovered.

5 Definition provided by Lindon Sear (Technical Director, UKQAA)
6 UKQAA
7 *Survey of arisings and use of alternatives to primary aggregates in England 2005: other materials*, Department for Communities and Local Government, 2007.
8 *The sustainability and environmental issues of using PFA in comparison with virgin materials*, L K A Sear, UKQAA.
9 The standard for concrete restricts the maximum carbon to 7 per cent as measured by Loss on Ignition (LOI). Higher LOIs lead to problems with colour and the performance of some chemicals (e.g. air entraining agents) in the concrete.
10 Communication with the TAG.

C.1.9 There is some evidence that designating PFA as waste is limiting the use of PFA in some applications.[11] A high profile example of PFA not being used because of its designation as waste was during Walsall Borough Council's Bosty Lane contract in 2004. In the end, the contract was completed using virgin material at a cost of an extra £500,000.[12] This included a 40 per cent increase in vehicle movements due to the increased cement content and mass of sand required.

C.1.10 Total ash managers[13] are often subcontracted by power stations to sell PFA into the end applications and are based on the power station site. There are also agents employed in ash sales that may or may not be based on site.

C.1.11 The average amount paid for PFA is £20 per tonne including transport costs, though PFA can cost up to £25 per tonne.[14] The high value applications are cement, concrete[15] and aerated block markets. No ash is sold at less than cost.[16] No companies are paid to remove the ash except for disposal.

C.2 Current and future PFA, FBA and cenosphere utilisation in the UK

C.2.1 PFA could be sold in underdeveloped markets such as in road construction – as a binder, in ground stabilisation applications, capping, etc.

C.2.2 Annual utilisation of PFA rose until 2004 when it was over 60 per cent, but fell back in 2005 mainly due to a reduction in the amount going to grouting applications (Figure C1). Market applications of PFA are summarised in table C.1.

C.2.3 Virtually all FBA is used in lightweight concrete block manufacture, where FBA is a direct replacement for expanded clay.

C.2.4 Cenospheres are used in plastics, paints and for other similar applications.

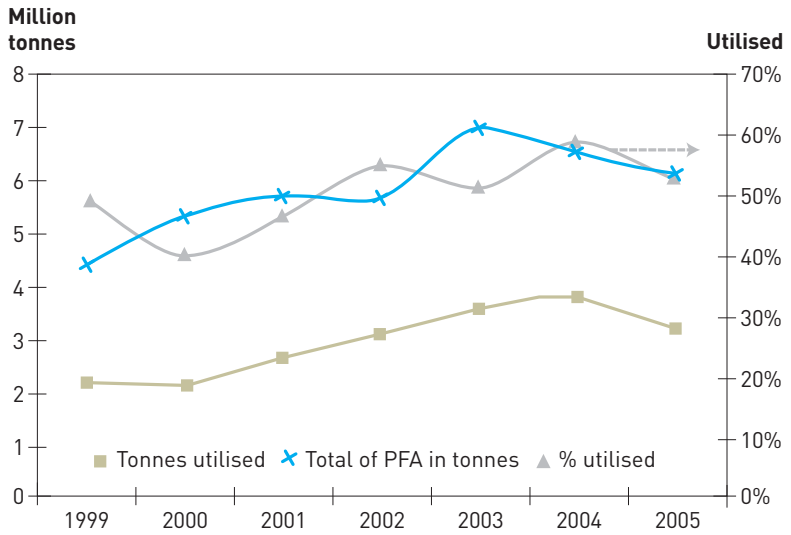
11 *Survey of arisings and use of alternatives to primary aggregates in England 2005: other materials*, Department for Communities and Local Government, 2007.
12 Estimate by David Oliver of Walsall Metropolitan Borough Council and Chris Sakalas of High Point Rendell (consultants)
13 Examples include Pro-Ash, CEMEX and ScotAsh.
14 *PFA from Didcot Power Station*, Report No. SRL/PFA/001.2, 28 August 2006.
15 Personal communication from UKQAA.
16 UKQAA response to the questionnaire 'Questions for the PFA TAG to aid the Financial Impact Assessment'.

Table C1 Market applications of PFA

Product	Details
Aerated and non-aerated concrete 'breeze' block manufacture	All aerated concrete blocks contain 80+ per cent PFA. Demand depends on the housing market.
Cement (raw and blend) manufacture	PFA is a partial alternative to Portland cement. The increased use of PFA by cement companies is a direct result of increased pressure on cement companies to reduce their CO_2 emissions. About 12 million tonnes of cement are produced annually in the UK. Of that, 5 per cent could be PFA used as a 'minor additional constituent'; 27 per cent could be added to around 30 per cent of the cement produced in the UK. For example, 1,572,000 tonnes of PFA could be used in cement manufacture in principle in the UK without difficulty.
Concrete addition at the concrete plant	Replaces part of the cement component in concrete. Usage has fallen in the last two years. This is partly due to the growth in the share of market by ground granulated blast furnace slag (GGBS) and PFA's increased carbon content. UK production of ready mix concrete was 22.4 million m^3 in 2005.*
Fill and ground stabilisation	PFA competes with virgin aggregates. Price is the determining factor. In 2005, 5.17 million tonnes of sand and gravel were used for fill.*
Grouting	Few materials can compete with PFA for grouting. There is an underlying and consistent market for grouting for housing and industrial plots. Once in a while there are massive one-off jobs requiring hundreds of thousands of tonnes that distort the market. In the absence of waste regulation, PFA will always be preferred. It is lightweight, easy to handle, mix and pump and provides good strength. Virgin substitutes do not bind as well as PFA with cement. Greater quantities of cement would be needed. This would add to the monetary cost and the cost to the environment. In addition, virgin substitutes are around twice the price of PFA.
Other uses such as sintered lightweight aggregate (Lytag)	There is currently zero production in the UK; 70,000 tonnes of PFA derived lightweight aggregate are imported from Poland each year.

* UKQAA and JEP response to the questionnaire 'Questions for the PFA TAG to aid the Financial Impact Assessment'.

Figure C1: Tonnage and utilisation of UK PFA



Source: UKQAA and JEP response to the questionnaire 'Questions for the PFA TAG to aid the Financial Impact Assessment'.

C.3 Barriers to growth of sales in end markets

C.3.1 The limited use of coal in power generation is the main constraint to the supply of PFA in the UK. The production of PFA could fall due to the possible reduction in reliance on coal as an energy supply or new technologies resulting in residues with different properties than PFA.

C.3.2 It is very hard to predict how the arisings of PFA will develop over the next 10 years and beyond as the power generation mix is very dependent on Government policy and commercial pressures. Consultation with TAG members suggests that, given recent trends and a high degree of uncertainty, a best guess is to assume that arisings will stay around 6 million tonnes a year over the next 10 years[17].

C.3.3 Over the long term, annual arisings of PFA are likely to fall. However, the quantity of stockpiled material is large compared with annual arisings.

C.3.4 A high proportion of PFA is landfilled. There are huge existing stockpiles of PFA and the markets that PFA is supplied into are large (Table C2).

Table C2: UK use of PFA in the cement industry (approximate tonnages)

	As 'addition'	As a component of blended cement
Portland cement	n/a	12.5 million tonnes.
Ground granulated blastfurnace slag (GGBS)	2 million tonnes	Minimal
PFA	500,000 tonnes	~100,000 tonnes
Silica fume	3,000 tonnes	Minimal
Natural pozzolans	Minimal	Minimal
Limestone fines	<10,000 tonnes	~50,000 tonnes

Source: Higgins, D. 2006. Sustainable concrete: how can additions contribute? Presentation to 'Concrete for a Sustainable Future', Institute of Concrete Technology annual technical symposium held March 2006. Available from http://www.sustainableconcrete.org.uk/PDF/ICT%20Convention%202006%20-%20paper%20-%20Higgins.pdf [Accessed 7 August 2008].

C.3.5 There is potential to expand the supply of PFA into end markets. Existing barriers to growth are discussed below.

- The status of PFA as a waste material has led to stigmatisation of the material and is a significant impediment to future utilisation.[18] The United Kingdom Quality Ash Association (UKQAA) considers the downturn in the use of PFA in grouting in 2005 was the direct result of the classification of PFA as a waste.[19]
- PFA products compete on the open market against primary materials and other recycled/secondary materials. Many of these markets are very large and competitive. Cost pressures that increase the sale prices of PFA are likely to threaten competitiveness with primary materials and affect PFA utilisation in the UK.
- The cost of producing concrete using ground granulated blast furnace slag (GGBS) has fallen and this has affected sales of PFA to this market. GGBS is now ground to a finer level, increasing its reactivity and the need for cement. GGBS has also been subject to aggressive marketing.[20]
- In the fill and ground stabilisation applications, PFA competes with virgin aggregates. The market is very price sensitive; the price in turn depends on location and availability.

17 UKQAA and JEP response to the questionnaire 'Questions for the PFA TAG to aid the Financial Impact Assessment'.
18 *Technology status review of ash utilisation from coal based plants*. Presentation made at the DTI conference centre in June 2004 by UKQAA and Hatterall Association.
19 UKQAA response to the questionnaire 'Questions for the PFA TAG to aid the Financial impact Assessment'.
20 UKQAA and JEP response to the questionnaire 'Questions for the PFA TAG to aid the Financial Impact Assessment'.

- The vast majority of coal-fired power stations are in the Midlands. There is one in the north east and some in Yorkshire. The amount of ash produced in these regions far exceeds demand in the local area. Other regions of the UK are therefore an important market for PFA utilisation. Although haulage costs are a competitive disadvantage relative to virgin materials, increased use of bulk trains has eased the situation.
- Not all ash is suitable for all applications. The ash needs to be high quality (low carbon and with less coarse material) for use in concrete and block manufacturing. If the carbon content was lower, the ash would be more widely used in these applications. High carbon is not a barrier to the use of PFA as a fill, as high carbon usually means lower density which can be a benefit in an embankment built on weak soils. High carbon may also not be a problem in grouts as BS 3892-3 permits LOI values up to 14 per cent.

C.3.6 The demand for PFA in the construction industry could be restricted if timber continues to grow in popularity relative to concrete blocks.

C.3.7 For FBA, the barrier to growth is the limited amount of FBA available. Virtually all of it is currently utilised. Demand outstrips supply. If there is an increase in demand from end users, then its price is likely to rise.

C.4 Opportunities for the growth of PFA into end markets

C.4.1 Some of the opportunities for growth are outlined below.

- Large-scale construction in the south east England could create market opportunities. The construction sector is likely to remain the dominant market for ash. The European Coal Combustion Products Association (ECOBA) and the American Coal Ash Association (ACAA) in the USA consider the fill market the best prospect for increased high volume ash utilisation.[21]
- Pressure on producers to reduce carbon dioxide (CO_2) emissions could increase the demand for PFA relative to virgin substitutes. This has been the case in cement production.
- Aggregates are a substantial market for PFA. Total aggregate sales in Great Britain in 2003 were just less than 280 million tonnes[22] and the then Office of the Deputy Prime Minister (ODPM) predicted a total market growth of +1.2 per cent per year.[23] The quantity of recycled and secondary aggregates in 2004 was around 70 million tonnes.

  ODPM forecasts for England were for total aggregate use in England to rise to around 260 million tonnes and aggregate recycling to increase to 60 million tonnes by 2016. WRAP forecasts growth to 3 million tonnes of PFA and FBA recycled by 2015. ODPM forecast that 23 per cent of the total aggregate market would come from recycled and secondary aggregate production,[22] though WRAP forecast that this figure would be 28 per cent.[24]

  The availability of sustainable resources will fail to keep up with the growth in total market demand.[23] Thus it is likely a majority of the market will continue to be supplied with virgin materials as a result of the barriers described above. In particular, price including haulage costs is often the deciding factor between choosing virgin materials or recycled/secondary materials.
- Policy, regulatory and fiscal drivers such as the landfill tax and aggregates levy may increase the incentive to utilise secondary and recycled materials in construction projects. The Sustainable Buildings Task Group has recommended setting a minimum standard for the overall percentage of reused and recycled material used in construction projects.

21 Technology status review of ash utilisation from coal based plants. Presentation made at the DTI Conference Centre in June 2004 by UKQAA and Hatterall Association.
22 Sustainable development report, Quarry Products Association, 2007. www.qpa.org
23 National and regional guidelines for aggregates provision in England, 2001-2016, June 2003, Office of deputy prime minister (ODPM).
24 *Sustainable waste management and recycling. Achieving the potential of recycled aggregates*, J C Barritt, WRAP, 2004.

Appendix D Definitions

In this technical report, the words and phrases below have the following meanings:

Term	Description
Addition	Finely divided material used in concrete to improve certain properties or to achieve special properties. This document deals with two types of inorganic additions: ■ nearly inert additions (Type I); ■ pozzolanic or latent hydraulic additions (Type II).[25]
Aggregate	Granular material that does not contribute to the hardening reaction of the mortar.
Admixture	Material added in small quantities to produce specified modifications to the properties. E.g. used in concrete, they can enhance workability and control the set time. Common admixtures include water-reducing admixtures and air entraining admixtures.
Bleed water	Bleed water can arise from segregation of the grout due to the inability of the solid constituents to hold all the mixing water as they settle downwards (water has the lowest specific gravity of all the constituents). The volume of bleed water can be up to 15 per cent of the total volume of the grout. Such high bleed volumes result from the requirement for a high water–cement ratio to achieve the flow characteristics that are required to enable the grout to be pumped over long distances and to flow through fissures within the mine.[26]
Bound applications	Where PFA is used as an ingredient/component within another product and is fully bound within that product.
Cement clinker	Solid material produced at the cement kiln stage.
Cenospheres	Hollow PFA particles.
Coal combustion	Where only coal is combusted.
Co-combustion	Where coal is combusted with other materials such as biomass and petcoke (petroleum coke).
Duty of Care	The Duty of Care is set out in section 34 of the Environmental Protection Act 1990 and associated regulations. It applies to anyone who is the holder of controlled waste. Persons concerned with controlled waste must ensure that the waste: ■ is managed properly; ■ is recovered or disposed of safely; ■ does not cause harm to human health or pollution of the environment; and ■ is transferred only to someone who is authorised to receive it. The duty applies to any person who produces, imports, carries, keeps, treats or disposes of controlled waste or, as a broker, has control of such waste.
Electrostatic precipitator	Removes particles from a gas using electrostatic charges.
Eluate	The product of a laboratory leaching test.
Environment Agency	The Environment Agency is the leading public body for protecting and improving the environment in England and Wales. Its job is to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

25 BS EN260-1: 2000 Concrete. Specification, performance, production and conformity.
26 UKQAA and JEP response to the questionnaire 'Questions for the PFA TAG to aid the Financial Impact Assessment'.

Term	Description
Furnace bottom ash (FBA)	Ash that in a molten state adheres to the boiler tubes within the furnace and falls to the bottom of the furnace where it is cooled using high-pressure water jets and flushed from the bottom of the furnace.
Flue gas	Gas produced during the combustion process.
Fly ash	Accepted EU wide phraseology for PFA therefore has same definition as PFA.
Leachate	The liquid that drains (product) from uses of ash.
Masonry mortar	Mix of one or more inorganic binders, aggregates, water, and sometimes additions and/or admixtures for bedding, jointing and pointing of masonry.
Mixer-blended cement	PFA is blended by the concrete producer in the concrete mixer.
Permit	Environmental permits or exemptions issued under the Environmental Permitting (England and Wales) Regulations 2007, which came into force on 6 April 2008, or low risk waste activities in accordance with Environment Agency guidance. From 6 April 2008, the following automatically became environmental permits: ■ PPC permits issued under the Pollution Prevention and Control (England and Wales) Regulations 2000 (as amended); and ■ Waste Management Licences (WMLs) issued under the Environmental Protection Act 1990 (as amended). Exemptions from the need for a Waste Management Licence, registered under Regulation 18 and Schedule 3 of the Waste Management Licensing Regulations 1994 (as amended) now come under Schedule 3 of the Environmental Permitting (England and Wales) Regulations 2007.
Petcoke	A substance, mostly carbon, derived from oil refining process. Short for petroleum coke.
Potentially Toxic Element (PTE)	Chemical element that has the potential to cause toxicity to humans, flora and/or fauna. The majority are also known as 'heavy metals' or 'transition metals' (e.g. lead, cadmium, mercury, copper, zinc, nickel).
Pozzolanic material[27]	A material that sets and hardens with lime [Ca $(OH)_2$ or CaO] in the presence of water to form stable and durable compounds.
Pre-blended cement	PFA is pre-blended in the cement before sold to the concrete producer.
Processor	Someone who processes and tests the PFA and FBA to ensure that it meets appropriate standards and specifications.
Producer	The operator of the coal-fired power station that produces PFA and FBA.
Pulverised fuel ash (PFA)	The residual solid material from the combustion process in coal fired power stations. For the purposes of this document, PFA is defined as including coal-combustion PFA, co-combustion PFA and cenospheres.

27 UKQAA Technical Data Sheet 6.0 *Fly ash bound mixtures for road and airfield pavements.*

Term	Description
Quality Protocol	A Quality Protocol sets out criteria for the production of a product from a specific waste type. Compliance with these criteria is considered sufficient to ensure that the recovered product may be used without risk to the environment or harm to human health, and therefore without the need for waste regulatory control. In addition, the Quality Protocol indicates how compliance may be demonstrated and points to best practice for the use of the recovered product.
REACH	This Regulation aims to control and limit the risk to human health and the environment from the use of chemical substances and preparations in materials that are available to purchase on the open European market. Its full title is 'Regulation (EC) No. 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC'.
Recovery	Any of the operations provided for in Annex II, B of the Waste Framework Directive.
'Run-of-station PFA'	PFA that remains/is stored on site, has not been lagooned or put in permanent storage.
Test methods	Product and process testing that complies with recognised national or international standards issued by organisations such as BSI or CEN.
User(s)	The individuals or organisations that obtain PFA, from a producer or third party, with the intention of using that PFA in a product.
Unbound application	Where PFA is used without any binding agent.
UKQAA	United Kingdom Quality Ash Association.
Waste management controls	Controls under legislation that govern the treatment, handling, containment, and storage of waste, e.g. Environmental Permitting Regulations (England and Wales) 2007.
WRAP (Waste & Resources Action Programme)	WRAP helps individuals, businesses and local authorities to reduce waste and recycle more, making better use of resources and helping to tackle climate change.

Appendix E A CE mark for EN450-1 fly ash for concrete[28]

Figure E1: Example of CE marking information

CE 01234	CE conformity marking, consisting of the "CE" symbol given in Directive 93/68/EEC. Indentification number of the certification body
AnyCo Ltd, PO Box 21, B–1050 03 01234-CPD-00234	Name or identifying mark and registered address of the producer Last two digits of the year in which the marking was affixed Certificate number
EN 450-1 **Fly ash for concrete** **Fineness category: N** **Declared value of fineness in case of category N: 25%** **Loss on Ignition Category: A** **Particle density: 2300kg/m³** **Dangerous substance: NL, F²⁾**	No. of European standard Description of product and information on regulated characteristics Abbreviation of the name of the country where the fly ash complies with national regulation.

28 Provided by TAG member.

Appendix F Typical chemical composition of PFA and FBA[29]

Chemical	Units	PFA		FBA	
		Minimum	Maximum	Minimum	Maximum
Aluminium	% w/w	24	26		
Aluminium	mg/kg			2,000	123,000
Aluminium oxide	% w/w			18.91	26.1
Antimony	mg/kg	1	325	0.3	4
Arsenic	mg/kg	4	128	<3	33
Barium	mg/kg	0	36,000	32	3,100
Barium oxide	% w/w			0.12	0.32
Beryllium	mg/kg	0.2	9.1		
Boron	mg/kg	5	310	0.5	145
Cadmium	mg/kg	<0.1	4	0.06	0.6
Calcium	% w/w	5.3	5.7		
Calcium	mg/kg			1,610	33,800
Calcium oxide	% w/w			4.57	8.07
Carbon	mg/kg			23,000	23,000
Chloride	mg/kg	0	2,990	3,000	3,000
Chromium	mg/kg	16	220	16	950
Cobalt	mg/kg	2	115	4	72.9
Copper	mg/kg	10	474	7	310
Fluoride	mg/kg	0	230	<5	145
Fluorine	mg/kg			<5	68.5
Gold	mg/kg			<5	<5
Iron	% w/w	7.7	9.5		
Iron	mg/kg			7,630	119,000
Iron oxide	% w/w			11.96	21.58
Lead	mg/kg	<1	976	<5	100
Magnesium	% w/w	2.1	2.6		
Magnesium	mg/kg			299	15,000
Magnesium oxide	% w/w			1.83	2.92
Manganese	mg/kg	0.27	1,600	31	2,223
Manganese oxide	% w/w			0.17	0.31
Mercury	mg/kg	<0.01	1.3	<0.01	0.06
Molybdenum	mg/kg	<2	81	4	22.8
Nickel	mg/kg	8.3	583	40	620
Phosphorous	mg/kg	262	2,818	220	270
Phosphorous	% w/w	0.6	2.1		
Phosphorous pentoxide	% w/w			0.23	0.7

29 Data for PFA and FBA materials were derived from a variety of available sources including UKQAA and JEP. Data were obtained for coal-fired power stations, coal and petcoke and biomass co-firing, as well as from Aberthaw power station, which uses ammonia injection to improve ESP performance.

Chemical	Units	PFA		FBA	
		Minimum	Maximum	Minimum	Maximum
Potassium	% w/w	1.8	3.4		
Potassium	mg/kg			166	10,000
Potassium oxide	% w/w			1.31	2.17
Selenium	mg/kg	<1	162	0.3	<1
Silica	% w/w			39.35	53.34
Silicon	% w/w	48	56		
Silicon	mg/kg			325	187,000
Silver	mg/kg	0.126	0.126		
Sodium	% w/w	0.7	1.1		
Sodium	mg/kg			126	5,000
Sodium oxide	% w/w			0.3	0.9
Sulphur	% w/w	0.9	1.1		
Sulphur	mg/kg			4,500	4,500
Sulphur trioxide	% w/w			0.08	1.39
Thallium	mg/kg	0.374	0.374		
Tin	mg/kg	<2	1847	1.2	1.2
Titanium	% w/w	1	1.1		
Titanium	mg/kg			124	5,100
Titanium dioxide	% w/w			0.76	1.05
Total sulphate	mg/kg	1,600	4,240		
Uranium	mg/kg	3.65	3.65		
Vanadium	mg/kg	44	1,339	11	540
Zinc	mg/kg	43.3	918	20	230

Appendix G Source Protection Zones

How zones work – taken from the Environment Agency website (http://www.environment-agency.gov.uk/maps/info/groundwater/963948/?version=1&lang=_e)

The shape and size of a zone depends on the condition of the ground, how the groundwater is removed, and other environmental factors. When we define a zone we find out how the groundwater behaves in that area, what constructions there are to get the water out into the public water supply, and the process for doing this. From this we can develop a model of the groundwater environment on which to define the zones.

We divide groundwater source catchments into four zones. The zones are divided as follows:

Zone 1 (Inner protection zone)
Any pollution that can travel to the borehole within 50 days from any point within the zone is classified as being inside zone 1. This applies at and below the water table. This zone also has a minimum 50 metre protection radius around the borehole. These criteria are designed to protect against the transmission of toxic chemicals and water-borne disease.

Zone 2 (Outer protection zone)
The outer zone covers pollution that takes up to 400 days to travel to the borehole, or 25 per cent of the total catchment area – whichever area is the biggest. This travel time is the minimum amount of time that we think pollutants need to be diluted, reduced in strength or delayed by the time they reach the borehole.

Zone 3 (Total catchment)
The total catchment is the total area needed to support removal of water from the borehole, and to support any discharge from the borehole.

Zone of special interest
Sometimes, we define a fourth zone. This is usually where local conditions mean that industrial sites and other polluters could affect the groundwater source even though they are outside the normal catchment area.

Waste & Resources Action Programme

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