Designation of Pulverised Fuel Ash and Furnace Bottom Ash as Wastes in the United Kingdom

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ABSTRACT

Pulverised fuel ash (PFA) and furnace bottom ash (FBA) have been used in a wide range of construction products for at least 70 years within the United Kingdom. A comprehensive range of standards and protocols has developed to enable the use of these raw materials in diverse processes. The application of these procedures has been highly effective, ensuring the manufacture of sustainable products, of the necessary quality and required technical performance. The environmental impacts of PFA and FBA use have also been addressed in recent standards and protocols.

The wider classification of PFA and FBA as wastes could reduce their acceptance by customers. This would result in greater amounts of ash discarded in landfill, leading to increased reliance on primary aggregates. The continued development of realistic standards and protocols would also be impeded, further reducing rational utilisation. These unsatisfactory outcomes should be avoided.

This paper reviews the existing processes and criteria used to define 'end of waste' (EoW) status for PFA and FBA, allowing their reclassification as products. In addition, the paper considers the continual discussions with the various regulators to develop these processes further, thereby encouraging the continued use of PFA and FBA as products in construction markets.

1.0 Introduction

Manufacturers of construction products in the 21st century should strive to ensure that products are sustainable and the use of pulverised fuel ash (PFA) or furnace bottom ash (FBA) is one way of achieving this aim. The most useful description of sustainability is probably the 'Brundtland definition' [1,2] :

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

PFA and FBA are used in a wide range of construction products in the United Kingdom. The environmental and technical benefits are such that when used in a construction product, they can help to contribute to sustainable development. A critical aspect is the resource efficiency achieved by using the by-products. Valuable primary raw materials, such as natural aggregates are not extracted, but left for future generations to use if required. The specific technical benefits provided by

PFA and FBA often improve performance, thereby ensuring further resource efficiency. For example, the improved durability achieved by using PFA within concrete contributes to a long service life of a structure and reduced maintenance.

The designation of a by-product either as a waste or non-waste can have profound effects on its utilisation as a construction material. Stating that a material is a waste may reduce its acceptance and preclude widespread use, even if strong technical and environmental benefits exist. Potential customers may be unwilling to apply for the necessary environmental permits or waste transfer licences. Rational end of waste (EoW) criteria must be developed and applied in a systematic way.

This paper discusses the use of PFA and FBA, notes the high level of technical and environmental compliance achieved, which ensures the sustainability of the construction products. The significance of the European Waste Framework Directive (WFD) [3] is reviewed and the development of Quality Protocols (QP) as EoW criteria discussed.

2.0 Examples of the use of PFA

Use of PFA and FBA can be divided between bound and unbound applications. These terms have particular significance in respect of Quality Protocols. Concrete with partial replacement of cement by PFA is discussed below as an example of a bound application. PFA used as a fill material is cited as an unbound application. Figure 1 shows the degree of technical and environmental compliance that typically must be achieved and maintained by suppliers in the United Kingdom.

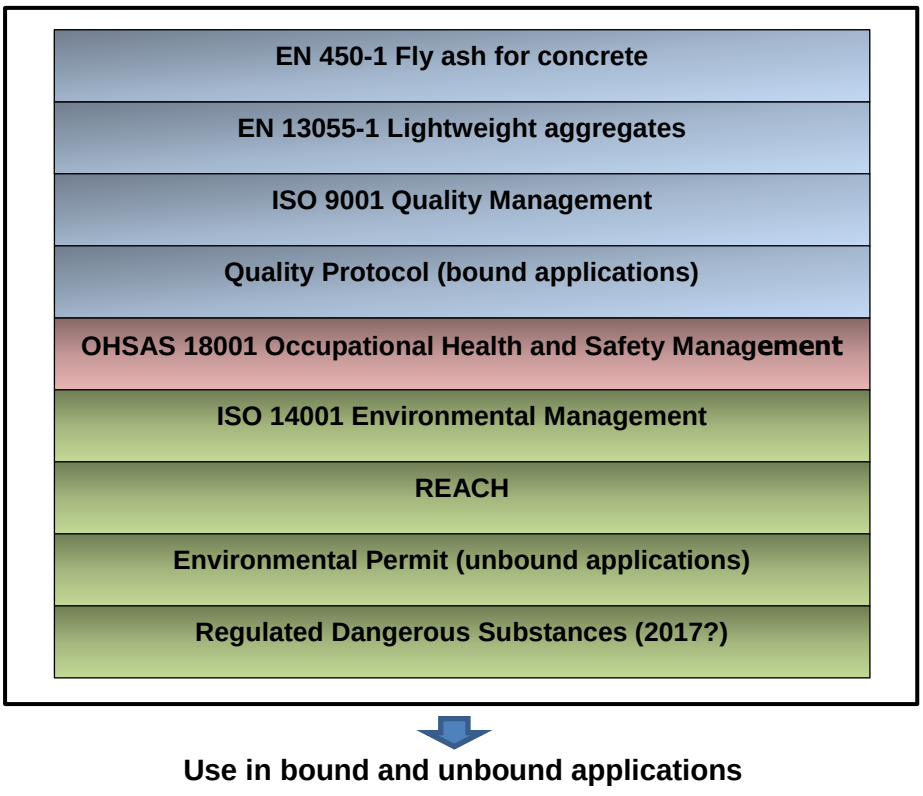

Figure 1 Technical and environmental compliance for PFA/FBA applications

2.1 Concrete

Within ready-mixed and precast concrete plants, use of PFA as a cementitious addition is well-established, accounting for ~ 16% of the annual production in the United Kingdom. In the terminology of EN 206-1[4], the European standard for concrete and the complementary United Kingdom standard BS 8500[5], PFA is a Type II addition; one which counts towards the cement content of a mix for the purposes of minimum cement content and water/cement ratio. Thus, PFA is recognised as a pozzolan and significant replacement of cement is allowed. Table 1 refers to a typical example, where up to 55% of the cement may be replaced by PFA produced to EN 450-1 [6], the harmonised European standard.

Use of PFA in well-formulated concrete gives a significant water reduction, which improves cohesiveness in the wet mix and lessens the tendency to bleed. The lower cement content gives a reduced exothermic reaction, which minimises excessive temperature rise within the poured mass. Thermal stress is less, thereby reducing the incidence of cracking. The specified strength will be achieved in 28 days and strength will continue to increase due to the pozzolanic reaction between the fine ash particles and lime which persists for a considerable time. The ultimate compressive strength achieved will usually be greater than for concrete cast without the PFA addition. The cured concrete will have low porosity, impeding the movement of chloride ions and other deleterious species throughout the matrix and be resistant to alkali-silica reaction (ASR).

A prime environmental benefit of the use of PFA in concrete is the reduction in the amount of cement used. Cement consumes a significant amount of energy during manufacture and generates substantial quantities of carbon dioxide (CO_2). PFA has a carbon dioxide equivalent of 4 kg CO_2 e /t [7], which compares with 913 kg CO_2 e /t for Portland cement. Typically, 35% of the cement may be replaced by PFA, giving a value of 595 kg CO_2 e /t. The PFA content may be increased to 55%, resulting in a figure of 413 kg CO_2 e /t. Concrete made with these combinations of cement and PFA will have lower embodied energy and a reduced carbon footprint compared with conventional concrete. Reduced amounts of primary calcareous and siliceous raw materials are quarried and less PFA is sent to landfill, improving resource efficiency. Concrete with PFA will be durable and provide a long service life. Life cycle analysis (LCA) would show a lower environmental impact over the lifetime of the structure.

Benefits	
Technical	Environmental
Water reduction	Resource efficient
Greater cohesiveness	Reduced landfill
Reduced temperature rise	Lower embodied energy
Lower porosity	Reduced CO_2
Lower chloride permeability	Durable concrete and long service life
High final strength	
Increased resistance to ASR	
Increased durability	
Improved surface finish	

Table 1 Benefits of PFA use in concrete

The supply of PFA and FBA for industrial applications, such as described previously, is highly regulated. Over many years, technical specifications have evolved into sophisticated product standards. Quality management, environmental management and health and safety management systems have been adopted voluntarily by the industry and environmental regulations have become more stringent. Figure 1 illustrates the extent of the compliance which is typical when PFA is supplied as a Type II addition to concrete, or FBA delivered as a lightweight aggregate.

PFA must meet the physical properties and performance specifications of EN 450-1 in order to be used for the manufacture concrete compliant to either EN 206-1 or BS 8500. FBA supplied as a lightweight aggregate for concrete, mortars, grouts and unbound hydraulic applications must comply with the properties given in EN 13055. Suppliers of PFA and FBA operate an ISO 9001 Quality Management System. A Quality Protocol (QP) has been developed in the United Kingdom to define end of waste criteria for "bound applications" and will be discussed in detail later within this paper. OHSAS 18001 the Health and Safety Management System is widely adopted within the UK ash industry. ISO 14001 the Environmental Management System is fully adopted across the industry. Both PFA and FBA have been registered under the REACH Regulations, which involved submitting a comprehensive dossier to the European Chemical Agency (ECHA) about environmental impacts and toxicity.

It is noteworthy that ISO 9001, ISO 14001 and OHSAS 18001 are all third party accredited schemes. In addition, when EN 450-1 and EN 13055 are revised, from 2017 onwards, the standards must take account of the regulated dangerous substances covered in Annex 1 of the European Construction Products Regulation (CPR) [8].

The major producers of concrete within the United Kingdom comply with BES 6001, a responsible sourcing standard which has third party accreditation from the Building Research Establishment (BRE). Nineteen performance indicators are monitored annually and targets have recently been tightened in order to reduce environmental impact of concrete over the period 2012 to 2020 [9]. The UKQAA operate a responsible sourcing scheme, based on five categories and 18 key performance indicators [10].

2.2 Fill applications

PFA is widely used as an engineering fill material and has several technical advantages[11]. It is lightweight, with a density of ~ 1.5 Mg/m^3 compared with 2.0 Mg/m^3 for typical soils. When correctly compacted it shows less than 1% shrinkage. PFA is a cohesive material and its shear strength increases with time. It therefore is self-hardening and generally stronger than many natural clays or granular materials. An immediate strength gain allows simple shallow trenches to be produced without shoring.

PFA fill can be supplied freshly conditioned, directly from the silos at the power plant with a controlled amount of water. Alternatively, conditioned PFA may be obtained from a stockpile. According to the specification for Highway Works[12] raw material may be classified for general fill (type 2E), structural fill (type 7B), or for stabilisation with cement (type 7G), to form a capping layer (Class 9C). Only freshly conditioned

PFA is suitable for types 7B and 7G. Significant environmental benefits are achieved by using PFA as a fill material. Projects may be completed with significantly less primary aggregates. Due to PFA's lower density, the total mass of material delivered to site is less, with significantly fewer truck movements and lower fuel consumption. Unbound uses of PFA or FBA, such as within embankments, must comply with an Environmental Permit issued by the relevant regulatory body.

2.3 Overview

The supply chain from the production of PFA and FBA to a typical end use is relatively short, highly regulated with substantial environmental benefits achieved in many applications. There are further well-established unbound and bound applications for PFA and FBA, which use similar amounts of materials. These uses demand a comparable level of technical performance, quality assurance, compliance with environmental standards and regulations as for the two examples given. As a consequence of the CPR, harmonised European standards from 2013 onwards will require construction products to be assessed for liberation of dangerous substances into ground water, marine waters, surface waters or soil. This measure will provide further environmental safeguards.

The established applications for PFA and FBA have significant environmental benefits and demonstrate a high degree of compliance with technical standards. On many counts the derived products can be judged as sustainable and in line with the "Brundtland" definition. High levels of customer acceptance have been achieved based on the understanding that PFA and FBA are by-products, rather than wastes. If this perception changes, loss of market could follow. Effective EoW criteria must provide a means of retaining by-product status. However, this has been challenging, given the complexities associated with interpreting the WFD.

3.0 Waste Framework Directive (WFD)

3.1 Outline

The Directive, revised in November 2008, is the primary regulation in the European Union for the control of waste. Each member state interprets and enforces the WFD through national regulatory bodies. Within the United Kingdom, these bodies are the Environment Agency (EA) in England and Wales, the Scottish Environment Protection Agency (SEPA) and the Northern Irish Environment Agency (NIEA).

The first objective of the WFD is…"to minimise the negative effects of the generation and management of waste on human health and the environment." A secondary aim is that…"Waste policy should also aim at reducing the use of resources, and favour the practical application of the waste hierarchy." (see Figure 2).

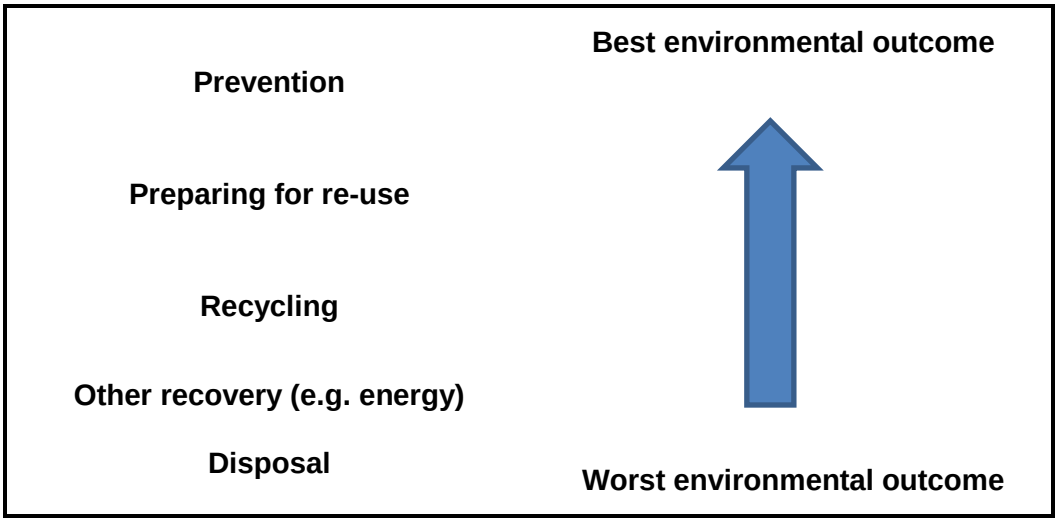

Figure 2 WFD waste hierarchy

Member states are instructed…"to encourage the options that deliver the best overall environmental outcome." The Directive notes that… "this may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking ". For PFA and FBA the two prime aims of the WFD may be satisfied, thereby achieving "the best overall environmental outcome".

The WFD defines waste as:

"any substance or object which the holder discards
or intends to discard or is required to discard"

It is noteworthy that there is no reference to any intrinsic property of the substance or object, its usefulness or indeed potential for re-use.

3.2 Hazardous waste and non-hazardous waste

Description of hazard	Code
Explosive	HP1
Oxidising	HP2
Highly flammable	HP3
Irritant	HP4
Harmful	HP5
Toxic	HP6
Carcinogenic	HP7
Corrosive	HP8
Infectious	HP9
Toxic for reproduction	HP10
Mutagenic	HP11
Releases toxic or very toxic gas	HP12
Sensitizing	HP13
Ecotoxic	HP14
Waste yielding another substance with properties listed above	HP15

Table 2 Hazardous waste categories

Hazardous waste is considered to be material which displays one or more of the hazardous properties listed in Annex III of the Directive (see Table 2). There is a requirement to manage hazardous waste from “cradle to grave”.

PFA and FBA are listed in the European Waste Catalogue (EWC). Neither by-product is categorised as hazardous and therefore is not designated with an asterisk. At the time of writing (February 2013) the EWC is under review and unconfirmed reports from the Commission indicate that the classifications of PFA and FBA will remain unchanged. The relevant EWC reference numbers are:

PFA 10 01 02

FBA 10 01 01

There are concerns that PFA and FBA could be classified as irritant (HP4) because of the nominally high lime content ($CaO/Ca(OH)_2$) of certain ashes. It is believed that the Commission has agreed a derogation providing that within the “high-lime“ samples the CaO or $Ca(OH)_2$ is present in such a form that does not display irritant properties. Such waste would be considered as non-hazardous. In the United Kingdom, however, PFA and FBA generally have low CaO contents.

The pollution incident at the Kingston Fossil Plant, Tennessee in December 2008 has highlighted concerns about the potential environmental impacts of PFA and FBA. At some stage assessments of ecotoxicity may be required for by-products to determine whether they are classified as hazardous or non-hazardous. The use of “M-factors” has been proposed, which is a technique used to evaluate chemicals. This method is poorly understood and may not be applicable to wastes. This could introduce another layer of complexity to the marketing of industrial by-products such as PFA and FBA.

PFA and FBA are considered substances for the purposes of the REACH regulations. In order to achieve registration, a comprehensive dossier of information was submitted to ECHA regarding potential toxicity and environmental impacts. PFA and FBA are registered under REACH as, “mineral raw material and construction material in bound and unbound applications” and neither by-product is considered a dangerous substance.

3.3 End of waste (EoW) criteria

The WFD does not specify criteria to determine when a waste ceases to be a waste. A significant statement is that EoW criteria should …“provide a high level of environmental protection and an environmental and economic benefit;”.

Classification of any material as a waste is not intended to prevent its further use. However, such a classification can have this undesirable effect and limit its use as a secondary raw material.

The definition of waste given in the WFD gives little guidance on EoW criteria. This approach may maximise the protection given to the environment and human health, but lacks clarity and does not encourage use of by-products. Within the European Union any EoW criteria must be drafted with regard to:

- Reference to the WFD.
- Case law from the Court of Justice of the European Union (CJEU).
- Case law from the Courts of Member States.
- Interpretation by Member States' regulatory bodies.
- Procedures established by industrial users of by-products.

The role of case law in determining EoW status must be stressed. The aim was not to produce EoW criteria centrally, but to consider the facts of a particular industrial setting. This approach avoids centralised and prescriptive interpretations of waste status, theoretically allowing flexibility and local factors to influence decisions. However, the EA like many European regulatory bodies has been reluctant to make definitive statements regarding particular by-products and industry has been unwilling to seek legal judgement which might establish case law. Consequently, the development of rational EoW criteria that protects the environment and also encourages the use of valuable by-products, has been slow to date.

Described as "illustrative terms", some guidance is given in the WFD. A product is defined as "all material that is deliberately produced in a production process". Production residue is "a material that is not deliberately produced in a production process but may or may not be a waste". Importantly, conditions are listed whereby a production residue may be deemed to be a by-product, rather than a waste:

- Further use of the substance or the object is certain.
- The substance or object can be used directly without further processing, other than normal industrial practice.
- The substance or object is an integral part of the production process.
- Further use is lawful – "no overall adverse environmental or health impacts".

All four conditions must be satisfied and these have been used as the basis for Quality Protocols.

4.0 Quality Protocols

4.1 Origins

Quality Protocols (QP) were developed by the Waste & Resources Programme (WRAP), the EA and industry to achieve workable EoW criteria. The industrial collaborators for the PFA and FBA QP were the UKQAA, the Joint Environmental Programme (JEP) and the Association of Electricity Producers (AEP). Discussions began in 2000 and the final document was published in October 2010, showing how difficult and time-consuming it has been to gain regulatory guidance on EoW status.

4.2 Bound uses of PFA and FBA

In respect to the Quality Protocol, the EA considers bound applications for PFA to be when "used as an ingredient / component within a product and is fully bound within that product." Designated bound applications are:

- Type I addition to concrete (filler or lightweight filler aggregate).
- Type II addition to concrete (cementitious component).
- Cement manufacture – e.g. kiln feed.
- Ceramic tiles and brick making.
- Paints, plastics and rubber.
- Lightweight filler for bitumen bound materials.
- Hydraulically bound mixture in pavement construction – e.g. road base.

The designated bound application for FBA is as a lightweight aggregate for concrete. Grouting is another designated application for PFA, with the approved product standard quoted as BS EN 12715, Execution of special geotechnical work, Grouting.

4.3 Description of the Quality Protocol for bound PFA/FBA

To quote the Quality Protocol [13]…"Compliance with these criteria is considered sufficient to ensure that a fully recovered product may be used without undermining the effectiveness of the Waste Framework Directive and therefore without the need for waste management controls."

The scheme covers PFA, FBA and cenospheres. Co-combustion is allowed, providing that any ash complies with EN 450-1. It is a voluntary scheme and suppliers have no legal obligation to conform with its requirements. Should this be the case, the EA would normally regard any raw material under consideration to be a waste and full regulatory requirements would be enforced, such as the need for waste transfer licences. The PFA and FBA may be processed by methods such as segregation, screening, classification or carbon reduction. This is considered as waste recovery and subject to national waste management regulations and the WFD. Full recovery and EoW status is achieved once the following apply:

- The PFA or FBA meets an approved product standard relevant to the end use. For example EN 450-1, if the ash was to be used in structural concrete. Alternatively, a technical specification agreed with the customer has been met.

- If required, additional customer specifications have been achieved.

- A designated bound application has been identified.

- No further processing is required before use.

- Documented evidence is available showing compliance.

There is a need to consider the environmental impact of the use of PFA or FBA. There must be no adverse effect on the sustainable use of water resources. Similarly, designated conservation areas must not be affected. Stockpiled PFA is subject to normal waste management regulations. Figure 3 reproduces the diagram given in the WRAP/EA Quality Protocol. Significantly, stage 4 is the "point at which material ceases to be waste", thereby meeting the requirements of the WFD. Once fully recovered, any by-product may become subject to the REACH regulations.

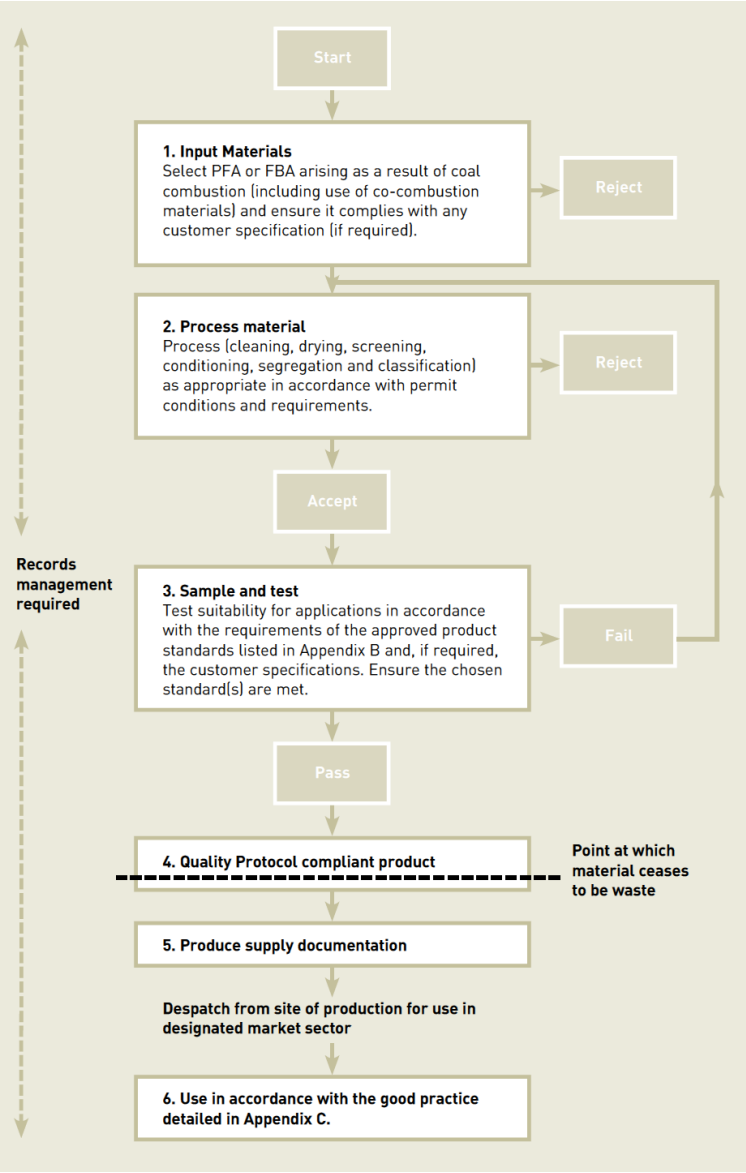

Figure 3 Extract from the Quality Protocol for bound PFA/FBA

4.4 Progress of the Quality Protocol for unbound PFA/FBA

The EA is reluctant to include unbound uses in the current Quality Protocol. The concern is that unbound PFA or FBA has a greater potential to cause environmental harm, particularly to groundwater. Realistic estimates of the leaching of pollutants from PFA or FBA are required. However, most measurements are from laboratory experiments which cannot be scaled-up successfully for typical fill applications.

A research project was proposed by the EA to obtain reliable field data to assist preparation of a Quality Protocol for the unbound use of PFA and FBA. Originally, the plan was to build a fully-compacted embankment, typical of a fill project. Water draining through the ash profile would be periodically collected and tested for leachates. Similarly, water drain off would be tested. Mass flow of water through and off the embankment would be estimated. Unfortunately, budgetary constraints have prevented this scale of project from starting. The EA has reduced the scope of the project and propose to use lysimeters for obtaining leachates from the PFA. In early 2013, representatives of the ash industry held discussions with the EA to review the proposed project. The industry considered that lysimeter tests may be an improvement of earlier laboratory work, but the original design of the "embankment trial" was still valid and should be pursued. Only robust field tests are likely to approach the actual behaviour of the unbound PFA in construction works. It is hoped to fund an "embankment trial" independently from the EA lysimeter measurements.

The EA has drafted a regulatory position statement to deal with unbound applications of PFA or FBA and gives interim guidance whilst a QP is being developed. For a single project, up to a limit of 100,000 t an environmental permit is not normally required, "where the wastes are suitable for use in construction and meet the relevant civil engineering standards for use". The document states that the objectives of the WFD must be met. There are specific requirements to protect local groundwater and environmentally sensitive locations, such as a Site of Special Scientific Interest (SSSI). The document only applies to end use and any processing or storage requires a permit.

5.0 Conclusion

Interpretation of the Waste Framework Directive in order to achieve sensible EoW criteria for PFA and FBA has been difficult and time-consuming in the United Kingdom. The Quality Protocol approach has been successful for bound applications and is achieving recognition with ash suppliers and users.

Slow progress has been made with a Quality Protocol for unbound applications, such as structural fills. The Environment Agency's regulatory position statement offers guidance for projects up 100,000 t, but is only an interim measure and could be withdrawn at short notice.

Field trials should be undertaken in order to assess the performance of unbound PFA and FBA, as this will enable leachate loss to the environment to be modelled realistically. An "embankment trial" is the preferred option of the ash industry. With this information progress may continue on developing a Quality Protocol for unbound applications.

Ecotoxicity measurements such as the use of "M-factors" should be assessed for their relevance and applicability for the hazard classification of wastes.

Rational and evidence based procedures should guide the development of EoW criteria to ensure that PFA and FBA remain as valuable by-products, readily available for the construction products market.

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