Best Practice Brochure:
Residue Utilisation at Didcot Coal-fired Power Station

INTRODUCTION

Coal-fired power stations currently produce about 37% of the world's electricity. Although this is expected to remain fairly constant, consumption oi power station coal is expected to increase significantly, as emerging nations continue their development.

Many coal-fired power stations use pulverised coal for efficient combustion. The consequence of this process is the production of process residues and of by-products. These are normally in the form of flue gases, water and steam tVom the cooling systems, and a significant proportion of solids from the non-combustible part of the coal.

This solid is the silt content of the parent coal and the amount available depends upon the efficiency of the combustion process and upon the coal type. The mineralogy and trace element concentration of the ash are influenced, primarily, by the magnitude and frequency of the subsidence which took place in the ancient peat swamp, and the manner in which organic and inorganic compounds were deposited into the peat by the natural geological processes of erosion and deposition.

The ash can represent up to 20% of the coal and, for a 2000MW_e power station, this means approximately 1 million tonnes could be produced per year This is a significant volume of material that needs to be handled economically and in a way that reduces the impact on the surrounding environment.

Two types of ash are generally produced from the combustion of pulverised coal About 80% of the ash produced is a fine powder known as Pulverised Fuel Ash (PFA) or Fly Ash. PFA is light and fine; as such, it is carried in the gas stream out of the boiler, ultimately being collected by mechanical arrestors and/or electrostatic precipitators. The remainder of the ash (about 20%) is much coarser and is called Furnace Bottom Ash ;FBA). FBA falls to the bottom of the furnace into a hopper and is removed by high-pressure water jetting along sluiceways to a coarse crusher and then to storage pits.

During the formative years of pulverised fuel combustion, all the ash was tipped and left without any regard to the possible unique benefits that the material could bring. However, the increasing amounts to be disposed of encouraged the industry to examine the ash more closely. It is the results of this early work (work which continues today) that has allowed confident use of ash in many construction applications over the last 50 years Ever more stringent environmental regulations and continued costs of material disposal still encourage positive use of ash and are likely to for as long as ash is produced. Therefore the positive use of ash remains integral to the operational plans of a coal-fired power station.

This Best Practice Brochure describes the technology and operational practices used by Didcot Power Station, to allow the station to be best placed to take advantage of any beneficial route for the utilisation of its ash.

DIDCOT COAL-FIRED POWER STATION

Innogy is a leading integrated energy company focusing on energy generation, trading and retail. When National Power demerged in October 2000, Innogy inherited its operating and maintenance expertise within the UK. The company has a generating capacity of almost 11,000MW_e consisting of a variety of generating technologies including wind, hydro, gas and coal combustion.

Didcot Coal-fired Power Station is the largest power station that Innogy inherited, with an installed generation capability of 20Q0MW_e. Didcot Power Station stands on the outskirts of the town of Didcot in Oxfordshire, approximately 9 miles south of Oxford.

The station has been generating since 1970 and in the early 1990s it underwent a £20 million improvement scheme on the precipitators which enabled the station to burn coal with a much lower sulphur content. The station was also modified to burn gas as an alternative to coal, to take advantage of any economies available during fuel price changes.

The station can burn up to 19,000 tonnes of coal per day; the coal is sourced from around the world and imported via a purpose-designed bulk handling terminal at Bristol. Coal is delivered by rail on a 'merry-go-round' rail system and can be supplemented in small quantities by road.

Coal specification limits are in the region of:

Total Moisture	(%)	4.0-12.0
Ash Content	(%!	9.0-34.0
NetCV	(GJ/te)	(7 67-26 *U*
Volatiles	(%)	23.0-32.0
Sulphur	(%)	0.5-3.5
Chlorine	(%)	0.03-0.9

Coal is automatically unloaded from trains consisting of 36-40 specially designed coal trucks holding about 32.5 tonnes of coal each or by modern bogie wagons with a capacity of 75 tonnes each. From the holding hoppers the coal travels by conveyor to the bunker house which can store 2000 tonnes of coal for each unit. When coal is not required to fill the boiler bunker it discharges through the surge tower and is removed to stock by large mobile scrapers; the stockpile can hold up to 1.5 million tonnes.

Didcot has four Babcock front-wall-fired boilers with 48 burners to each boiler, all of which have been modified for low oxides of nitrogen (NO,) emission. Each boiler is fed by eight Babcock 10E pulverising mills which have ten 76cm rotating steel balls and can feed pulverised fuel at 27-3C lonnes per hour.

Each of the four boilers produces 422kg/s of steam at 568°C and 165.5 bar for its own turbine generator. The turbine is a 500MW_e Parsons-GEC and consists of five separate sections: a single high-pressure turbine developing 27% of the power, one intermediate-pressure turbine developing 31% of the power and three low-pressure turbines developing a total of 42% of the power.

The steam, with its useful energy now spent, is condensed by two condensers back into feed water The make-up water for the six cooling towers is taken from the River Thames.

The boiler produces ash at the maximum rate of approximately 3,420 tonnes/day. About 20% of the ash is sluiced from the boiler as FBA. The remaining ash is PFA which is carried in the hot gas stream en route to the chimney. Approximately 99.9% of the PFA is collected m electrostatic precipitators where it is blown by compressed air through a dust pump and stored in a dust bunker. PFA that is not sold is mixed with water and pumped to disused gravel pits about 10km north of the Power Station, with the aim of restoring them to beneficial use.

Figure. Didcot Coal-fired Power Station

WHY BEST PRACTICE AT DIDCOT COAL-FIRED POWER STATION?

Best practice in the utilisation of residues from a coal-fired power station ensures maximum benefit to the production economics and a minimum impact on the surrounding environment.

The ability to reduce the costs for disposal of residues, by minimising the amount of unwanted by-product made available for disposal, and then to gain income from a process by-product, must be seen as valuable.

The ever-increasing environmental considerations arising from local government authorities, increasing legislation, and sensitive public opinion have brought about added pressures that have given a high degree of priority to utilisation of the ash produced in our power plants and by other industries.

Many current UK coal-fired power stations are fairly old plant, in terms of the number of years they have been generating. Many of the original production plans were made during the building of these stations when they were operating in a very different market. Innogy Power Stations now operate in the world's longest established privatised electricity market and the influences of this have altered many operational working practices. One of the benefits during this period has been to run coal-fired power stations more economically and beyond the original life expectancy. This has also had an impact on the availability of additional disposal areas and therefore it is important that these are used as economically as possible to maintain future generation capacity.

WHAT IS GOOD PRACTICE AT DIDCOT FOR VARIOUS RESIDUES?

As a result of improved operational practices and technological advances, Didcot is expected to generate well into the future. The additional life span and the change in combustion technology has had a great effect in altering both the disposal options and the make-up of the coal combustion products from the Power Station, particularly for ash.

Didcot pursues best practice in the utilisation of residues from a coal-fired power station to ensure maximum benefit to the production economics and a minimum impact on the surrounding environment.

BEST PRACTICE ENSURES THAT SUITABLE CONSIDERATION IS PLACED ON:

- Sustainability of fuel
- Sustainability of aggregate
- Waste minimisation
- Income from residue
- Restoration of land for positive benefit
- Maintenance of generation capacity
- Ensuring operation within legislative requirements
- Public, shareholder and customer opinion.

Sustainability

Sustainability is defined as the ability to leave sufficient resources for future generations and yet satisfy the needs of the current generation. The modern world needs electricity; coal is one of the most abundant sources of fuel for generating electricity and is a relatively sustainable resource. Additionally, the impact of obtaining primary aggregates is increasingly unacceptable. The use of ash in a wide variety of construction applications reduces the demand on primary aggregates. When ash from power stations is fully utilised it can have significant environmental benefits and reduce the need for primary aggregate extraction.

Waste Minimisation

The effect of making positive use of a by-product is to turn it from an otherwise potential waste material into a valuable resource. This allows the need for disposal to be reduced to a minimum and offsets the continual reduction of land available for tipping. The Power Station is also able to reduce its operational costs; these would otherwise increase in terms of physical movement of material, cost of land for disposal and taxation. Disposing of waste material to land is becoming less acceptable, thus requiring the minimisation of waste production.

Income from Residue (By-product)

The sale of by-products into suitable market places provides a means of deriving value from those by-products. The development of a market is critical and in most cases time consuming. It is important that the product be made suitable for its local markets and be seen as a reliable source of supply. When this is achieved, income can be derived for the power station. The income can often be in excess of expenditure on the disposal operation and therefore can provide additional earnings for the power station.

Land Restoration

It is inevitable that changes in the landscape are brought about by the use Df power station residues. However, high quality restoration and management of disposal areas allows every opportunity for conservation and habitat improvement to be exploited to the full. The end use of the land is made compatible with the natural environment and social surroundings, producing an area of land often better than that which it replaces.

Maintaining Generation Capacity

It is evident that disposing to land for disposal is becoming a less acceptable method of residue disposal. Without sufficient development and control of by-product utilisation, the land available for disposal will eventually become minimal or disappear completely. The impact of this will then reduce the flexibility of the power station, restraining its ability to generate and ultimately preventing generation altogether. Obviously, this prevents the power station from continuing to be effective in its core business and is a particularly difficult position to accept, especially when the generating plant is likely to have economic life left within it.

Operation within Legislative Requirements

Legislation within the power industry is extensive and impacts on all areas of the business. The continued stringent environmental regulations have an effect on operational methods and the handling of power station residues. It is important that the power station not only operates within legislative requirements but is also aware of any impending changes and the effect the changes would have on other parts of the business. It can be seen that changes to generation practices and combustion equipment can alter the residues produced and therefore impact on the suitability of the material to fit the original marketing and disposal plans.

Public, Shareholder and Customer Opinion

People are the most important asset to any progressive commercial business - not only their employees but also the individuals that they interact with such as the public, customers and shareholders. The manner in which a company conducts its business has a high impact on everyone and this is particularly relevant for environmental and waste issues. If these are handled in an inadequate manner then the 'bad press' generated can prove to have consequences that are extremely difficult to recover from.

Not only are companies driven by legislation and economics to to control their environmental impacts, but progressively lenders, insurers and investors require demonstrable evidence that environmental issues are being managed effectively. It is also evident that supplier and customer pressure is increasing; in this sensitive business *dtea,* some companies are now choosing to compile supplier rankings based on environmental efficiencies

TECHNOLOGIES USED FOR RESIDUE UTILISATION

Markets for the use of power station ash have continued to develop since the early days of pulverised fuel firing and the product has become a valuable resource. The markets are wide ranging and each carries its own unique requirements, in terms of both technical and physical needs. The differences between the available types of ash are important to the end user and these fall into the following categories:

- Cenospheres
- Furnace Bottom Ash (FBA)
- Dry ash (PFA)
- Classified ash (PFA)
- Conditioned ash (PFA)
- Lagoon ash (PFA or PFA and FBA mixed).

Cenospheres

Cenospheres are a component of normal PFA, but are unique in their make-up as they have a density less than 1.0. They are formed when bubbles of carbon monoxide are contained within molten glass droplets. This gives rise to hollow spherical particles. The quantity of cenospheres in ash varies from 0.01 % to 5% by weight, but the bulk density is about one quarter of PFA,

The chemical composition of cenospheres is as follows:

Compound	Maximum %	Minimum %
Silicon oxide (SiO_2)	61	55
Aluminium oxide (Al_2O_3)	30	26
Iron oxide (Fe_2O_3)	10	4
Calcium oxide (CaO)	0.6	0.2
Magnesium oxide (MgO)	2	1
Alkali (Na_2O,K_2O)	4	0.5
Carbon (Loss-on-ignition)	2	0.01

Many plastics, composites and paints use fillers during their manufacturing processes. Cenospheres can be used as a filler and offer many of their own unique advantages including a very low density, a spherical shape and high-strength particles Each application has specific requirements and examples of these applications are:

- Pattern making
- Mould making and casting
- Foam-filled sandwich glassfibre panels
- Fire-resistant boarding
- Urethane systems
- PVC frames
- Putty
- Paint and varnish
- Radio and infra-red stealth.

Current technology only allows for cenospheres to be harvested from lagoon disposal sites. Didcot Power Station is able to harvest the cenospheres from the lake at Radley and approximately 400 tonnes *are* made available each year. Due to the density of cenospheres, they are found as *a* thin layer floating on the top of the water. As such, when sufficient material is available to undertake reclamation, they are guided by boats to an area where they can be scooped off from the lagoon surface. Cenospheres are then placed for storage at the side of the lagoon tc facilitate drainage: approximately 25% moisture can be achieved in a week. The compounds need to be covered with tarpaulins to prevent wind blow The cenospheres are then loaded into sheeted lorries and transported to the processing plant for further drying and classification.

Furnace Bottom Ash (FBA)

FBA is extensively used in the manufacture of non-aerated concrete blocks, commonly known as Medium Density Blocks. The inclusion of FBA, as an aggregate in the mix, improves the casting operation and gives a better surface finish. In addition the blocks are lighter than natural aggregate blocks and are able to retain an equal crushing strength. The use of FBA in blocks has become such an important part of the mix ingredient that the demand for FBA cannot be completely met within the UK.

Although the demand for FBA in blocks within the UK is extensive, opportunities for the use of FBA in other areas have arisen. FBA is a free-draining granular material and therefore it is a useful material for laying as a base in applications such as pathways and menageries. In addition to being free-draining, FBA is non-susceptible to frost heave and makes an ideal sub-base material for highway construction.

FBA Storage

Didcot Power Station is contracted to supply FBA to independent block manufacturers in the local area. To allow the customer to make best use of the F8A, the Station has made a concentrated effort on the design of the FBA collection and storage facilities. To allow the full benefit of the material to be harnessed, the FBA is collected and processed independently of any other ash. From the furnace the FBA drops into the furnace bottom where it is cooled by water and then removed to a crusher by high-pressure water jetting, from where it is sent to storage. The construction of the storage area allows for the material to drain and subsequently dry. The drainage of the material is monitored to allow the material to become dry but also to allow the material to retain sufficient moisture to be easily handled and to suppress dust. When the FBA in the storage area has achieved acceptable moisture content and sufficient material is available, it is removed by a loading shovel and sheeted tipper trucks. Prior to being used in block manufacture, the FBA is graded to give a consistent size distribution. The resulting aggregate can then be batched with the concrete constituents to form blocks of a suitable density and size

Pulverised Fuel Ash (PFA)

PFA is a fine alumino-silicate material, which consists of predominantly spherical particles and varies in colour from cream to grey. PFA can be supplied to end users in different forms.

Dry ash is taken directly from the precipitators and stored in suitable silos where it can be loaded into bulk dry powder tanker trailers for subsequent distribution and transfer into end user silos.

Conditioned dsh is PFA which has had water added to it, usually sufficient to aid handling and prevent dust blow. It can be stored on controlled stockpile mounds and transported in suitable sheeted tipper trucks. Certain applications require different moisture contents and these can be accommodated within certain limits by the conditioner units at the power station.

Lagoon ash is PFA which has been transferred in a slurry form to settlement ponds. This can be subsequently reclaimed and supplied in a similar form to conditioned ash. However, there is less control on the moisture and little control of the constituents of the types of ash found ir the lagoon, which results in variable particle size distribution.

Classified ash is dry PFA which has been processed to remove the coarse fraction of the material; this improves the nature of PFA when used in concrete. This classified ash is subsequently stored and transported in the same way as dry ash.

Didcot supplies PFA in both conditioned and a standard dry state. The station has South and North Silos which are able to store a total of 5000 tonnes of dry ash. This can then be loaded directly into tanker trucks to distribute the dry ash or loaded through conditioners to supply conditioned ash into tipper trucks.

PFA is used in the widest range of applications and consideration of its physical and chemical properties must be undertaken to establish the suitability of target markets. Each power station provides material with slightly different characteristics and in some circumstances it can be totally unsuitable for certain industrial uses.

PFA is a glassy material and its principal constituents are silica, alumina, iron and calcium. About 2-5 % of PFA is water-soluble and the solution is generally alkaline. The following main properties of PFA are important factors in it becoming one of the main raw materials for the building and construction industry:

- It is a fine, lightweight powder
- It combines with free lime (pozzolanic reactivity)

- It has predominantly rounded particles
- It can take up water.

These properties have allowed PFA to be used in the following capacities.
- Structural fill
- Aerated block manufacture
- Lightweight aggregate manufacture
- Concrete and cement
- Grout
- Stabilisation
- Brickmaking.

PFA as a Load-bearing Fill
When suitable PFA of sufficient moisture content is properly compacted in layers of appropriate thickness, it forms an excellent load-bearing fill. Many millions of tonnes of PFA haw been used in this way on various types of construction, which have included some of the largest projects in the UK. Two properties are important in fill:

- PFA is light in weight. The compacted bulk density is generally between 1300kg/m^3 and 1600kg/m^3 which is less than most conventional fill materials. Road embankments built with PFA are relatively light in weight and this is an advantage on ground of poor load- bearing capacity.

- PFA is in most cases self-hardening; it differs from other materials of similar grading in that strength increases with time. There is consequently negligible settlement within the fill, using properly compacted PFA. An additional benefit is the reduction in horizontal pressures on structures, eg the rear face of bridge abutments which can often be designed more economically when PFA is used as backfill.

Two types of PFA are supplied for fill: freshly conditioned and conditioned stockpiled. Many jobs are supplied with freshly conditioned PFA but stockpiles are the normal source of very large tonnages over short periods.

PFA in Concrete and in Cement Manufacture
PFA is used widely in structural concrete and in precast concrete products. It can improve concrete as well as produce cost savings. Three properties of PFA are mainly responsible for its effects:

1. Ability to combine with free-lime (pozzolanic reaction)
2. Rounded particle shape
3. Reduced water demand.

PFA combines with free lime released during hydration of Portland Cement to form additional cementitious components. Advantage has been taken of this reaction for many years by using PFA to replace part of the cement in concrete. Partial cement replacement can not only save money but also produce various technical benefits, such as reduced heat of hydration, which can be advantageous in mass concrete structures. Concrete can be damaged internally by expansive reactions between the free lime and certain chemicals, notably sulphates. PFA reduces the risk of such damage by combining with the lime. Simple partial replacement of cement by PFA can cause some reduction in early strength of concrete, but this can be accommodated in the mix design.

The rounded particles in PFA can improve the workability of concrete when mixed with the more angular shapes in cement and some aggregates. This effect often produces greater compaction of the concrete, which is less likely to be penetrated and attacked by aggressive chemicals, such as sulphates in some waters. PFA can be beneficial, therefore, below ground level and in marine works.

When compared with Portland Cement, PFA usually reduces the amount of water needed to produce the same workability in concrete. Reduced water content usually helps to avoid segregation and bleeding in fresh concrete as well as improve strength and long-term durability.

Cement manufacturers use PFA to produce pre-blended PFA cements which can be produced either by intergrinding during cement manufacture or by dry powder blending post cement production. The relative advantages of using either blended cements or adding PFA at the concrete mixer will depend mainly on cost, type of concrete and the quality of the cement and PFA.

PFA for use in concrete or cement is usually supplied as a dry powder and is also supplied as a classified

PFA to meet relevant British and European standards.

PFA in Grouting

PFA can be used in grouts either neat or mixed with cement or lime to fill voids for foundation and structural purposes. The main benefits *are* as
follows:

- Rounded particle shape of PFA improves grout flow and reduces wear on plant.
- Small particle size and low density of PFA keeps cement in suspension and improves penetration characteristics of grout.
- PFA grouts are lighter than those containing only cement or cement and sand.
- Reaction of PFA with free lime released by cement increases sulphate resistance.

Examples of the use of PFA grouts include curtains under dams and around foundations, strengthening embankments, railway tracks, bridge abutments and void filling in abandoned tunnels, and in mineshafts to prevent subsidence. PFA grouts are also used to repair brick and masonry structures such as bridges piers, church towers, railway tunnels and viaducts.

PFA in Lightweight Aggregate

There are several uses for lightweight sintered PFA. It is used as an aggregate in the structural concrete of multi-storey buildings, in precast structural cladding panels and in concrete blocks. Concrete based on sintered PFA has only about two thirds the weight and about twice the effective thermal insulation of equivalent gravel aggregate concretes. The maximum benefits of sintered PFA are obtained, however, only if the design of a structure is based on the material and not merely on substitution for dense aggregate at a late stage of construction. When used in blocks, sintered PFA aggregate can be mixed with certain fractions of furnace bottom ash to meet standards of thermal insulation.
Other uses of sintered PFA include: insulation screeds on floors and roofs, arrestor beds for road vehicles and aircraft, and in agriculture for land drains and as a growing medium.

Cement-stabilised PFA

A mixture of PFA and cement or lime mixed with an appropriate amount of water forms a strong, hard material when compacted properly. These mixtures have been in continuous use for some years as hard standings at several sites used for heavy industrial and agricultural storage, road bases and sub-bases, motorway hardshoulders, bridge abutments and similar structures where lean concrete and other traditional materials would have been used.

Cement-stabilised PFA normally contains about 5-10% cement and the moisture content should not be less than the optimum for maximum dry density. After compaction the surface may be treated with a sealant before finally topping with surface treatment.

Current trends towards building on disused industrial areas and 'brownfield' sites are discovering the advantages of these methods for capping land prior to construction.

PFA in Building Blocks

PFA is used either as part of the cementitious material or as aggregate (or both) in the manufacture of dense and aerated blocks. In non-aerated blocks PFA can produce one or more of the following benefits; reduced costs, improved casting operations, improved surface finish and reduced weight. The benefit obtained depends not only on the type and quantity of the PFA but also on the nature of the other materials.

Aerated Blocks

In aerated blocks, fine-grained PFA is used with cement (and sometimes sand) to form a slurry which is foamed and cut into blocks after the initial set and then steam cured under pressure. The resulting blocks are very light (about 800kg/m^) and have low thermal conductivity (k value of 1.2 to 1.3). They are suitable as load-bearing blocks and aerated blocks have the advantage of being easily cut, chased and drilled with hand tools.

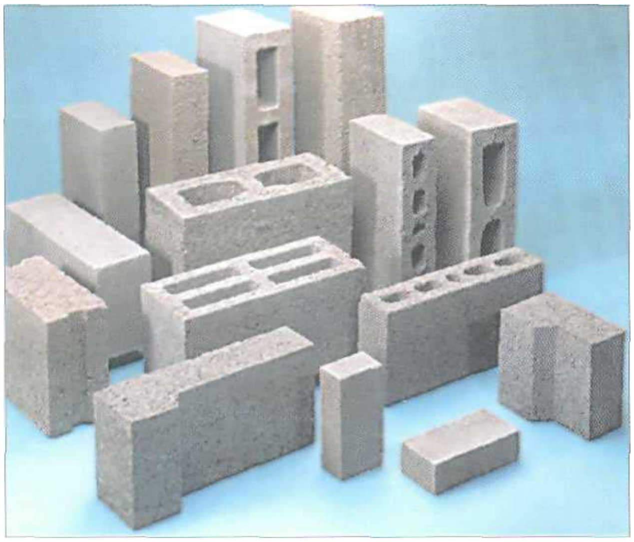


Figure Block; manufactured from pulverised fuel ash at Didcot Power Station

Market Segment	**Prefered LOI** (%)	**Max LOI** (%)	**Fineness 45 Micron Sieve**	**Comments**
Grouting	5-10	<14	<60 preferable 30	Dry or conditioned Limits on CaO, SO_3, Cl
Ready Mix Concrete	As standard	BS 3892 Prti <7 EN450 <7	BS3892 Prti <12 EN450 + or- 10% from stated mean	Dry Limits on CaO, SO_3, Cl
Other Concrete & Precast Blocks	5-7	<12	<60 preferable 30	Dry or conditioned Limits on CaO,
Aerated Concrete Blocks	5	<10	N/A	Dry
Stabilised Road Base/Sub-base Hydraulic Road Binders		<10 HRB <8	<60 preferable 30 (free limit of 1%)	Dry or conditioned
Lightweight Aggregates		<10	N/A	Dry or conditioned
Cement	As standard	<5	<12 (unless interground when there is no requirement)	Dry
Specialist Uses in Steel Industry		>10	N/A	Dry
Fill		N/A	N/A	Conditioned

Other PFA Uses

PFA has many other uses. In these it is used either in the form produced at the power station or after processing to obtain suitable fractions The different fractions have a range in density, heat resistance, thermal insulation and composition which is advantageous in specialised applications which include foundry work, ceramics, plastics and as drying agents for sludge and similar materials. New uses for PFA are continually sought and, as improved industrial techniques are developed further opportunities for PFA will be identified

MARKET PRODUCTS

In addition to the different types of ash available, importance has to be placed on the quality of the ash in terms of its suitability to the market in question. Each end user needs certain types of quality and it can generally be assumed that the higher the quality of material required, the larger the potential profit will be to the power station.

Much of the material's quality is measured by its loss-on-ignition (LOI) and fineness. The table below shows the general requirement of the common markets.

The construction industry can vary its quality requirements depending on the production process. However, it needs to seek consistency of product quality.
The ash produced at Didcot Power Station is generally suitable for most end uses to varying degrees. However, it is unable to provide the PFA suitable for the requirements of quality ready-mix concrete suppliers or end-product cement suppliers and thus limits the returns that are available for this product. This is common to all UK power stations without specialist ash processing equipment.

Didcot PFA Data

LOI (%)	7-15
Fineness (%-45 micron sieve retention)	15-24
Sulphate (% as SO_3)	0.66-1.09
Chloride (%)	<0.005
Calcium Oxide (% as CaO)	1.8-3.6
Free Calcium Oxide (%)	0.05-1.5
Magnesium (% as MgO)	1.2-1.9
Sodium (% as Na_2O)	0.2-0.5
Potassium (% as K_2O)	1.0-1.7
Sodium Equivalent (% as Na_2O)	0.9-1.6
Aluminium (% as Fe_2O_3)	23.9-25.8
Iron (% as Fe_2O_3)	6.3-9.9
Silicon (% as SiO_2)	44.7-47.2
Titanium (% as TiO_2)	1.2-1.5

The largest users of Didcot PFA are block manufacturers, particularly for aerated concrete blocks. The other regular markets include fill, grout and general precast concrete. The block manufacturers and the precast concrete industry have a stable requirement for PFA and this proves useful for planning PFA logistics. The fill market often proves particularly erratic and, due to the nature of fill projects, the requirement tends to be large volumes of material over short periods. Grouts are also required over short periods; however, the logistical difficulties are reduced as the volumes required are usually far less than for fill projects.

Serving the Ash Market

When considering the different requirements of the ash market, it can be seen that emphasis has to be placed on understanding the customers' needs. Normally these customers are from the construction industry and obviously have very different requirements from customers in electricity generation. For this reason, Didcot Power Station has a dedicated team, known as National Ash (a division of Innogy Pic responsible for ash sales and related issues), which deals with the ash market. This includes Technical and Laboratory Support, Contract and Customer Support and Distribution and Logistical Support. The team works closely with the Materials Handling Department at the Power Station and allows a suitable level of focus on improved residue utilisation.

Didcot Power Station has suitable procedures in place to allow advantage to be taken of monitoring ash quality during normal power station operation. Because there are different requirements for different end users, this is taken into account in the working procedures. The working procedures form the basis of daily working practices and are also used for maintaining the quality. Consideration is also given on the physical design of the station, which includes the following:

- Suitable storage areas for FBA.
- Well-managed stockpiles to ensure flexibility for conditioned customers.
- Appropriate loading shovels for PFA tippers.
- Dedicated weighbridge area for ash sales.
- Dedicated routing for ash vehicles.
- Storage silos to improve flexibility for dry customers.
- Suitable silo discharge points for tanker loading.
- Operator-controlled conditioning units for PFA moisture control.
- Conditioner unit outlets for tipper loading.
- Sample points to measure quality of ash available for sale.
- Online carbon-in-ash monitors.
- Split storage silos for materials of different quality.
- Silo inlet diverter valves, to allow selection of preferred quality material during appropriate boiler load periods.

In addition to the physical aspects of the facilities, it is also important to emphasise the cultural dimension with respect to the workforce who operate any of the plant associated with ash sales. They are expected to have an understanding of the need for and importance of ash utilisation and they carry out their ash sales and handling duties with the same commitment as is applied to the generation of electricity.

End Use Technology

Many of the markets which Didcot Power Station supplies involve established construction techniques, which are adapted for the use of ash.

Fill applications are engineered for each scheme and, in many of these projects, the fill material is required to make up land levels or shape suitable land areas. The quality of material is not normally of great importance, provided it has no detrimental environmental implications. Therefore the main factor influencing the decisions regarding which material is to be used is the cost of supply. Many types of material can be used and much of the expense is associated with the cost of transport. This is why many fill projects are completed with locally available materials.

Grouting

Grouting has been defined as the injection, under pressure, of suspensions, emulsions and solutions to improve the geotechnical properties of soils and rocks and to facilitate the filling of voids for structural purposes. PFA for grout is mixed on site with water and cement to make a liguid-type material. The grout has to be suitable to achieve a required flow distance yet strong enough to provide an engineered strength.

Figure PFA mixed into slurry form

Block Manufacture

There are different types of block manufactured using PFA. In some cases the PFA is used as an aggregate or as an additional cementitious component and as such it is combined into a normal material mix design. These types of block also make extensive use of FBA as an aggregate and all the FBA from Didcot is sold to this market.

Aerated Concrete Block Manufacture

The most common use of PFA in blocks is in the manufacture of aerated concrete blocks. Didcot Power Station supplies up to 100,000 tonnes/year of PFA to aerated block manufacturers and PFA constitutes up to 90% of the mixture used in this type of block manufacture. The mix is typically made up of PFA, cement, lime, water and aluminium powder. The PFA is mixed into a slurry form at the beginning of the process and the remaining mix constituents are then added at the mixer.

Figure Aerated block manufacturing process

The grout-like mixture rises like a cake, forming air bubbles within the mix. This is caused by the hydrogen gas which is formed due to the reaction of the aluminium powder. After a few hours the cake is cut with steel wires into suitable sizes and shapes and then transferred to autoclaves to be steam cured with dry steam.

The curing allows the blocks to gain strength (2.0Mpa to 10Mpa). This is created from the lime-silica pozzolanic reaction and PFA provides an excellent source of silica for this reaction. The aeration ensures the blocks are of low density (480kg/m^3 to 700kg/m^3) and maintain excellent thermal insulating properties.

Aerated Block Manufacture

Aerated blocks are used for many construction applications. They provide high levels of thermal and loadbearing performance and excellent resistance to moisture penetration, combined with speed and economy of construction. Externally, the blocks can be easily finished with render, tile hanging and decorative cladding.

The blocks can be used for cavity walls, solid walls and separating party walls. They are also suitable for suspended floors, where the blocks are suspended across long-span concrete T beams. With their excellent frost and sulphate resistance and loadbearing capabilities, aerated blocks can make excellent foundations for buildings.

PRODUCT HEALTH AND SAFETY

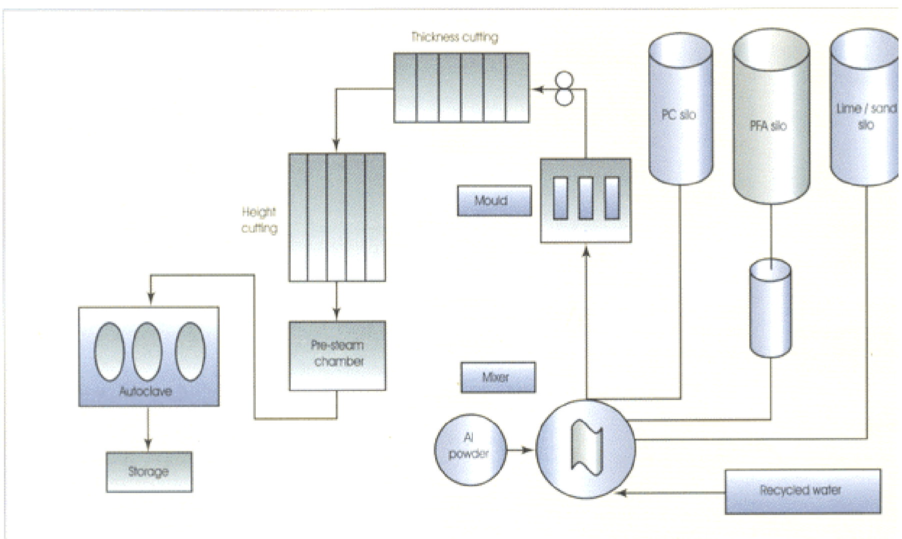
Composition

Ash from coal-fired generation is composed of inorganic material with a small proportion of carbon particulate resulting from incomplete combustion of the coal. The ash is not considered to have any hazardous components that would affect normal patterns of production, handling, storage and use Ash is not considered to be hazardous to health but should be handled with good occupational hygiene and safety practices. PFA is a dust-like material and in high concentrations may cause irritation to eyes.

Storage and Handling

Storage

- Dry PFA - should be stored in silos or sealed containers/bags.
- Conditioned PFA - when stored in stockpiles the exposed surfaces should be kept damp; small stockpiles can be covered with sheeting.
- FBA - preferably stored on a hard standing and in an enclosed area.



Handling

- Avoid creating airborne dust wherever possible. Where dust is generated, engineering control measures should be considered to maintain the airborne dust concentration as low as is reasonably practicable.
- Avoid prolonged skin contact especially where the product is dampened.
- Wear protective clothing; good working practices as well as high standards of housekeeping and personal hygiene should be maintained.

Exposure Controls and Personal Protection

The exposure limits according to UK Occupational Exposure Standards, which are published in H5E Guidance Note EH40, are:

PFA and FBA	Total Inhalable Dust	10mgnr^3 on 8hr time-weighted average
	Respirable Dust	10mgnr^3 on 8hr time-weighted average

Control Measures

Engineering control measures, such as enclosing transfer chutes and pipes, should be employed wherever reasonably practicable to prevent/control dust generation and exposure. Conditioning/dampening the dust can also reduce exposure.

Stability and Reactivity

Coal Ash	**FBA**	**PFA**
Conditions to avoid	None	Dry material can become airborne in moderate winds. Dry materials should be stored in silos. Materials stored out of doors should be maintained in damp conditions.
Materials to avoid	None	None
Hazardous decomposition products	None	None

Physical and Chemical Properties

Coal Ash	**FBA**	**PFA**
Appearance	Semi-vitrified clinker-like granular material	A fine grey powder
Odour	Virtually none	Virtually none
PH	Moderately alkaline when damp	Moderately alkaline when damp
Boiling point/boiling range	Not applicable	Not applicable
Melting point/melting range	Not applicable	Not applicable
Flash point	Not applicable	Not applicable
Auto flammability	Not applicable	Not applicable
Explosive properties	Not applicable	Not applicable
Oxidising properties	Not applicable	Not applicable
Vapour pressure	Not applicable	Not applicable
Bulk density	1.5-1.8g/cm^3	1.2-1.7g/cm*
Specific gravity	1.5-2.0g/cm^3	1.8-2.4g/cm^3
Solubility	<1% in water	<2% in water

Toxicological Information

Eyes

Due to the reaction with moisture in the eye, irritation of the conjunctiva occurs if dust remains in contact with the eye.

Skin

Dry PFA will have little effect on the skin. However, when moist it is alkaline and prolonged or repeated contact can cause abrasion and irritant dermatitis.

Ingestion

There are no adverse health effects following ingestion.

Inhalation

After 60 years of exposure experience there is no clinical evidence of a significant risk of harm to the respiratory tract or lung. Heavy exposure in power stations (of the type no longer found) over a number of years has been shown to cause only small changes in lung function and minor symptoms, neither of which are considered to be of clinical significance. Pneumoconiosis does not occur. The Health and Safety Executive has reviewed the scientific literature and assigned PFA an Occupation Exposure Limit of 10 milligrams per cubic metre respirable dust (8-hour time-weighted average). PFA workplace air exposure levels are given overleaf.

Ecological Information

Coal Ash	FBA	PFA
Mobility. Persistence and degradability. Bioaccumulation potentials. Aquatic toxicity.	FBA has no currently known ecotoxic effects in existing patterns of production, handling, storage and use.	PFA has no currently known ecotoxic effects in patterns of production, handling, storage and use. Fresh material has been shown to have some boron phytotoxicity but this rapidly diminishes with weathering and amelioration.

FUTURE AND ONGOING DEVELOPMENTS

It is evident that the savings attributed to improved utilisation of ash from coal-fired generation are attractive in their own right. As such the future aim of the Didcot Power Station is to look towards increasing the amount of material made suitable for its current markets and other markets it currently does not supply. The goal would be for 100% utilisation and for consideration to be given to modification of the ash where possible to meet both customer requirements and improved utilisation.

Quality and availability of material have the biggest impact on market suitability and, with this in mind, Didcot Power Station is preparing a study of preferable technologies to allow further improvements to residue utilisation.

Storage

Initial focus is being placed on the possibility of increased storage. It is expected that further storage can improve flexibility in supply and allow increased control of the ash product. The main advantages of further silo capacity are as follows:

- Allows collection of product during periods of high production for subsequent sales during periods of low production.
- Option for selection of material during periods of higher-quality production to store for sales.
- Customer confidence regarding material availability.
- Improved control of material being supplied, eg condition limits.
- Improved loading facilities, reducing environmental impact during loading and ensuring safer traffic movement.
- Reduction in loading times.

Ash Beneficiation

Improvement of ash quality is of great importance to the construction industry. If advances in ash utilisation are to be made, it is critical that ash quality is monitored and made suitable for markets that are currently not served (see Market Products section).

PFA is seen as a valuable resource in its own right. However, the full benefit of the resource can only be realised if the quality of the PFA is suitable for use in markets where higher value can be obtained. Many coal-fired power stations in the UK are unable to provide PFA of a quality suitable for these markets. The highest value market for PFA can be considered to be cement replacement and it is this market that has the highest technical constraints; PFA in this market is currently known as BS 3892 Part 1 PFA and EN450. To achieve the quality required, power stations have to consider adopting modern technologies to improve the quality of their PFA, and before deciding to invest in process equipment, it is important to establish the availability of appropriate returns to finance a beneficiation scheme.

Future Technologies

Carbon removal has the greatest impact on ash quality improvement. Numerous technologies can be considered for carbon removal and these include:

- Pneumatic.
- Electrostatic.
- Burn-out.
- Flotation.
- Composites.
- Microwave.

To complement the process of carbon removal, it is also beneficial to further select or control PFA fineness. This can be undertaken with classification, which can be completed with current tried and tested technology.

Further beneficiation options are available and include:

- Lightweight aggregate manufacture.
- Sewage stabilisation products.
- Cement raw-feed substitution.

Many technologies require some form of investment and this can often be quite substantial. Therefore, if suitable returns on the investment are not possible, it usually follows that ash beneficiation programmes can be difficult to justify.

However, as the world continues to consider its environmental obligations and further emphasis is placed on sustainability, future financial returns from many of these programmes may ensure that they become easier to justify. It is with this in mind that future developments will be monitored, technically and financially, so that a shift in market and customer requirements can be accommodated further in terms of the use of coal-fired power station residues.

Didcot Power Station will continue to place emphasis on the use of its residues and Innogy has continued aspirations for the future, in terms of both business commitment and responsibilities to the global environment.

CONCLUSIONS

When suitable consideration is given to the utilisation of residues from coal-fired power stations, the outcome can only be seen as positive.

The application of best practice in these circumstances, at Didcot Power Station and elsewhere, shows how Innogy and the UK generating industry have given substantial prominence to meeting their obligations to the surrounding environment. Many industries continue to benefit from residue utilisation. In fact, it is not a new concept that has emerged because of recent political and environmental pressure, but has been normal business practice for many years.

Although it is the advances in knowledge and technology transfer that allow further progress in terms of additional uses of residues, it is the people involved and their use of best practice that ensure satisfactory service to residue customers is maintained and that, as a result, power station residues remain a viable resource.

Moreover, it is not only the environmental benefits of residue utilisation but also the production economics, the ability to maintain future generation capacity and the revenue created, which are of key importance in the modern business world in which the UK generating market necessarily operates.

Reference:

Best Practices Brochure 004
Residue utilization DIDCOT coal-fired power station
February 2002