Ash Utilisation from Coal-Based Power Plants

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Abstract

The UK Department of Trade and Industry (DTI) recently commissioned a study to carry out a world-wide review of the status of technologies for the utilisation of ash from coal-based power plants, and to assess the market potential for exploiting these technologies.

The review addressed the sources and properties of ash, including the established technologies and the new and developing cleaner coal technologies.

Worldwide ash production and use was surveyed, focussing on the high ash producing countries and regions of; China, India, Russia, Eastern Europe, South Africa, North America (US and Canada), Europe, Japan, Australia, Israel and Turkey.

Global ash utilisation trends were summarised, concentrating on the established high volume uses in the construction sector but also addressing developing applications. Particular attention was paid to the role of beneficiation technologies in producing ash products of high consistency to meet market demands.

Market framing influences such as legislation and standards and the barriers to increased utilisation have been addressed.

A summary of perceived research and development needs, and conclusions and recommendations from the study are presented in the paper.

Introduction

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Sources and Properties of Ash Worldwide

Coal remains the single largest fuel source for the generation of electricity worldwide, with about 38% of the world's electricity currently being generated, predominantly, by pulverised coal-fired power stations[1]. Thus, in the foreseeable future, coal will remain a major by-product. As well as continuing to be utilised in established markets, it will also find growing application within the expanding economies of developing countries such as China and India.

Ashes produced by coal-fired plant can take various forms and those emanating from conventional pulverised coal-fired plant may differ from those produced by some newer coal-based technologies.

Pulverised Coal Combustion

Available global reserves of coal are estimated at more than 200 year's supply[2] and in some locations high quality coal is produced using low-cost surface mining techniques. Much of this coal is exported to other countries. For many national economies, coal-fired power generation remains the least expensive option, and in the UK, some 36% of electricity generation is still produced in this way.

Coal itself can take several forms (anthracite, bituminous or hard coal, lignite, and brown coal), each comprising a combination of carbon and a mixture of various minerals (shales, clays, sulphides and carbonates). In the UK, the predominant power station coal is bituminous or hard coal that, as delivered to power stations, normally contains ~15% of ash by weight after combustion.

Fly ash (or *Pulverised Fuel Ash* - PFA) produced by power stations can be used in a wide range of construction applications ranging from a cementitious component of concrete, to a simple fill material. For the purpose of the present review, PFA can be considered to be the ash resulting from the burning of, predominantly, pulverised bituminous, hard coals in power station furnaces (operating at ~1400°C). The resultant material is a siliceous ash consisting of oxides of silica, aluminium and iron, and containing less than 10% calcium oxide (Figure 1).

Within a coal-fired furnace, the average residence time for a particle of coal is approximately 3-4 seconds[3]. The ash produced during combustion is in a molten state and remains in suspension in the furnace gases. It is transported by the combustion gases (now the "flue gas") through the convection parts of the boiler after which it is captured in an electrostatic precipitator at the boiler outlet.

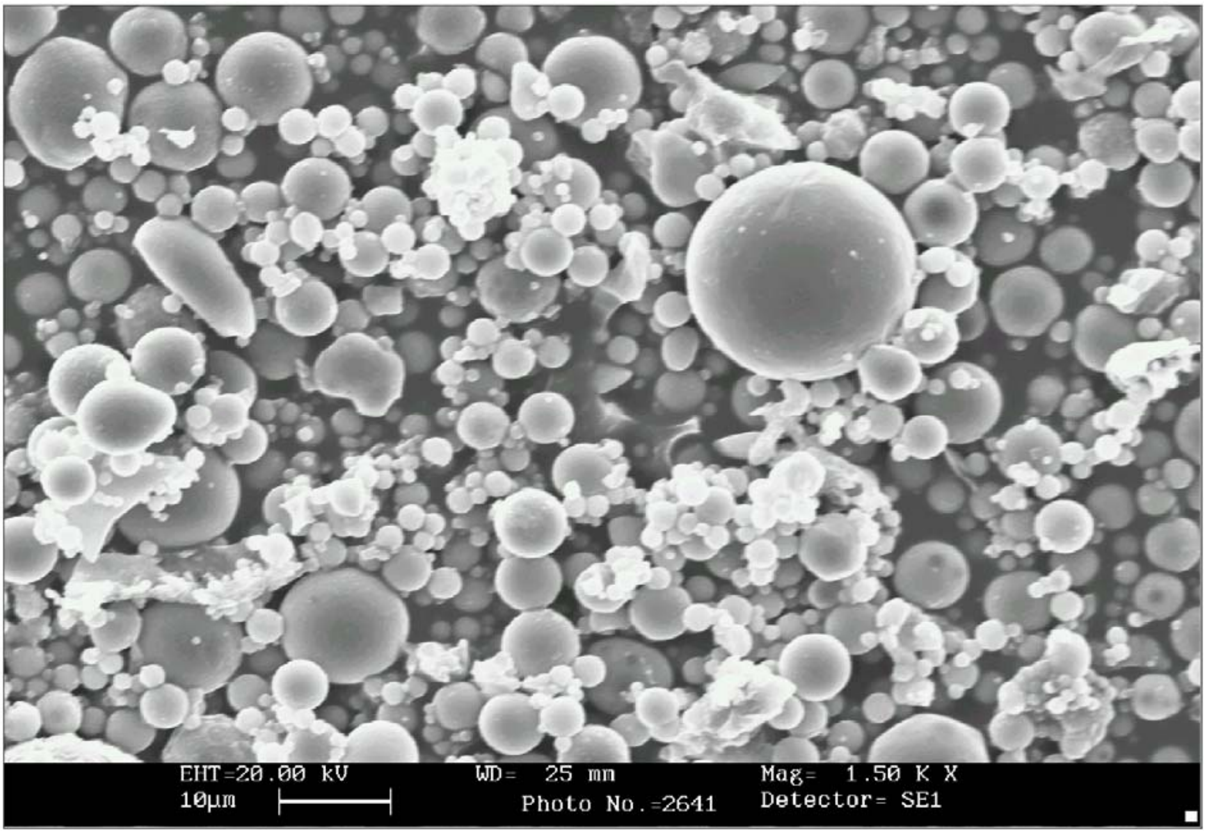

Figure 1 Pulverised coal fly ash particles

Approximately 80-85% of the ash exiting the furnace is extracted by mechanical and electrostatic precipitators. These are connected in series to remove the finer and lighter materials. The remaining 15-20% condenses on the boiler tubes and subsequently falls to the bottom of the furnace where it sinters to form *furnace bottom ash* (FBA). Within the UK, the latter is flushed from the bottom of the furnace, crushed then delivered to storage pits (Figure 2), prior to shipment. The primary use is for the manufacture of concrete building blocks.

Figure 2 FBA collection pits at a UK coal-fired power station

Properties of fly ash

The nature and properties of fly ash are dependent on a variety of factors that include temperature, type and fineness of the coal, and the length of time the minerals are retained in the furnace.

Some of the more important variables of fly ash are the carbon content and chemical and mineralogical properties. The former, as assessed by measuring loss on ignition (LOI), can vary widely (1-10%) and depends on the particular plant configuration; the application of low NO_x burners generally increases levels. When a station operates continuously, the typical LOI value is 3.5%. However, the pattern of operation inevitably results in some fluctuations. Figure 3 shows typical variations in LOI with time for fly ash from a large UK power station.

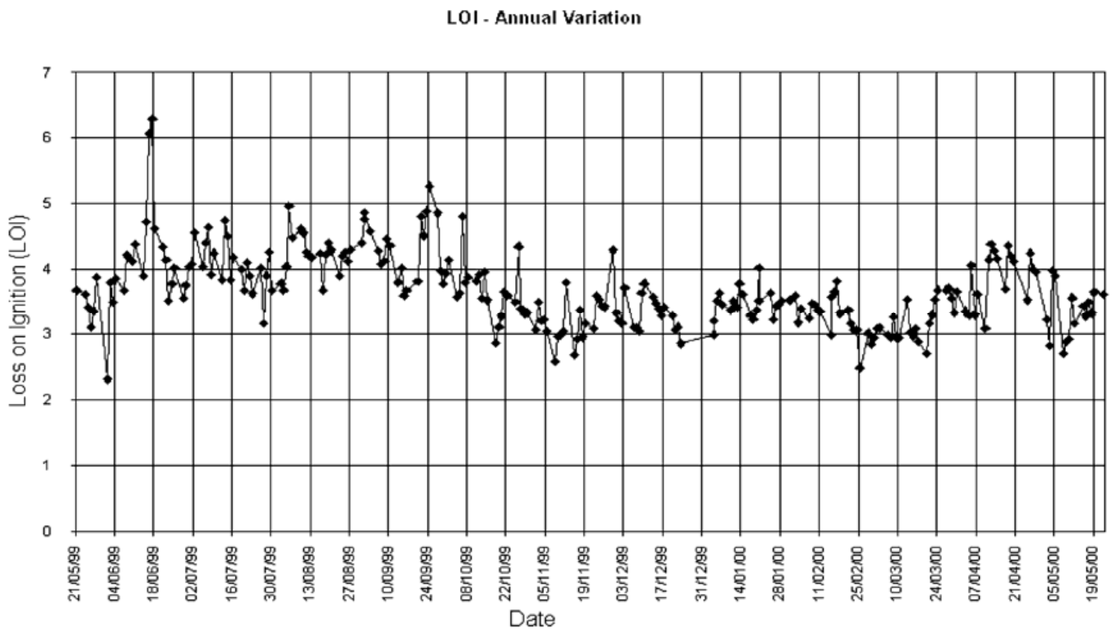

Figure 3 Typical variations in LOI with time for fly ash from a large UK power station.

Fly ash comprises three predominant elements: silicon, aluminium, and iron, the oxides of which account for 75-85% of the material. It consists principally of glassy spheres together with some crystalline matter and unburned carbon. A typical range of chemical analyses from UK fly ash shows the oxides present (Table 1).

Element	Typical range of values for fly ash
Silicon (% as SiO_2)	38 – 52
Aluminium (% as Al_2O_3)	20 – 40
Iron (% as Fe_2O_3)	6 – 16
Calcium (% as CaO)	1.8 – 10
Magnesium (% as MgO)	1.0 – 3.5
Sodium (% as Na_2O)	0.8 – 1.8
Potassium (% as K_2O)	2.3 – 4.5
Titanium (% as TiO_2)	0.9 – 1.1
Chloride (% as Cl)	0.01 – 0.02*
Loss on ignition (%)	3 – 20
Sulphate (% as SO_3)	0.35 – 2.5
Free calcium oxide (%)	<0.1 – 1.0
Water soluble sulphate (g/L as SO_4) *2:1 water solid extract*	1.3 – 4.0
Total Alkalis (% as $Na_2O_{eq.}$)	2.0 to 5.5%
Water soluble Alkalis (% as $Na_2O_{eq.}$)	0.3 to 1.0%
pH	9 – 12
* Chloride may be up to 0.3 % for fly ash conditioned with sea water	

Table 1 Typical range of analyses from UK fly ash

New and Developing Technologies (Fluidised Bed Combustion, IGCC and Variants)

Although the dominant technology for coal-fired power generation remains pulverised coal combustion, newer, cleaner coal technologies such as fluidised bed combustion and gasification (usually as part of an integrated cycle) have been developed and are increasingly finding application. In addition, there is great interest in the co-combustion of biomass and waste-derived fuels with coal, and a number of utility companies worldwide routinely burn a mixture of coal and one or more biomass or waste supplementary fuels in their boilers.

The ash produced by these advanced technologies is often different in character to “conventional” coal ash and requires special consideration when evaluating potential utilisation options. As these new technologies become more widespread, it is important that sustainable utilisation options are found for the residues produced.

- **Fluidised Bed Combustion**

Fluidised bed combustion (FBC) has been used successfully to burn all types of coals, as well as coal wastes and a wide variety of other fuels, either singly or co-fired with coal.

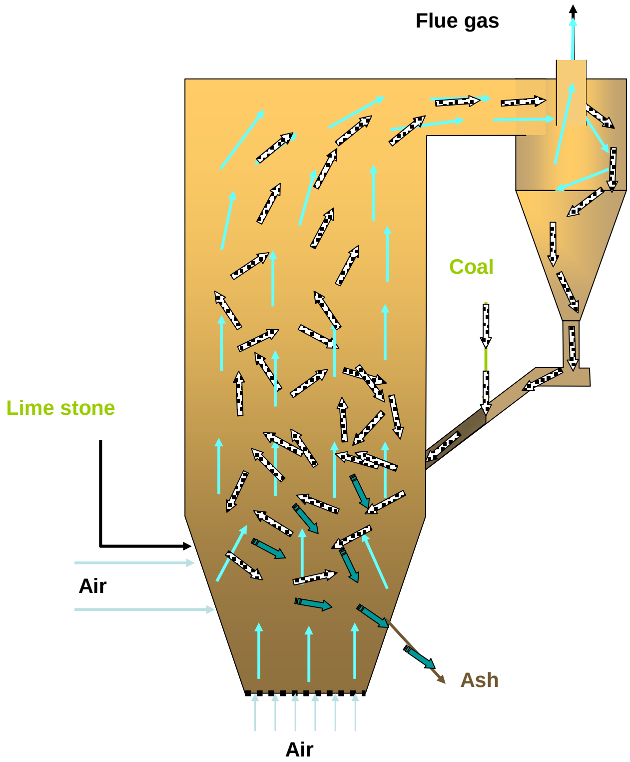

Figure 4 Generalised schematic of a circulating fluidised bed combustor (CFBC)

FBCs generate two major ash streams that comprise fly ashes, elutriated from the fluidised bed and collected in either a bag filter or electro-static precipitator, and bottom ash from the bed off-take. In both cases, the ashes may contain a mixture of fuel ash, unburned carbon residues, calcium sulphate and sulphite, and un-reacted lime or limestone. FBC ash properties are substantially different to those of PF ashes and fly ash particles are significantly larger.

FBC ash is not used widely in construction materials, the majority being used for low value infill or land reclamation. At present, specifications only accommodate the use of PF ashes in the manufacture of cements and other products. However, FBC ash may have potential for structural infill, land and mine reclamation purposes.

- **Coal Gasification**

Integrated Gasification Combined Cycle (IGCC) is a highly efficient electricity generating technology (gross energy efficiency 47%, net efficiency 42%) that involves the conversion of coal into a clean fuel gas. However, such systems produce significant amounts of slag and fly ash. Several types of gasifier (fixed bed, entrained flow, and fluidised bed) can be employed, some variants operating at temperatures of up to 2000°C. Respectively, these produce dry ash and granulated vitreous solids, vitreous slag, and dry or agglomerated ash.

IGCC slags are relatively inert under normal conditions, and under current disposal regulations, they require no special processing before transport and disposal (although more stringent future environmental regulations may make disposal more difficult). However, when residues arise from fluidised bed gasifiers that use in-bed limestone for desulphurisation purposes, the situation can become more complicated.

- **Co-combustion**

There is now considerable interest in the utilisation of biomass and municipal/industrial wastes within existing coal-fired plant. The use of biomass and wastes in such plant is now perceived by governments and industry as a viable option. This area is now the subject of a number of on-going research and commercial activities within the European Union and USA.

Potentially, there is an enormous reserve of biomass and wastes that could be utilised for energy production. Their use would help minimise global emissions of CO_2 and acid gases emitted by replacing a proportion of the fossil fuels used for energy production. There are several distinct advantages where biomass and/or wastes are utilised in existing PF power plant, namely: an established market for the heat and power produced, plant modification (hence capital investments) required may be modest, and plant emissions are often reduced.

Unsurprisingly, most biomass ashes are very different from coal ashes. They are not alumino-silicate systems, but comprise mixtures of simple inorganic salts, principally the oxides, phosphates, carbonates and sulphates of silica, calcium and potassium. However, biomass materials tend to be co-fired at relatively low levels, hence the properties of the mixed ash is dominated by that of the coal ash. Similarly, ashes from waste co-firing can differ from conventional coal ashes.

- **Residues from Emissions Control Technologies**

Increasingly, emissions control systems are being fitted to coal-fired power plant. From the standpoint of generation of solid residues, the most important technologies are those employed to reduce oxides of sulphur (principally SO_2) from the flue gas stream. These are termed collectively *flue gas desulphurisation (FGD) technologies* and systems are now being applied in 27 countries. There are a wide range of FGD options available commercially, the main variants comprising wet scrubbers, spray dry scrubbers, and sorbent injection systems. At present, the largest FGD market share is taken by wet scrubber processes, producing high quality gypsum as a by-product; this is utilised widely in a range of construction products.

Ash Beneficiation

Coal ash taken as run-of-station is limited in the markets into which it can be sold. Developing specifications for construction products and other higher value applications demands some form of product improvement. There is the concept that materials initially regarded as wastes, may be improved through a process of quality control and upgrading to become increasingly accepted as a valuable resource (Figure 5), and ash can be treated in this way via beneficiation processes.

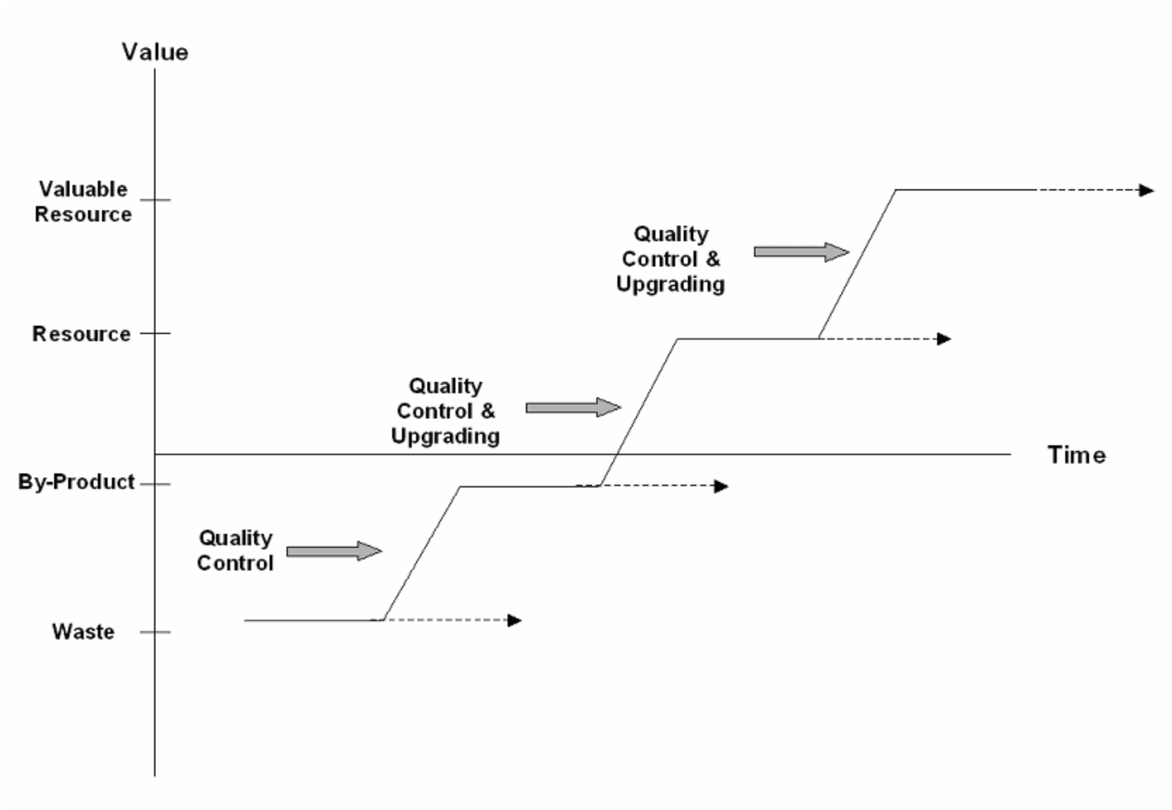

Figure 5 Improving and enhancing the value of ash as a resource

A number of methodologies and systems for improving ash quality have been developed, that include:

Classification and Blending

Ash may be separated into components having useful properties through classification, usually by sieving into different size fractions. This process often helps reduce residual carbon content. A number of plants have been set up within Europe for beneficiation and blending. An example is shown in Figure 6.

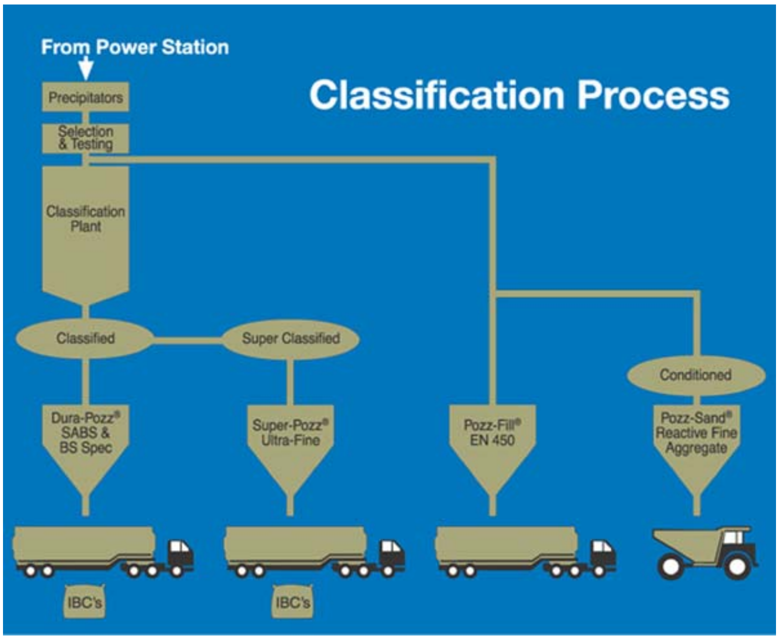

Figure 6 Ash Resources S.A - Ash Beneficiation to Products

Ash Milling

The size range distribution of fly ash is sometimes non-ideal for specific applications and cannot be improved by classification and blending alone. For example, in high strength and high durability concretes, finer fly ash (<10 μm) would be the preferred feedstock. Grinding or micronisation is sometimes used to reduce all particles to below the maximum size specified, allowing product properties to be enhanced.

Ash Floatation

Ash floatation is practiced in its simplest form by the separation of cenospheres from the surface of fly ash ponds. More complex flotation systems based on minerals processing technology use frothing and other agents to separate materials as a suspension. The process has been demonstrated as a viable method for separating carbon from fly ash. The downside is that the materials may require drying.

Magnetic Separation Technologies

Many fly ashes contain significant concentrations of ferromagnetic material and this may be refined by magnetic separation. Removing the magnetic fraction from fly ash, using an electromagnet, can produce ash which may impart a higher flowability to mortars[4]. The process often forms part of a combined system.

Carbon Removal

The presence of high levels of carbon restrict applicability. Consequently, considerable efforts have been made to develop techniques for its reduction. These techniques include[5] carbon burn-out (in an FBC), electrostatic separation, froth flotation, pneumatic transport separation, and triboelectric separation. The first two are being used commercially and a schematic of the latter is shown in Figure 7.

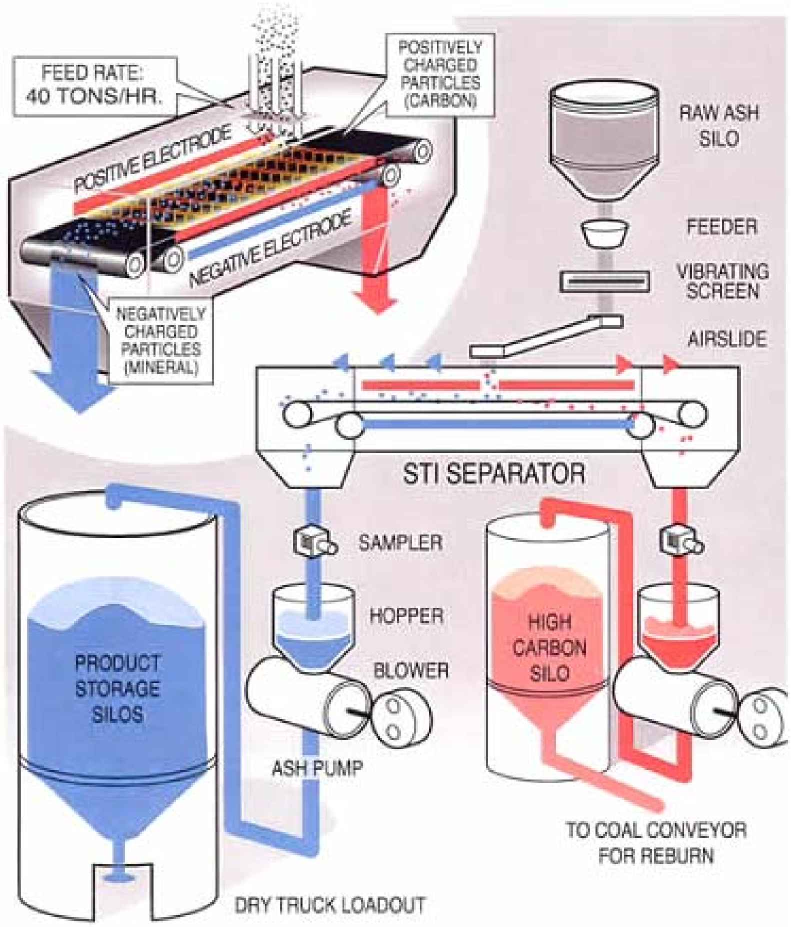

Figure 7 Schematic of the STI electrostatic carbon reduction process

The electrostatic separator can readily process a wide range of fly ashes, reducing unburned carbon content from 30% to a consistent 2%, thus meeting all standards for use in concrete.

Chemical Processing

Where a fly ash has a low pozzolanic activity, its reactivity can be enhanced by treatment with Na_2SO_4 or $CaCl_2$. Ashes having relatively high concentrations of leachable salts can be rendered usable by “weathering over” in long-term storage ponds. Ash residues with high levels of free lime, particularly those from the newer clean coal technologies, can be rendered usable for cement and concrete applications by a hydration processing step.

Combined Beneficiation Technologies

A number of beneficiation and blending facilities have been set up for the production of quality-assured ash products (Figure 8). Some may specialise in, for instance, the supply of premium PFA and PFA cementitious products primarily to the construction sector, although specialist materials may also be produced.

Figure 8 ScotAsh's bagging facility at Longannet power station

Several processes are in use in the UK, one being that of RockTron. This processes run-of-station and reclaimed ashes to yield a range of products[6]. The process treats both fresh fly ash and material that has been stockpiled for protracted periods. The process also yields energy savings and a reduction in overall environmental impact.

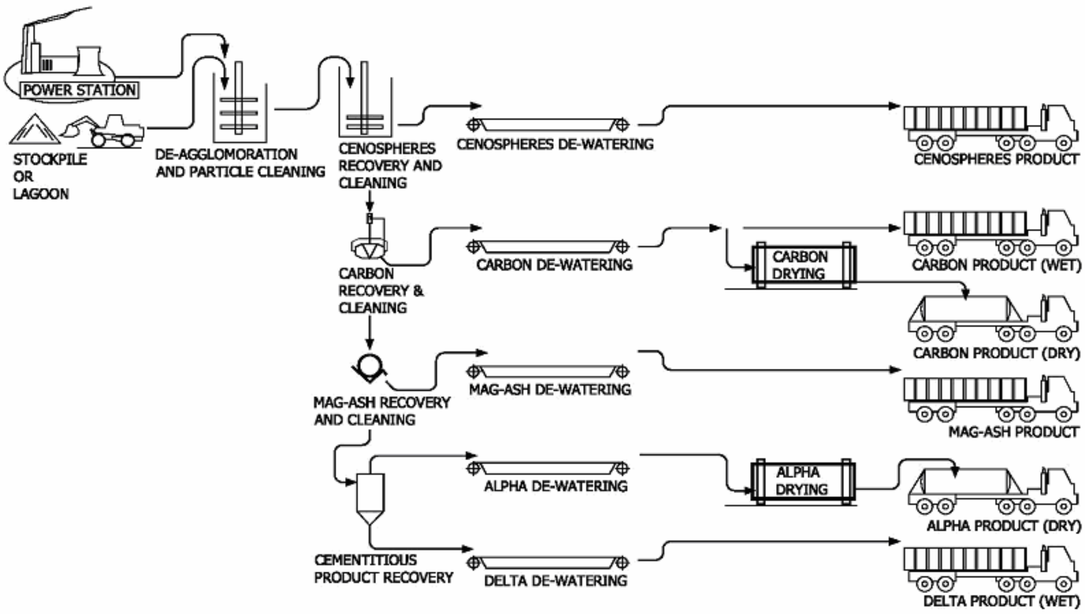

Figure 9 Simplified schematic of the RockTron ash beneficiation process

The Status of Ash Utilisation Worldwide

Overview of Ash Production from Coal-fired Power Generation

At current production levels, coal reserves are estimated to last over 200 years. Recent reviews suggest that there were an estimated 985,000 M tonnes of coal reserves at the end of 2002[7]. Coal resources are available in almost every country worldwide, (with recoverable reserves in around 70 countries) with the largest coal deposits located in the USA, the Russian Federation, and China.

Global hard (black) coal production has grown by over 46% in the last 25 years to 3837 M tonnes in 2002; major producers include China 1326 M tonnes, USA 916.7 M tonnes, India 333.7 M tonnes, Australia 276.0 M tonnes, South Africa 223.0 M tonnes, Russia 163.6 M tonnes, Poland 102.6 M tonnes, Indonesia 101.2 M tonnes, Ukraine 82.9 M tonnes, and Kazakhstan 70.6 M tonnes.

Brown coal/lignite production totalled 876.5 M tonnes in 2002, with Germany, Greece and North Korea among the leading producers and consumers.

Over 23% of the world's primary energy needs worldwide are met by coal, with ~38% of global electricity being generated from coal; Poland, South Africa, Australia, China and India all rely on coal to produce much of their electricity. The Czech Republic, Greece and Germany all rely on coal for over 50% of their electricity[8].

Major users of coal for electricity generation are given below in Table 2

Country or Region	Contribution of coal-fired electricity generation
Poland	94.8%
S Africa	93.0%
India	78.3%
Australia	76.9%
China	76.2%
Czech Rep	66.7%
Greece	62.3%
Germany	52.0%
USA	49.9%
Denmark	47.3%
UK	32.9%
EU15	27.2%

Table 2 Major users of coal for electricity generation

It has been estimated[9] that in 2000, world production of coal ash was ~480 M tonnes (Figure 10), with the majority of ash arisings originating from seven countries or regions.

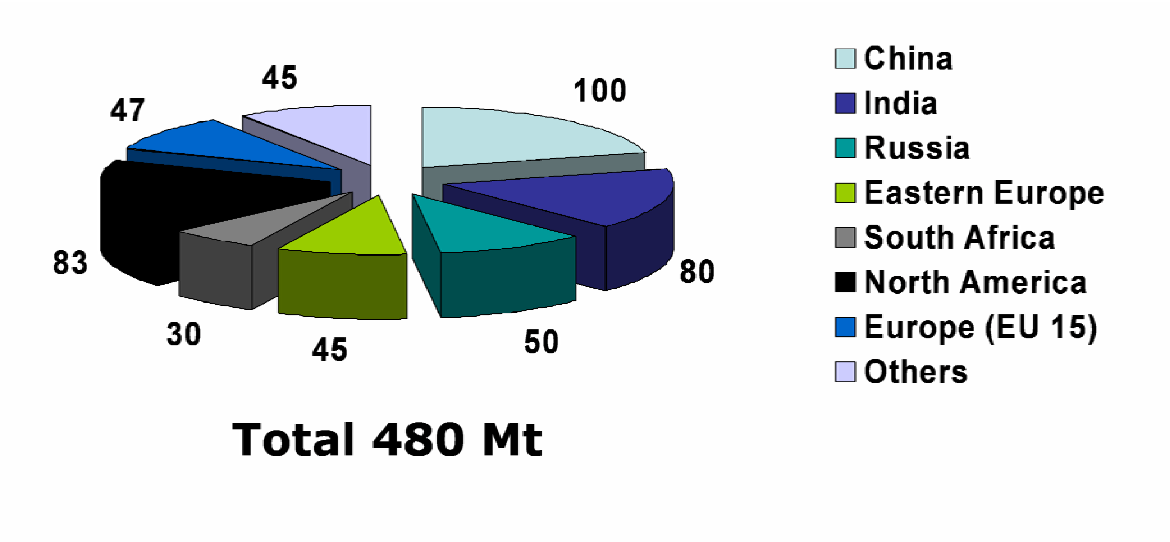

Figure 10 World Production of Coal Ashes 2000 (M tonnes)

China

Since 1949, over 2.2 billion tonnes of ash has been deposited, covering ~300 square kilometres of land. In recent years, coal-fired power generation, and hence, ash production, has grown sharply, with current annual production levels of ~160 million tonnes. Levels are predicted to grow to 250-260 M tonnes in 2005, 320-380 M tonnes in 2010, and 570-610 M tonnes by 2020. The Chinese government is seeking ways to address this issue.

For many years, a policy of ash utilisation has been pursued, although until the 1980s, utilisation rate remained low (~10%). Since then, utilisation has increased rapidly. In 2002, total ash production was 150 million tones, of which, about 100 million tonnes was utilised. Recent years have seen the increased application of modern ESP systems for flue gas cleanup and this has improved quality and consistency of ash, thus enhancing prospects for its use. Modern coal-fired boilers now produce high quality ash, applicable for cement-based applications and brick-making. The government is promoting strongly the increased use of ash for various applications. As a result, ash use is predicted to increase to 65% by 2005.

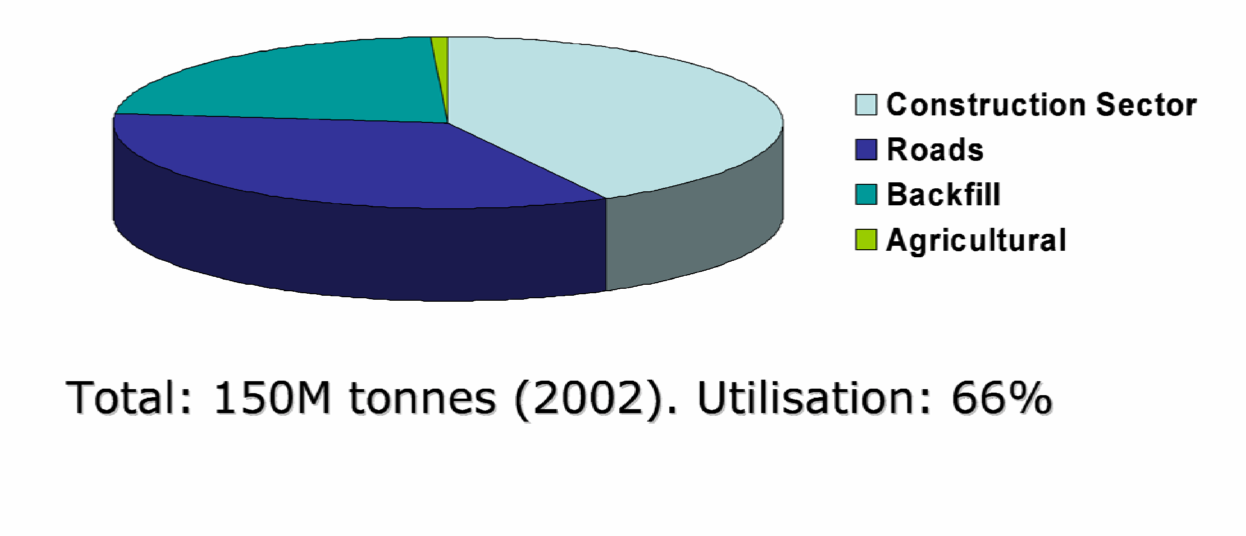

Figure 11 Ash utilisation in China

Figure 11 shows the relative proportions of ash use by application. The pattern of utilisation is dominated by construction uses for which over 20 national standards have been published. There are presently a diverse range of utilisation applications in China, some more developed than others. They include cement, concrete, wallboard, pottery and brick production; backfill for civil engineering; road construction; agricultural uses; and as a fertiliser. To help mitigate agricultural land shortages, old ash storage lagoons are usually reclaimed (Figure 12 and Figure 13).

Figure 12 Ash Lagoon (Qingzhen power station, Guiyang Province)

Figure 13 Cultivated Reclaimed Ash Land (Qingzhen power station, Guiyang Province)

India

Approximately 80-100 million tonnes of fly ash is generated annually from around 75 utilities, with a further 10 million tonnes from captive industrial power stations. With an average ash content of 40%, and predicted annual power plant coal consumption of ~285 million tonnes during the next five years, the subsequent ash (fly ash plus bottom ash) production is expected to be ~115 million tonnes per year.

Levels of fly ash utilisation have increased significantly from less than 10% in 2000, to the present level of ~26%; of this, 19 million tonnes was used for cement production and the remainder for land filling, etc. Such growth has taken place largely as a result of government pressure requiring almost complete utilisation of ash from new power facilities over the next nine years, and for existing plant, over the next fifteen years. As part of initiatives to increase ash utilisation, various initiatives and government-led programmes are developing improved awareness of fly ash utilisation and disposal techniques; a number of key areas have been identified and a several demonstration projects commissioned.

India's installed capacity for cement manufacture is over 125 million tonnes per annum and demand continues to grow. The production of PPC has been increasing and its current share is over 50%; this is likely to increase if more dry ash of suitable quality is made available by the utilities. There is a large undeveloped market in India for fly ash with a high growth housing /construction/ road sector and potentially, the markets for fly ash-based products could increase significantly.

Russia (including the Commonwealth of Independent States)

With 173 billion tonnes in proven coal reserves, Russia holds the world's second largest reserves. Both Russia and Kazakhstan have significant coal-producing enterprises and coal-fired power plants although many are due for replacement. Most Russian plants produce water-conditioned ash and to meet new emissions standards, most existing (and new) plants will require the installation of bag filters or ESPs. Annually, coal-fired power generation plants produce more than 75 M tonnes of ash and cinder waste of which, only ~11% is utilised, mainly in the form of secondary construction materials. Distances between point of production and possible markets may be considerable.

Ash conditioning and transport water often feeds directly into rivers and lakes and there is considerable concern over the environmental impact of this along with the impact of historical ash deposits. Consequently, much of the effort within Russia related to ash is concentrated on cleaning-up the Soviet legacy of pollution.

Figure 14 Fly ash disposal – Former Soviet power plant

Eastern Europe (the new EU accession countries)

In May 2004, Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia joined the EU. A number of these, primarily Poland, the Czech Republic and to a lesser degree, Hungary, produce and consume considerable quantities of hard coal and/or lignite.[10] The major producer and user of hard coal in former Eastern Europe is Poland, followed by the Czech Republic, producing 15 and 103 M tonnes of hard coal annually, respectively.

In 2000, the largest producers of coal/lignite ash within these countries were Latvia (23.3 Mt), the Czech Republic (10.4 Mt), Poland (10.3 Mt), and Romania (6.4 Mt).

In the case of Poland, ~15 million tonnes of ash is produced annually, with a high proportion being utilised (70% in 2001). Ash utilisation has increased significantly since gaining independence from the Soviet Union, as illustrated by the activities of one utility where ash use rose from almost zero in 1990 to 100 k tonnes in 2003 (Figure 15)[11].

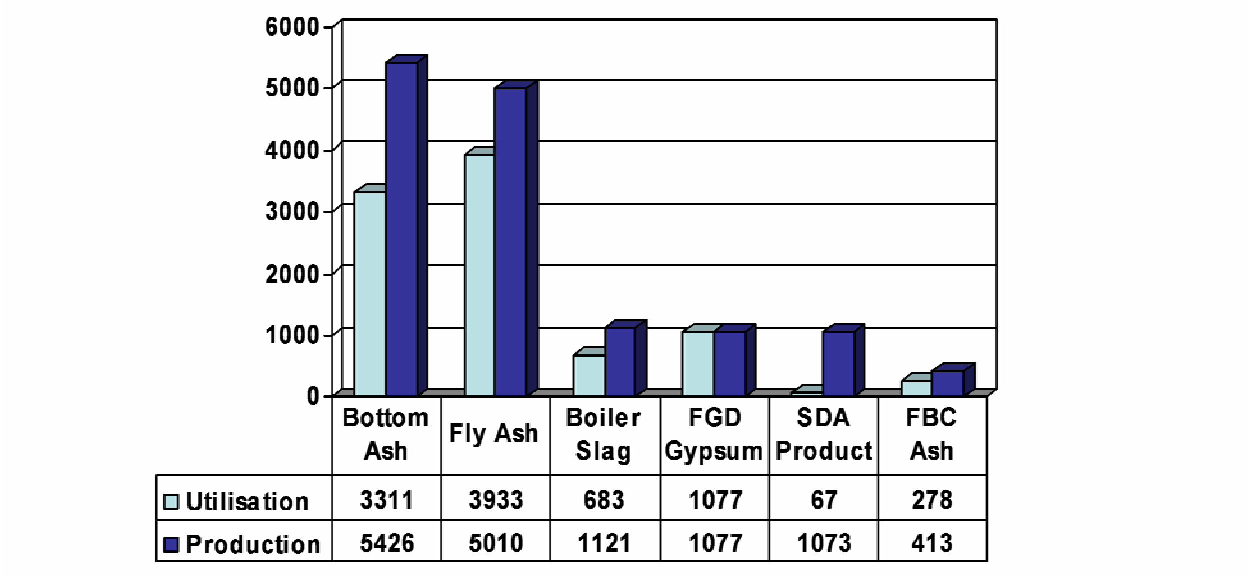

Figure 15 Poland – Fly Ash Utilisation 1990-2003

In 2001 the pattern of ash production and utilisation in Poland[12] was as follows, illustrated graphically in Figure 16:

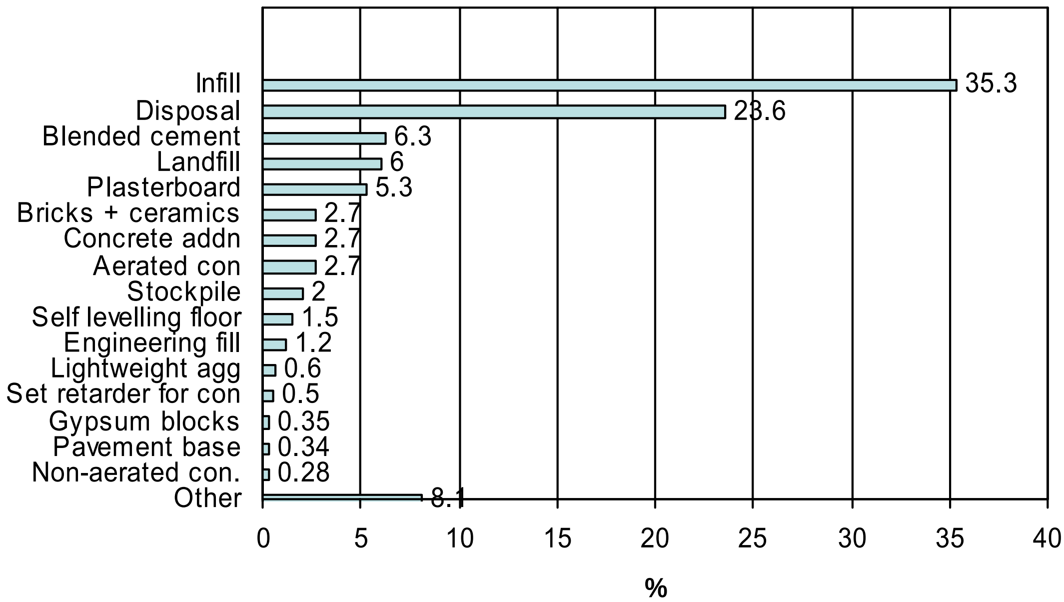

Figure 16 Ash production and utilisation in Poland (k tonnes)

Increasingly, in the future, the pattern of use of ash will be framed by the adoption of EU norms in respect of standards and legislation.

South Africa

South Africa's coal-fired power stations produce annually ~22-24 million tonnes of ash although the Sasol coal liquefaction plant also generates a coarse ash, plus fly ash from associated captive power stations. Thus, ash is generated mainly by bituminous coal-fired plants and used for a variety of applications. Quality and consistency are assured by continuous quality control testing in accordance with internationally recognised standards. The LOI of fly ash is typically very low at <1%, probably as low NO_x burners are not used. As power stations are located close to the coal mines from which they source their coal, excess fly ash is sometimes used as mine backfill. Within the country, a range of materials, mainly for the construction sector, is produced, and new applications are under development.

North America - United States

In 2002, CCP (termed collectively *coal combustion products*) production totalled 128.7 million tonnes, with an estimated 45.5 million tonnes (35.4%) being utilised. However, on an annual basis, total production can vary significantly, being influenced by total coal burn, coal ash content, and the amount of flue gas treated by scrubber systems. At ~76.5 million tonnes, fly ash comprises the largest individual component and a significant amount (12-13 million tonnes annually) is utilised in, for instance, Portland cement.

Total annual US fly ash amounts to ~26.5 million tonnes, a total that is growing. The use of bottom ash and synthetic gypsum is also increasing, with ~7.6 million tonnes of the former being used annually for roadwork, embankments, and structural fills. Synthetic gypsum (from FGD systems) is used widely for wallboard manufacture, with 8 million tonnes a year being utilised in this manner. It is expected that overall, CCP production and use will increase further in the future.

Where ash is not utilised, it is often deposited in landfills, although ease of availability varies between regions. There are therefore often clear incentives to increase utilisation rates and increasingly, ash arisings are being viewed as potential sources of profit. But, not all power companies regard utilisation as an important issue, preferring to continue landfilling.

Historically, government attitudes to ash use have been somewhat confused by the material being administered by two different departments: US EPA has been responsible for the regulation of solid waste, although responsibility for ash also fell under the auspices of the Air Quality Directive. Specifications on fly ash use can also differ markedly between states.

North America - Canada

Ash utilisation in Canada is represented by the *Canadian Industries Recycling Coal Ash – CIRCA.* CIRCA brings together Canadian producers and marketers of CCPs to increase technically sound, environmentally-responsible, and commercially competitive use as mineral resources. Its work focuses mainly on fly ash from coal combustion, although other related materials (bottom ash and FGD residues) are also of interest.

Pressure is growing for changes to be made to the CSA (Canadian Standards Association) standards for the use of fly ash in concrete, these including the inclusion of more specific references to the use of fly ash, and for some applications, a minimum requirement for fly ash content. It is anticipated that ash utilisation will increase following agreed revisions. Efforts are also in hand to avoid potential problems related to the often ambiguous categorisation of coal ashes, sometimes as wastes and sometimes as products. Public perception of the suitability of ashes for utilisation is recognised as an important issue and activities are underway to increase public awareness of the potential benefits.

Several initiatives are also underway to promote the greater use of "supplementary cementing materials - SCM". These include the *National Action Plan on Climate Change* and *EcoSmart*, the latter promoting the use of fly ash as an SCM in concrete.

Canada's endorsement of the Kyoto Protocol is seen as an important driver for the future use of coal ashes, particularly in cement formulations as the coal-fired energy production and cement sectors can collectively reduce greenhouse gas emissions and, by extension, their respective environmental footprints.

Europe (EU15)

In the European Union (EU 15), ~60 million tonnes of ashes and related products were produced and utilised in 2001 (Figure 17 and Figure 18).

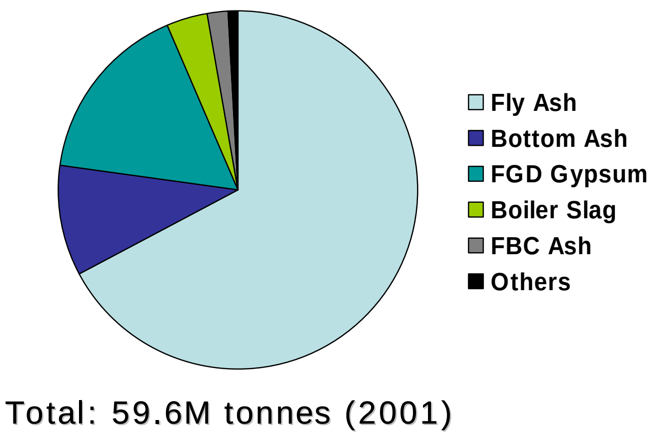

Figure 17 Sources of ashes produced by European power plant

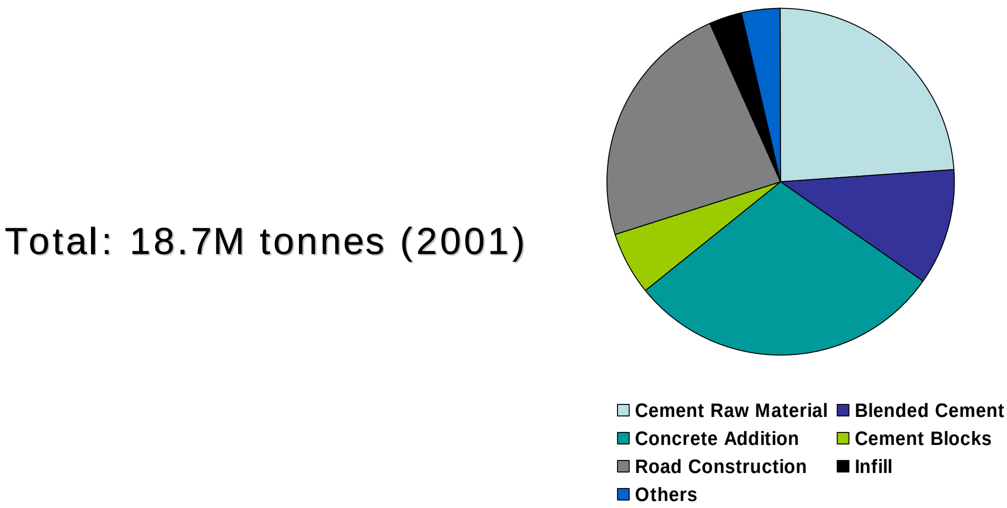

Figure 18 Utilisation of ashes produced by European power plant

Fly ash represents the greatest proportion of total CCP production. Within the EU, the utilisation of fly ash in the construction industry is currently ~46% and for bottom ash, ~41%; all boiler slag is utilised. In the majority of cases, CCPs are used as a replacement for naturally-occurring resources and therefore offer environmental benefits by avoiding the need for their quarrying or mining. CCPs can also help reduce energy demand and emissions to atmosphere. They are utilised in a wide range of applications in the building and construction industry that include use as an addition in concrete as a cement replacement, as an aggregate or binder in road construction, as mineral fillers, and as fertilisers. Use is governed by appropriate national and European building materials standard and regulations. The relative utilisation of coal ashes differs markedly from country to country. Thus, utilisation is high in The Netherlands (100%) and Germany, where 75% of the fly ash derived from hard coal is used in concrete. Depending on demand, ash may be traded between countries.

Across Europe, utilisation prospects are also influenced by the wide range of landfill costs and taxes. In addition, specific limits on the properties of wastes for disposal vary across the Union. Within the Member States, no common philosophy regarding ash utilisation has been adopted, with different countries taking individual approaches.

Environmental pressures are growing with respect to fly ash use and future EU legislation will govern its use, although local issues will remain important. Some recent concerns have included radiation emissions from building materials incorporating ash, and leachability issues in road construction. In addition, new regulations in the pipeline may impact on levels of heavy metals present.

The amount of ash from advanced coal-fired systems such as gasification plants remains low and is generally mixed with conventional fly ash. Its commercial potential is considered to be low.

- **Japan**

Japan relies almost entirely on imported coal for power generation and industrial uses. The current annual level of ash utilisation is 7 M tonnes (82% of production). Approximately 78% of the ash produced by electric power utilities is utilised, as is 95% from general industrial use. The cement sector accounts for the largest proportion, with 71% (4.89 M tonnes) of the total. Apart from conventional use in cement and concrete, various other uses are also being encouraged and developed.

- **Australia and New Zealand**

Ash produced in Australia and New Zealand during 2002 amounted to 12.5 M tonnes, of which, 4.1M tonnes were utilised. The main outlets comprised cementitious applications (1.35M tonnes), non-cementitious applications (0.47M tonnes), with the balance of 2.28M tonnes being used in projects such as road construction, mine backfilling and bulk fill applications. However, there are still a number of barriers inhibiting ash use that include the geographic isolation of some power plants, and poorly coordinated regulation and legislation. Under the terms of current government legislation, ash is considered as a waste; this has serious implications that may restrict its future market potential.

- **Israel**

Israel meets ~32% of its energy demand requirements from imported coal. Fly ash from power plants is not subjected to any beneficiation processes and is used mainly in concrete applications as a fine sand replacement, with only a small reduction of the cement content. Israeli power plants produce 1 million tonnes of ash annually, typically with a carbon content of 5-8%. Plants are close to centres of population and land area is limited, hence ash disposal can be problematical and a high rate if utilisation is encouraged. As costs are low, fly ash is used widely in ready mixed concrete. Both fly ash and bottom ash are also used as sub-base in road construction and a small amount is used for agricultural purposes. Overall, the ready-mix concrete industry uses 40% of the fly ash produced, the cement industry 30%, road and fill construction 25% and agriculture 1%.

- **Turkey**

Turkey has hard coal (anthracite and bituminous) reserves of around 1.1 billion tonnes, plus lignite reserves of up to 8 billion tonnes[13]. Of the eleven power plants producing ashes, six use lignitic coal and hence producing calciferous ash, while the remainder are based on hard coal producing siliceous ash[14].

The ash produced annually from power plants varies from 6.5-13 M tonnes and in recent years, fly ash has been used for ready mixed concrete applications. A number of separation plants have been established to sieve ash supplies for concrete producers. Other uses are also being investigated.

Barriers to Increased Utilisation

There are a number of technical, economic, institutional, and legal barriers to the continuing and increased use of large quantities of coal ashes and related residues. A recent study[15] in the United States identified eleven institutional barriers to increased ash utilisation:

- Lack of familiarity with potential ash uses.
- Lack of data on environmental and health effects.
- Restrictive or prohibitive specifications.
- Belief that fly ash quality and quantity are not consistent.
- Lack of fly ash specifications for non-cementitious applications, resulting in substitution in these applications of the more restrictive specifications for use of fly ash in cement and concrete.
- Belief that raw materials are more readily available and more cost-effective.
- Viewpoint of States that EPA procurement guidelines for fly ash in concrete are a rigid ceiling rather than general guidelines for use.
- Actions by environmental agencies that normally support beneficial ash uses in principle, but that frustrate the actual implementation by restrictive regulations.
- Restrictive regulation of fly ash as a solid waste in most states.
- Lack of state guidelines on beneficial ash use.
- Lack of clear federal direction on regulation of beneficial ash use.

In many countries, these perceived problems are being addressed by respective trade organisations representing ash producers and users, with each national association actively promoting better understanding of national fly ash use and potential. Many of these associations interact on an international level. For example, *Ecoba*, the European Association for use of by-products of coal-fired power stations, has members from 11 Member States of the European Union and works regularly with other organisations.

With deregulation and an increase in the number of private power plants in many parts of the world, there will be a tendency for plants to operate on the lowest costs possible and this will include adopting the lowest cost route for ash disposal/utilisation. This may restrict the long-term growth in utilisation of coal by-products unless efforts are made to expand applications and reduce costs. In practice, it may be appropriate for individual power plants to develop their own market strategies for ash utilisation.

A major impediment to the continuing and developing use of ash is its categorisation as a waste by many legislatative and regulatory bodies worldwide. Currently, there is much confusion throughout Europe about the definition of ‘waste’ and the implementation of the EU Waste Directive and how it applies to CCPs. Ecoba is encouraging ash to be categorised as a ‘product’. The problems arising from the official classification of many long-established ash products as wastes is particularly acute in the UK where it is the subject of an intense dialogue between the ash producers and users and the main regulatory body, the Environment Agency.

The issues with the implementation of the EU Waste Directive are not restricted to coal ash. They also impact on the recycling of other recovered materials. These classifications appear to run counter to the concept of sustainability which is increasingly at the heart of European developmental strategy.

Legislation and Standards

Legislation impacts on ash utilisation prospects at the national, international, and local level. e.g.

- EU-wide legislation and country-specific legislation.
- U.S. National and State legislation.

Legislation can encourage or impede ash utilisation. Examples of the former include an Indian government directive on fly ash use, and Chinese subsidies on ash transportation costs plus tax breaks for ash use in construction. Legislation impeding ash use includes limits to levels of heavy elements introduced into the environment (Germany) and the use of ash as mine backfill (USA).

Local legislation will determine elements of the disposal costs of ash, particularly the taxes levied on materials sent to landfill. Taxation levels can vary between countries and even location and these, plus transport, etc. impact significantly on economics of utilisation. Thus, an economically viable process in one location may not be viable elsewhere due to differences in "avoidable disposal costs" of ashes. The importance of these differences can be demonstrated by the OECD data on tax-related and landfilling costs for several countries[16] (Figure 19 and Figure 20).

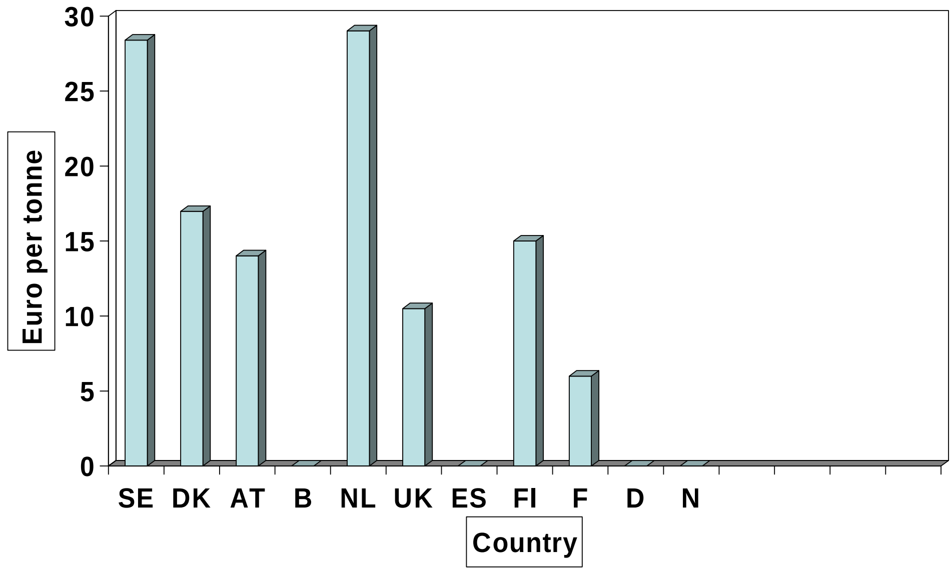

Figure 19 Tax-related costs of landfilling non-hazardous waste in selected countries

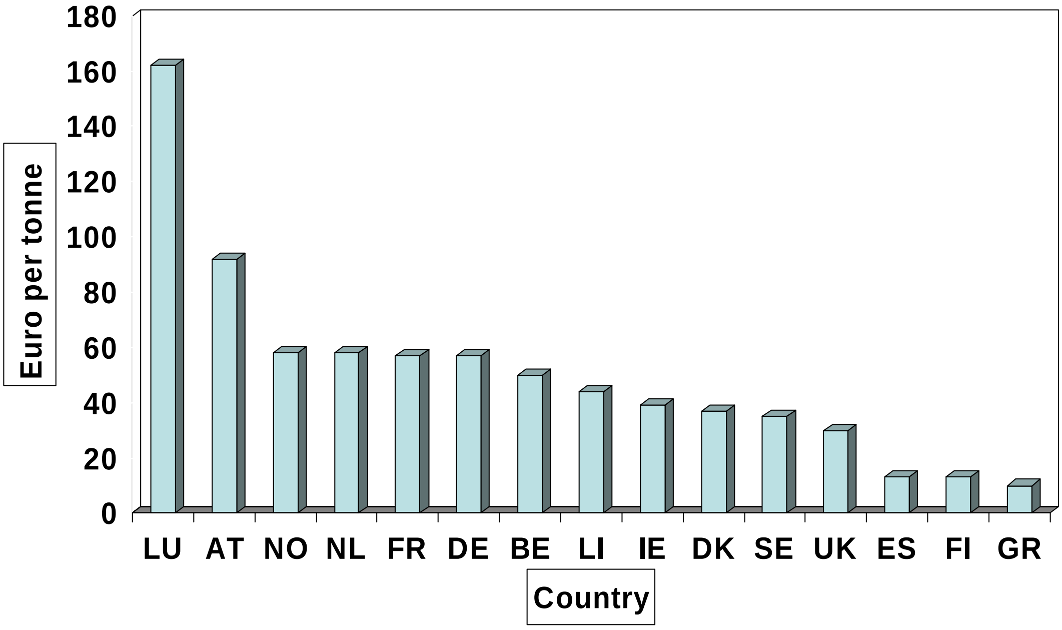

Figure 20 Costs of landfilling non-hazardous waste in selected countries

(excl. landfill tax and VAT)

The most significant impediment to maintaining or increasing the rate of ash utilisation is its categorisation as a waste. Specifications for developed uses have been established in many countries, the aim being to set minimum requirements for the performance of ash-derived products tested under laboratory conditions. Worldwide, there are numerous national specifications applied and varying views on the suitability of ash residues for different applications. The suitability of ash for a particular purpose is determined primarily by its meeting the requirements of specific tests set out in relevant standards or specifications. However, it is not universally accepted that all such tests are appropriate, and practical experience has shown that some ashes that fail to meet certain test requirements still produce technically acceptable final products.

Many current specifications focus solely on use of PF fly ash and exclude those from co-combustion, thus restricting its scope for utilisation. Similar problems can also occur with residues from advanced coal use technologies, such as FBC and IGCC. For instance, in some US states, CFBC residues are utilised widely, whereas in others, specifications automatically exclude their use. In reality, few of the common tests for additives in cement are appropriate, and new, more appropriate criteria based on final performance need to be developed.

In some countries, such as Japan, problems can arise with application of over-rigid standards and here, debate continues on standards for fly ash use in concrete, the aim being the suitable amendment of present standards. The Japanese case is an example of how established standards can present a barrier to ash products as they are frequently written around existing materials (so-called “recipe-based” standards).

Often, formulations are based on established (named) materials, an approach that may automatically exclude ash products. It would therefore be preferable for specifications to be based on technical performance of the end product. Input from interested parties such as technical standards committees and customer user groups can be instrumental in leading to such change. For acceptance of novel products, the situation may be no better, as relevant standards may not be applicable, or even exist. Where new standards need developing to assist such products enter the marketplace, the increasing drive to EU-wide standards requires a pan-European approach.

Future developments are likely to include an increasing role for Environmental Product Declaration Schemes (EPDs)[17] which, through environmental management systems, allow companies to manage all activities and services that can significantly impact on the environment. These tools allow a “level playing field” assessment of the total environmental impact of a manufacturing process and may result in incentives that encourage the increased use of coal ash over natural mined and quarried alternatives as part of a strategy of more sustainable development.

Conclusions

1. The importance of coal-fired power generation to the world’s energy requirements for the foreseeable future will guarantee the continued production of large quantities of ash.
2. Ash production from conventional pulverised coal-fired units, particularly in the developing markets of China and India, will continue to increase significantly.
3. The treatment of coal ashes as wastes in many countries in the developed world is a serious impediment to their continued utilisation.
4. The categorisation of ashes as wastes, and the environmental standards that they, but not their naturally-occurring competitors, are required to meet, runs counter to the concept of sustainable development being increasingly pursued in the developed world.
5. A progressive move away from “recipe” specifications (that expressly exclude ash products) to performance-based specifications will enhance ash utilisation.
6. As the newer cleaner coal technologies become more widespread, sustainable markets for their ash products need to be identified.
7. The coal ashes from modifications (e.g. co-firing of biomass) to existing practice need to be better represented in existing specifications.
8. The potential large-scale uses for ashes in the area of agriculture and fillers require further work.
9. A number of factors are inhibiting the development of long-term approaches to, and investments in, ash utilisation technologies in the developed world. These include:
    - Uncertainty on the future of coal-fired power generation in the developed world.
    - The requirement for very short-term payback on investments.

- Ash production, marketing and utilisation are seen as non-core business by many utilities.

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