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Joint EURELECTRIC/ECOBA Briefing:
The Classification of Coal Combustion Products under the revised Waste Framework Directive (2008/98/EC)

Each year, more than 100 million tonnes of coal and lignite ashes and desulphurisation products are produced by power stations throughout the European Union in addition to the main product electricity. These solid materials, which can be described collectively as coal combustion products[1] (CCPs [1]), are inevitable as they are produced as a result of requirements to meet air emission standards set in other EC Directives [2]. Each of the CCPs has specific physical and chemical properties that make them suitable for utilisation in established markets which have, typically, existed for many years. These applications include, amongst others, use in cement, as both raw kiln feed material and as a direct cement replacement [3], in concrete [4], in the production of lightweight aggregates and lightweight blocks [5], as aggregates in building and road industries [6], in mining and other operations as a construction or fill material [7], as mineral fillers [8] and, in the case of FGD gypsum, as a raw material in the gypsum industry for the production of plasterboard and as a set retarder in the cement industry [9]. Further details of the production, properties and use of various CCPs are described in an accompanying document [Annex 1].

In many applications CCPs are used as a replacement for naturally occurring materials and therefore offer environmental benefits by avoiding the need to quarry or mine primary resources. The use of CCPs is thus an excellent example of sustainability, results in the saving of natural resources and material and, in many cases, helps to reduce energy demand and emissions to the atmosphere which result from the extraction or manufacture of the substituted product [10]. A significant example of the positive environmental benefits that come from the use of CCPs is the use of coal fly ash in concrete and blended cement, where, as well as savings in natural resources and energy, the use of every tonne of ash saves about one tonne of CO_2 when compared to the use of cement itself [11]. Numerous studies (toxicity, lab and on-site evaluations etc.) have shown that CCPs have no negative impact on the environment or on human health when put to beneficial use. Also, to be effectively used in a number of applications, they have to satisfy relevant national and European building materials standards and regulations or user-imposed technical requirements. Not only do these standards set quality criteria for utilisation, but their existence in itself is a recognition that the materials are of value.

Where CCPs are used directly from the power station or after short periods of storage in dedicated silos, stores and stockpiles designed to maintain them in a form suitable for use, they are, in the producer's opinion, not discarded and are not 'wastes' as defined in the Waste

[1] The term "coal combustion products" (CCPs) is commonly used for ashes and desulphurisation products produced following the combustion of coal for power and steam generation. It is synonymous with terms such as "coal combustion residue", "secondary mineral", "secondary raw material" and "secondary product" used in other publications and regulations.

Framework Directive (2008/98/EC) [12]. The use of CCPs in these ways is consistent with the aims of the Directive and, in particular, with the waste hierarchy set out in Article 4, which puts waste prevention above options such as re-use, recycling and recovery [13]. In each case where they are utilised, their further use is certain, they are suitable for use in their existing form and without undergoing any further processing other than normal industrial practice and their use meets all of the relevant product, environmental and health standards applicable to that use. Therefore, CCPs going directly from the power station that produced them or from an associated production process to an end-user in a form which is suitable for immediate use are excellent examples of by-products as defined in Article 5 of the Directive [14]. As by-products will be substances that will be placed directly on the market, they will be subject to the REACH regulation [15]. As such CCPs should be included within any guidance to accompany the revised Directive as examples of industrial by-products which should never be considered as wastes. As the REACH registration contains a full description of the chemical, mineralogical, physical, toxicological and ecotoxicological characterisation of CCPs, as well as a chemical safety report and an assessment report with exposure scenarios reflecting the use of the materials, there is no need for additional parameters to verify the by-product status.

In circumstances where CCP production levels exceed demand or where demand varies temporally, some of them, and fly ash in particular, are discarded as wastes and are typically landfilled at mono-disposal sites. However, should demand subsequently increase it is very easy for the materials to be recovered and, with only minimal treatment, they can then be used in the same markets as ‘fresh’ materials. In these cases, the materials have ceased to be wastes at the place of recovery in line with the end-of-waste criteria set out in Article 6 of the Directive [16]. As such, recovered CCPs are an excellent example that could be used in any guidance to accompany the Directive as a waste stream which, when recovered, ceases to be waste.

In summary, the production of CCPs is an inevitable consequence of the combustion of coal in large power plant boilers. Although not the main commercial product of the process, CCPs are of value in a number of other ways and, as shown in Figure 1, are used either immediately or, in the longer-term, after recovery from stockpile or mono-landfill sites. In the former case, CCPs should be regarded as by-products and never as wastes; in the latter case, once recovered, CCPs should cease to be wastes and become products at the place of recovery (Figure 1).

EURELECTRIC and ECOBA believe that, in both cases, CCPs are very good examples for use in any guidance produced to accompany the revised Waste Framework Directive (2008/98/EC).

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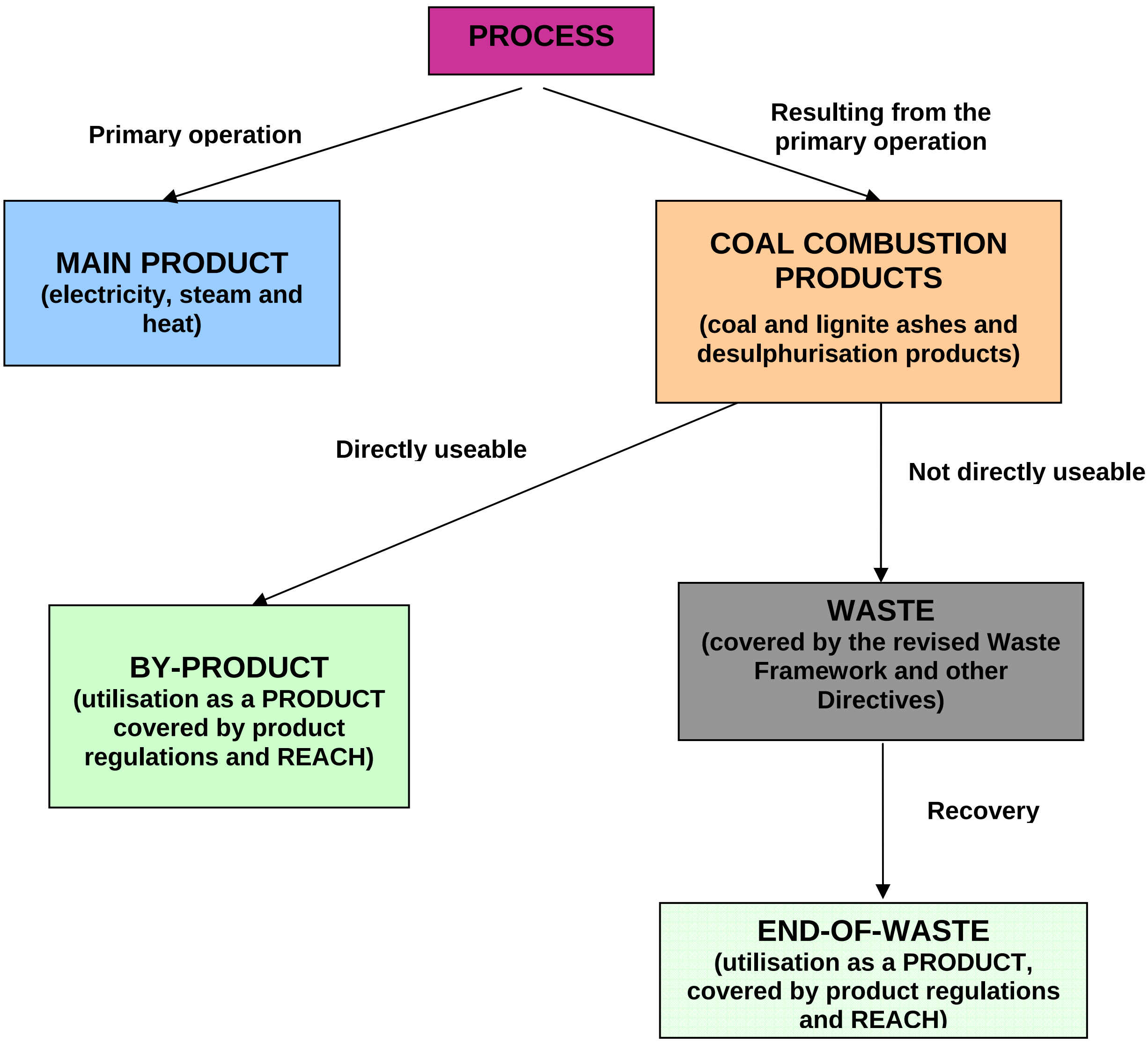
Fig. 1: Flow chart describing definitions



[1] For the purposes of this Note, coal combustion products (CCPs) are: bottom ash, boiler slag and fluidised bed combustion (FBC) ash (i.e. bottom ash, slag and boiler dust according to EWC Codes 10 01 01 and 10 04 15); coal fly ash (10 01 02 and 10 01 17); and calcium-based reaction wastes from flue-gas desulphurisation in solid form (10 01 05).

[2] As the descriptor suggests, bottom ash, slag and boiler dust are retained within the boiler following combustion and are removed in a number of ways depending on the furnace design. Fly ash, on the other hand, leaves the boiler entrained in the flue gases and, in order to meet air quality requirements set out in EC Directives, like the Large Combustion Plant Directive (2001/80/EC), is typically removed prior to the power station stack by electrostatic precipitation.

Flue gas desulphurisation products result from the treatment of the flue gases prior to emission to reduce the sulphur content of the exhaust gases. A number of techniques are commercially available to do this and the exact nature of the product depends on the technique employed.

An accompanying document [Annex 1] describes, in more detail, production routes and properties of various CCPs.

[3] Fly ash and bottom ash can be used in the manufacture of cement in two ways; as a raw material for cement clinker production or as a major constituent in the production of blended cement. In the former case ash serves as a source of silica and alumina, which traditionally come from natural sand and clay.

For the production of blended cement, i.e. Portland pozzolana and Portland fly-ash cement typically containing around 30% fly ash, ash has to meet the requirements of European standard EN197-1 which includes a requirement for conformity evaluation.

[4] Fly ash is added to concrete to enhance its technical performance for a number of reasons. The physical and chemicals properties of the ash that can be used in this application, together with details of the conformity evaluation, are detailed in European Standard EN 450, Fly ash for concrete – definitions, specifications and conformity criteria.

[5] Fly ash is used as a siliceous source in the manufacture of aerated concrete blocks. These have excellent insulating properties for a cementitious material and consist of ~85% fly ash. Ash used in these applications has, again, to meet the requirements of European Standards.

Fly ash has also been used as the raw material in the manufacture of lightweight aggregates according to European Standard EN 13055. Bottom ash is also used as a coarse and fine aggregate in the manufacture of ‘Lightweight Concrete Blocks’. For this application, it has to meet the requirements of the European Standard for lightweight aggregates, EN 13055. Bottom ash is the preferred material by all manufacturers due to the lightweight nature and stability of the aggregate.

[6] Fly ash, bottom ash and boiler slag are used in a number of applications as aggregates in building and road construction. Specific examples include the use of bottom ash as a drainage layer and road sub-base material and as a wearing surface in equestrian

centres and car parks. In these applications, the requirements of European and national standards typically have to be met.

[7] Fly ash has been widely used as a fill material for a number of years. In this application, and in road construction in particular, its use has been based on its availability, its ease of compaction and its ability to form stable, durable landforms. Examples include its use in embankments and bridge abutments. In addition, for use in underground mining, reactivity requirements have to be met.

[8] Fly ash, as well as cenospheres, i.e. hollow sphere fly ash particles with ultra-low densities, are used as a fill material in a number of applications, including paints, plastics, car body panels, glass fibre resin systems and refractory panels.

[9] Most of the FGD gypsum produced in Europe is utilized in the gypsum and cement industries in products like plasterboard, gypsum blocks and plasters. The quality criteria for the use of FGD gypsum as a raw material for the gypsum and cement industry are defined in a number of standards.

[10] In many of the applications developed for CCPs, their utilisation results in economic benefit. Most applications, however, also provide environmental benefits, including:

- saving of natural resources;
- saving of energy;
- saving of emissions of pollutants to the air;
- saving of CO_2 emissions;
- saving of landfill space.

At least one, and in most cases several, of the environmental benefits apply to all applications of fly ash.

[11] Following on from [10], the most impressive example is the replacement of a part of cement by fly ash in concrete or the use of fly ash as a main constituent of blended cement. For the production of one tonne of cement about 1.6 tonnes of raw material have to be mined, crushed, calcined and heated to a temperature of 1200 to 1400°C. In addition, 0.95 tonnes of material have to be finely ground to produce Portland cement. 2900 MJ of thermal energy and 100 kWh of electrical energy are needed to produce one tonne of Portland cement.

The production of Portland cement is not possible without emissions of pollutants to air even though the emissions from cement production have been drastically reduced in the last few decades. The production of Portland cement is also inevitably associated with CO_2 emissions due to the calcination process and the energy demand. The replacement of Portland cement by fly ash therefore makes a corresponding reduction in the various environmental impacts associated with cement production. In the EU15 member states it is conservatively estimated that the use of 2.9 million tonnes of fly ash in cement manufacture results in a reduction in CO_2 emissions of the same amount per annum.

Many of the other uses of CCPs do at the very least avoid the environmental impact of the mining of natural resources and the processing of the minerals and save the space needed for the disposal of CCPs.

[12] According to Article 3 of Directive 2008/98/EC on waste, ‘waste’ means ‘any substance or object which the holder discards or intends or is required to discard’.

[13] Article 4 of Directive 2008/98/EC describes the waste hierarchy and is reproduced below for reference.

Article 4
Waste hierarchy

1. The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy:
(a) prevention;
(b) preparing for re-use;
(c) recycling;
(d) other recovery, e.g. energy recovery; and
(e) disposal.

2. When applying the waste hierarchy referred to in paragraph 1, Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking on the overall impacts of the generation and management of such waste.

Member States shall ensure that the development of waste legislation and policy is a fully transparent process, observing existing national rules about the consultation and involvement of citizens and stakeholders.

Member States shall take into account the general environmental protection principles of precaution and sustainability, technical feasibility and economic viability, protection of resources as well as the overall environmental, human health, economic and social impacts, in accordance with Articles 1 and 13.

[14] Article 5 of Directive 2008/98/EC deals with by-products and is reproduced below for reference.

Article 5
By-products

1. A substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste referred to in point (1) of Article 3 but as being a by-product only if the following conditions are met:
(a) further use of the substance or object is certain;
(b) the substance or object can be used directly without any further processing other than normal industrial practice;
(c) the substance or object is produced as an integral part of a production process; and
(d) further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.

2. On the basis of the conditions laid down in paragraph 1, measures may be adopted to determine the criteria to be met for specific substances or objects to be regarded as a by-product and not as waste referred to in point (1) of Article 3. Those measures, designed to amend non-essential elements of this Directive by supplementing it, shall be *adopted in accordance with the regulatory procedure with scrutiny referred to in article 39(2).*

[15] REACH is the European Community Regulation on chemicals and their safe use (EC 1907/2006) which entered force on 1st June 2007. It deals with the **R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances. The aim of REACH is to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances.

Under the REACH Regulation, producers, manufacturers and importers are required to gather information on the properties of their chemical substances and to register the information in a central database run by the European Chemicals Agency (ECHA) in Helsinki.

The producers of CCPs have registered their products for use in the construction industry under REACH. All information about the chemical, physical, toxicological and ecotoxicological properties were compiled in a registration document which will be published at the ECHA.

[16] Article 6 of Directive 2008/98/EC deals with end-of-waste and is reproduced below for reference.

Article 6
End-of-waste status

1. Certain specified waste shall cease to be waste within the meaning of point (1) of Article 3 when it has undergone a recovery, including recycling, operation and complies with specific criteria to be developed in accordance with the following conditions:

(a) the substance or object is commonly used for specific purposes;
(b) a market or demand exists for such a substance or object;
(c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and
(d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.

The criteria shall include limit values for pollutants where necessary and shall take into account any possible adverse environmental effects of the substance or object.

2. The measures designed to amend non-essential elements of this Directive by supplementing it relating to the adoption of the criteria set out in paragraph 1 and specifying the type of waste to which such criteria shall apply shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 39(2). End-of-waste specific criteria should be considered, among others, at least for aggregates, paper, glass, metal, tyres and textiles.

3. Waste which ceases to be waste in accordance with paragraphs 1 and 2, shall also cease to be waste for the purpose of the recovery and recycling targets set out in Directives 94/62/EC, 2000/53/EC, 2002/96/EC and 2006/66/EC and other relevant Community legislation when the recycling or recovery requirements of that legislation are satisfied.

4. Where criteria have not been set at Community level under the procedure set out in paragraphs 1 and 2, Member States may decide case by case whether certain waste has ceased to be waste taking into account the applicable case law. They shall notify the Commission of such decisions in accordance with Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 laying down a procedure for the provision of information in the field of technical standards and regulations and of rules on Information Society services (1) where so required by that Directive.

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Annex 1

Coal Combustion Products (CCPs) - Generation and use -

Content **page**

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1 Introduction

In coal-fired electricity generating power plants solid minerals are produced during and after the combustion of fine ground coal with and without co-combustion in a fully controlled process. The materials under consideration are the ashes i.e. the unburnable mineral matter in the fuel (bottom ash, fly ash, boiler slag, FBC-ash), and, where abatement equipment is fitted, the desulphurisation products obtained from a chemical reaction between the sulphur dioxide, which is derived from the sulphur in the coal during the combustion process, and a calcium based absorbent, in flue gas desulphurisation installations (SDA product and FGD gypsum).

Most of the by-products are produced in so called dry-bottom furnaces, i.e. a combustion processes with temperatures of 1100 - 1400°C. The combustion process of in a dry-bottom furnace and the generation of coal combustion products (CCPs) is shown in figure 1.

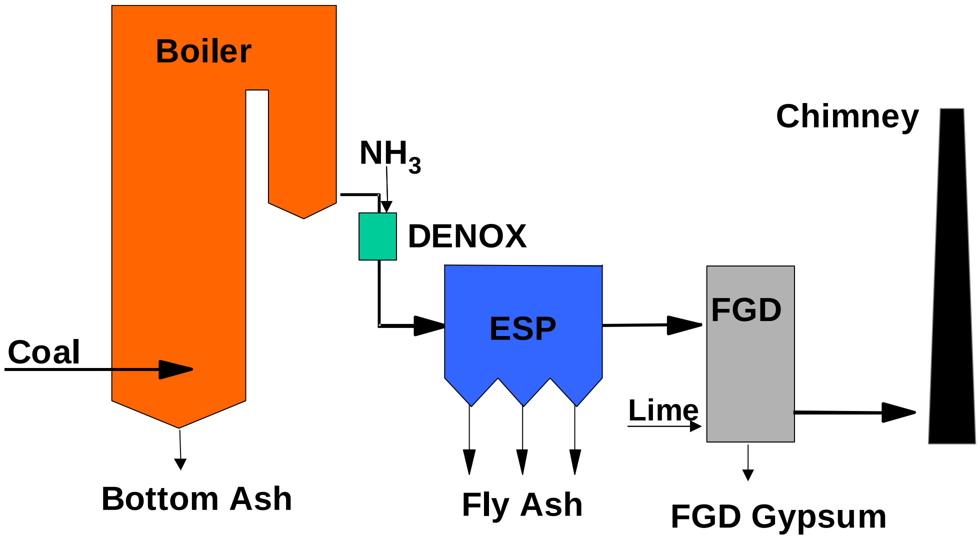

Fig 1 Production of coal combustion products (CCPs) in coal-fired power plants

A similar process (wet-bottom furnace) is used for production of boiler slag. Within this combustion process the burning temperature is higher (1500 - 1700°C) and the fly ash normally is fed back to the boiler where it melts again and forms boiler slag.

Fluidised bed combustion (FBC) ash is produced in fluidised circulating bed boilers at lower temperatures (800 to 900°C).

Spray dry adsorption (SDA) product results from dry and semi dry flue gas desulphurisation, FGD gypsum from wet flue gas desulphurisation.

2 CCPs: Production, use and requirements for the use

In 2008, the amount of CCPs produced in European (EU 15) power plants totalled 56 million tonnes and in the larger EU of 27 member states the total production is estimated to be about 100 million tonnes. Exact figures from the new member states are not available, yet.

Most of the CCPs produced are used in the construction industry, in civil engineering and as construction materials in underground mining (54 %) or for restoration of open cast mines, quarries and pits (36.5 %). In 2008, about 2.4 % was temporarily stockpiled for future utilisation and 7 % was disposed of[2].

The utilisation of the coal combustion products (CCPs) depends on their chemical, mineralogical and physical properties. These properties are influenced by the design and type of power plant, the source and feed of fuels as well as the type of coal and secondary fuels. A constant product quality is the major prerequisite for utilisation. Regarding this, ashes from coal combustion have more favourable prerequisites than most ashes from lignite, whose composition is subject to comparatively larger fluctuations. Therefore, lignite ashes are predominantly used for reclamation of opencast mines. All other fields of application follow the same rules as will be described for ashes from coal.

2.1 Bottom Ash

2.1.1 Generation

During the combustion of the fuel in the boiler (see figure 1), some mineralized, partly melted particles agglomerate within the boiler and become sintered together. Owing to their weight these particles do not pass out of the combustion chamber with the flue gas, but fall to the bottom of the boiler, where they are either removed directly or quenched in a water bath influencing the particle structure. This bottom ash may be processed, if necessary, by dewatering, screening, breaking and/or grading before an interim storage (silo, pit) or loading onto truck, train or barge at the power plant’s temporary store and dispatched to its intended use.

Samples for quality monitoring are usually taken direct from the loading equipment at the temporary storage facility. The nature and extent of quality monitoring depend on the area of application. Where the bottom ash is used as a lightweight aggregate for mortar and concrete, it typically has to comply with the requirements of European and national rules (application standards). In earthworks and civil engineering it often has to satisfy national regulations of the road authorities. In addition, specific requirements may be agreed between the bottom ash producer and the user.

2.1.2 Properties

Bottom ash consists of irregularly shaped particles with a rough surface. The main chemical components are silica, aluminium and iron oxide. The chemical composition of bottom ash is largely comparable to that of fly ash (see 2.2). Due to its porous particle structure, bottom ash combines low weight with good soil mechanics properties; however, its particle size distribution may vary considerably, as it depends on the fineness of the pulverized coal and the combustion conditions.

[2] ECOBA- Statistics on Production and Utilisation of CCPs in Europe (EU 15) in 2008

2.1.3 Use and requirements for use

In Europe, about 5 million tonnes per annum of bottom ash is produced following the combustion of coal and lignite. Whereas bottom ash from lignite power plants is almost entirely used for filling worked-out open-cast lignite mines, bottom ash from coal-fired power plants is used in other areas. The chemical, physical and mechanical properties of bottom ash and its compliance with the relevant standards, guidelines and regulations are crucial to its use as a building material. Some uses require further processing of the material by breaking or screening to make it more uniform. In other cases the requirements for high-grade use are satisfied even without additional processing steps.

In 2008, about 2.4 million tonnes of bottom ash were used in the construction industry. Out of this 37 % was used as a fine aggregate in concrete blocks, 41 % in road construction and about 16 % in cement (see figure A1 in Annex I).

Typical uses for bottom ash, together with details of the quality requirements it must meet for these uses, include:

- for concrete blocks: EN 13055-1[3] and national regulations
- in earthworks and road construction: according to national regulations.
  In particular, the properties of bottom ash are useful:
  - in open placement for the construction of roads and pathways and the creation of industrial and storage areas,
  - in landscaping and recultivation measures,
  - in the construction of bound and non-bound load-bearing layers and bound base surface layers ,
  - in road sub bases and
  - in the construction of noise barriers.
- as lightweight aggregate for concrete products according to DIN EN 13055-1[2] where the conformity evaluation has to follow a similar procedure as described in EN 450-2 for fly ash for concrete (see Section 2.2)
- as a raw material for cement clinker production: site specific requirements
- as filler for cement: EN 197-1[4]
- for brick production: national regulations
- for gardening and landscaping: national regulations

2.2 Fly Ash

2.2.1 Generation

Production of suitable quality fly ash in a coal or lignite-fired power plant is based on the principle of pulverized fuel firing (see figure 1, page 2).

The pulverized coal with or without secondary fuels is blown with air into the combustion chamber of the power plant boiler. Combustion (oxidation) of the fuel at a temperature of up to 1400°C produces mineralized particles which, after a residence time of up to several seconds, leave the firing chamber with the flue gas.

1. The flue gas containing the fly ash flows through the boiler passes and also, if present, the denitrification unit and economizer, and is then fed to the dust removal unit.

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[3] EN 13055-1: Lightweight aggregates for concrete, mortar and grout, 2004
[4] EN 197-1: Cement - Part1: Composition, specifications and conformity criteria for common cements, 2009

2. In the dust removal system, which usually works on the principle of electrostatic precipitation and comprises a number of stages (cells), the fly ash is separated from the flue gas and removed.
3. Monitoring of fly ash quality – assuming it is intended for high-grade use – takes place between the dust removal unit and the interim storage silos. The combustion process is controlled and material sorted depending on the monitoring findings.
4. On the basis of the results, the fly ash is stored in different silos depending on its quality (compliance or non-compliance with standards). From there it is transported to the place of use by road, rail or water. - If the power plant is equipped with only one silo the decision whether the fly ash in the silo is a fly ash according to EN 450 is taken on the results of the internal quality control.

The combustion process is fully controlled to meet stringent emission control parameters as well as to meet the requirements resulting from European standards for conformity evaluation of the products. Figures 2 shows the responsibilities of the producer for e.g. fly ash for concrete according to the European standard EN 450-2[5] (formerly national standards).

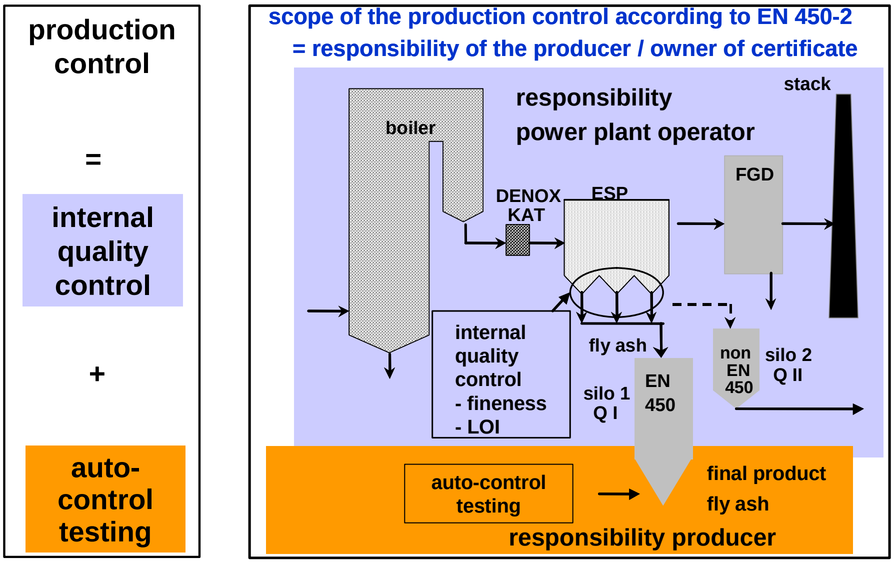

Fig 2 Production control for the production of fly ash for concrete according to EN 450-2[4]

The complete combustion process has to be described in a works quality manual and the process is monitored by an officially recognized monitoring body (third party control). A similar system for conformity evaluation is required by the European standard for lightweight aggregate (see page 4).

[5] EN 450-2: Fly ash for concrete - Part 2: Conformity evaluation, 2005

2.2.2 Properties

Fly ash is a fine grained dust consisting mainly of melted vitreous particles of spherical shape with a smooth surface. Depending on the fuel used, a distinction is made between siliceous and calcereous fly ash. The principal components are silica, aluminium and iron compounds, and also – in calcereous fly ash – calcium oxide or calcium compounds. The composition of siliceous fly ashes corresponds to that of naturally occurring pozzolans (volcanic ashes), while calcereous ashes also contain hydraulically active mineral phases in addition to pozzolanic components. A special property of siliceous fly ash is its pozzolanic reactivity, i.e. its capacity to react with lime and water at ambient temperature to form strength-giving mineral phases similar to those in Portland cement. In view of its fineness and particle size distribution, and also its pozzolanic reactivity, coal fly ash is mostly used in cement-bound building materials to improve their technical properties and replace cement.

2.2.3 Use and requirements for use

In 2008, about 38 million tonnes of fly ash from lignite and coal combustion were produced. Most of the fly ash from lignite combustion (about 17 million tonnes) is used for reclamation of open cast mines, pits and quarries.

About 18 million tonnes of fly ash was used in the construction industry and in underground mining, i.e. as concrete addition, in road construction and as a raw material for cement clinker production. Fly ash was also utilised in blended cements, in concrete blocks and for infill (that means filling of voids, mine shafts and subsurface mine workings) (see figure A2 in Annex I).

Typical uses for fly ash, together with details of the quality requirements it must meet for these uses, include:

- as addition to concrete according to EN 206-1[6]
  Fly ash is used as a concrete addition in various proportions depending on the individual mix design, and improves the properties of concrete, e.g. by reducing the heat of hydration, improving durability, increasing resistance to chemical attack. To some extent it replaces cement, enabling the content of the latter to be reduced in concrete accordingly. For this application fly ash has to be produced according to EN 450-1[7] and EN 450-2[8].
- in road construction: according to national regulations.
  In addition to its use in concrete layers, fly ash is used in bituminous surface layers and in hydraulically bound road bases. The relevant quality requirements are set out in instruction sheets and technical requirements issued by national authorities or by European or national standards (i.e. EN 13282[9])
- for cement production
  Fly ash is used as a raw material component (clay substitute) in cement clinker production or as a main constituent in the production of Portland fly ash cement or Portland composite cement. In the first case site specific requirements of the cement producer has to be met, for the production of blended cement the requirements in EN 197-1[10].
- for concrete blocks: national regulations

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6 EN 206-1: Concrete – Part 1: Specification, performance, production and conformity, 2000
7 EN 450-1: Fly ash for concrete - Part 1: Definition, specifications and conformity criteria, 2005
8 EN 450-2: Fly ash for concrete - Part 2: Conformity evaluation, 2005
9 EN 13282: Hydraulic Road Binders, Composition, specifications and conformity criteria, 2009
10 EN 197-1: Cement - Part 1: Composition, specifications and conformity criteria for common cements, 2009

- for infill, that means filling of voids, mine shafts and subsurface mine workings according to national regulations of the mining authorities
- for production of bricks (leaning of fatty clay): national regulations
- in earthworks and landscaping
  In earthworks and landscaping the mechanical properties of fly ash are used in setting up and improvement of road foundations (embankments), the construction of noise barriers, and for recultivation and soil improvement.
- for production of mortar, floor screed and plasters and mining mortars/civil engineering products: national standards and requirements

In line with the energy demand curve and the seasonal working load of coal-fired power stations, fly ash is largely produced during the colder months of the year when business in the building industry is slack. Silos with a capacity of up to 60,000 tonnes have therefore been built at some power plants to provide dry temporary storage facilities for fly ash prior to its use as a concrete addition. In some cases, certified fly ash in particular is stored in a moistened state during the winter months, before being re-dried in separate facilities in the summer months for subsequent use in the building materials industry.

2.3 Boiler Slag

2.3.1 Generation

Boiler slag is produced when coal is burned in slag-tap furnaces. In such furnaces the ash components are drawn off in a molten state at very high temperatures (1500 - 1700°C) and subjected to sudden quenching in a water bath (see figure 3). The individual process steps are:

1. Pulverized coal is blown by a transporting air stream into the combustion chamber of the power plant boiler.
2. In the combustion chamber, temperatures of over 1500ºC lead to liquid slag which is discharged at the bottom of the boiler.
3. The flue gas containing the fly ash flows through the boiler passes and also, if present, the denitrification unit and economizer, and is then fed to the dust removal unit. In the dust removal system, which usually works on the principle of electrostatic precipitation and comprises a number of stages (cells), the fly ash is separated from the flue gas and either conveyed to fly ash storage silos or fed back to the boiler.
4. The sudden quenching of the molten material flowing from the melting chamber into the water bath results in the formation of typical glassy (amorphous) grit-like granules.
5. The boiler slag granules are transported from the water bath to the dewatering unit, via a special filter bed if necessary.
6. After any necessary processing in the form of grading and breaking, the dewatered material is conveyed to the in-plant storage area. From here it is transported in batches to the intended uses.

Samples for quality monitoring are usually taken direct from the loading equipment at the temporary storage facility. The nature and extent of the quality monitoring depend on the intended use of the vitrified slag.

2.3.2 Properties

Boiler slag is a glassy material, has a broken particle shape due to the production process, and has a particle size of 0.2 to 11 mm. Special features of the granules are their low apparent density and installation weight, high angle of friction, excellent frost resistance, lack of sensitivity to environmental influences, high permeability and good filtering effect when used in beds.

The properties of processed boiler slag meet the requirements of normal size fractions, such as 0/5 high quality broken sand (natural sand classified for grain diameter of 0 to 5 mm).

Boiler slag does not contain any organic impurities. All trace elements are firmly and permanently embedded in the glass matrix. Systematic tests have shown that leaching of vitrified slag does not release any substances harmful to the environment.

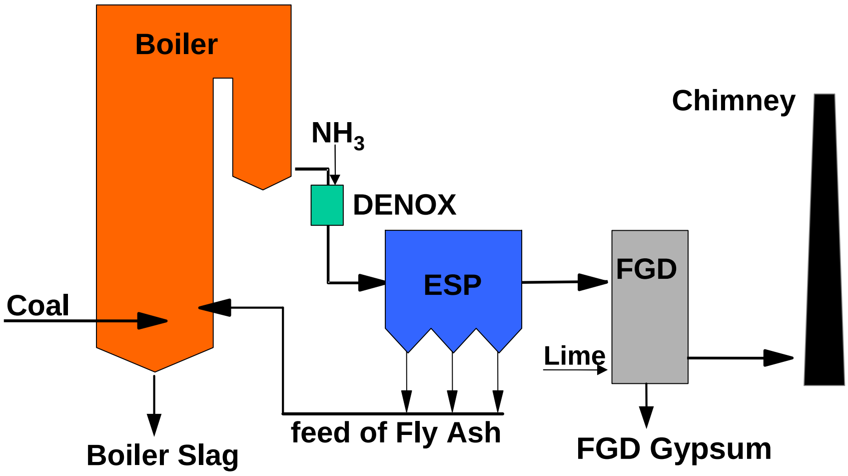

Fig. 3 Production of Boiler Slag

2.3.3 Use and requirements for use

The chemical, physical and mechanical properties of boiler slag and its compliance with the relevant standards, guidelines and regulations are crucial to its use. For some uses, further processing of the material by breaking or screening makes it more uniform.

In 2008, about 1.4 million tonnes of boiler slag were produced in Europe (EU 15). The utilisation rate was 100 %. About 45 % was used as blasting grit, about 30 % in road construction, 10 % was used as aggregate in concrete and about 5 % for grouting and drainage (see figure A3 in Annex I).

Typical uses for boiler slag, together with details of the quality requirements it must meet for these uses, include:

- for road construction: national regulations
  Boiler slag is used in road pavement, as bed material and joint pinning, infill of rural tracks, car parks and pathways.
- as blasting grid for surface treatment of metal and concrete[11]
- for concrete production : EN 12620[12] and national regulations
- for bricks: national regulations
- in earthworks: national regulations
  Boiler slag is used for soil improvement, as filter material for drainage, as backfill material and as a bed material
- in road construction: national regulations
  Boiler Slag is used for road pavement, as bed material, for joint pinning, infill of rural tracks, car parks and pathways.
- for drainage material and filter course on landfill sites: national regulations

[11] ISO 11126-4: Preparation of steel substrates before application of paints and related products - Specifications for non-metallic blast-cleaning abrasives - Part 4: Coal furnace slag, 1998
[12] EN 12620: Aggregates for concrete, 2008

2.4 Fluidized bed combustion (FBC) ash

2.4.1 Generation

Fluidized Bed Combustion (FBC) ash is produced in fluidized bed combustion boilers. The technique combines coal combustion and flue gas desulphurisation in the boiler at combustion temperatures of 850 to 900°C (see figure 4). The individual process steps are:

1. Pulverized coal and milled limestone for desulphurisation is fed to a fluidized bed combustion boiler. The fluidized bed consists of sand like material which is fluidized by addition of air from the bottom of the boiler.
2. In the fluidized bed coal and limestone are intimately mixed and heated up to a temperature of 850 to 900°C. By this, the coal is burned, the limestone is decomposed and reacts with the sulphur from coal combustion.
3. The minerals formed by coal combustion differ in size and density. The bigger particles are removed from the fluidized bed as bed ash, the finer particles leave the firing chamber with the flue gas, also the flue gas desulphurization products and unreacted adsorbens. In the dust removal system, either cyclones, baghouse filters or electrostatic precipitators, fly ash is collected and conveyed to storage silos or mixed with the bed ash and stored in silos or interim storage sites.

FBC ash is stored temporarily before undergoing final controls and being transported to the place of use, usually by road.

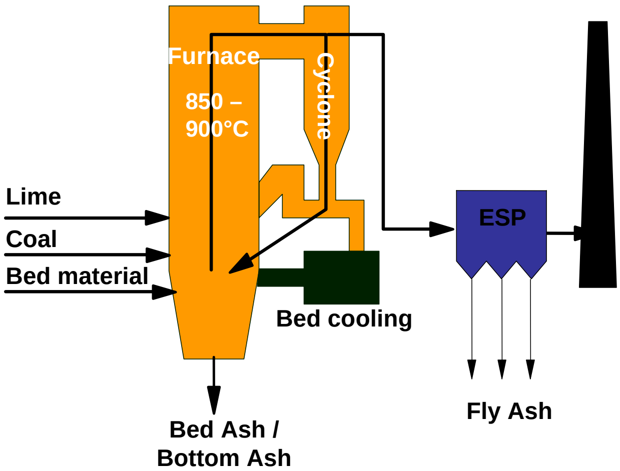

Fig. 4 Production of FBC ash

2.4.2 Properties

Depending on the desulphurisation process in the furnace FBC ash, as a mix of bed ash and fly ash, consists of coal ash, residual coal, desulphurization products and non reacted adsorbent. The comparatively low combustion temperature lead to formation of fine grained crystalline minerals. The maximum grain size is up to 10 mm stemming from bed ash particles. The ash is rich in lime and sulphur due to the combined desulphurisation process. Other main chemical constituents are silicon, aluminium and iron oxide.

2.4.3 Use and requirements for use

The amount of FBC ashes produced in Europe (EU 15) was about 1.0 million tonnes in 2008. The production has to be considered small compared to the production in Poland and the Czech Republic. In 2008, about 0.2 million tonnes of the FBC-ash produced in EU 15 member states was used for engineering filling applications (52 %), for structural fill (11 %) and infill (9 %) (see figure A4 in Annex I).

The typical uses for FBC ash, together with details of the quality requirements it must meet for these uses, are based on national regulations.

2.5 SDA product

2.5.1 Generation

With the desulphurisation of flue gases in European power plants using spray dry absorption techniques spray dry absorption product (SDA product) is generated. The desulphurisation process involves the following process steps within the plant:

1. The lime suspension introduced into the spray absorber reacts with the sulphur dioxide (SO_2) present in the flue gas.
2. The process temperatures are adjusted so that the water present in the system evaporates completely and the reaction product (normally SDA product) is output in a dry state at the dust removal units.
3. The finished SDA product is temporarily stored on site and transported from there to the user.

Depending on the location of the SDA installation in the flue gas stream (upstream or downstream the electrostatic precipitator) SDA product may contain fly ash up to 60 % by mass (see figure 5, case I or II). This has a major influence on its further use.

SDA product is stored temporarily in silos before undergoing final controls and being transported to the place of use, usually by road.

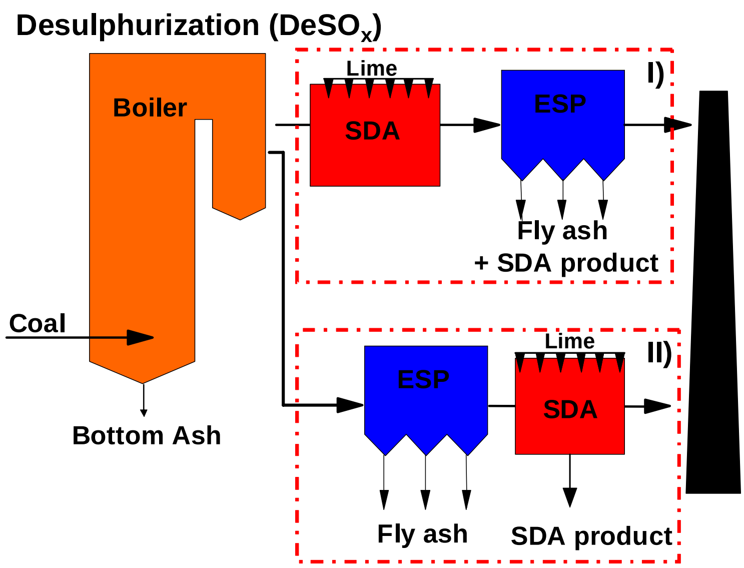

Fig. 5 Production of SDA Product

2.5.2 Composition and properties

SDA product is a fine-grained powder with a particle size mostly less than 60 µm and a residual moisture content of less than 10% by weight. Depending on the fly ash content, its colour varies from white to grey.

Owing to differences in process technology (with (II)/without (I) prior dust removal) and in the properties of the fuels and auxiliary agents used, the composition of the SDA product may fluctuate within a wide range. The SDA product is a mixture of the following minerals: calcium sulphite hemi-hydrate, calcium sulphate di-hydrate (gypsum), calcium carbonate, calcium hydroxide, calcium chloride and calcium fluoride.

2.5.3 Use and requirements for use

In 2007, about 0.4 million tonnes of spray dry absorption product (SDA product) were produced in European power plants (EU 15). No systems with spray dry absorption are in use in lignite power stations. The production has to be considered small compared to the production in Poland and Czech Republic.

About 0.2 million tonnes of the SDA product produced in EU 15 member states was mainly used in filling applications (structural fill and infill). About 3 % was used for plant nutrition and about 20 % as a sorbent in wet FGD (see figure A5 in Annex I).

The excellent fertilizer effect of the calcium and sulphur in SDA product is used in agriculture and forestry. In Germany, SDA product is listed in the Fertilizers Ordinance as a fertilizer type in its own right. The resulting requirements are satisfied by SDA products from systems equipped with prior dust removal.

The typical uses for SDA product, together with details of the quality requirements it must meet for these uses, are based on national regulations.

2.6 FGD gypsum

2.6.1 Generation

FGD gypsum is produced in the flue gas desulphurisation process of coal-fired power plants incorporating the desulphurisation of the flue gas in the power plant (see figure 1) and a refining process in the FGD plant including an oxidation process followed by gypsum separation, washing and dewatering.

The process involves the following sequence of process steps within the plant:

1. The suspension containing limestone/chalk ($CaCO_3$) or quicklime (CaO) which is sprayed into the flue gas scrubber reacts with the sulphur dioxide (SO_2) present in the flue gas to form mainly calcium sulphite ($CaSO_3$). This results in a liquid mixture, the solid components of which are calcium sulphite and the calcium sulphate circulated in the scrubber cycle.
2. Calcium sulphite is oxidized by adding defined quantities of air, and in the subsequent crystallization process it binds two molecules of water; this results in a suspension of gypsum (calcium sulphate dihydrate: $CaSO_4 \cdot 2H_2O$) in the scrubber sump.
3. In the further course of the process the gypsum suspension, which is monitored internally to track its chemical and physical properties, now passes through hydrocyclones where partial dewatering takes place and the gypsum particles are graded. The fine material is returned to the flue gas scrubber.

4. Further dewatering and purification of the gypsum with leaching of water-soluble components (e.g. chloride) takes place either in a centrifuge or on a belt-type vacuum filter. The washing water undergoes further reprocessing in a separate unit. The residual moisture content of FGD gypsum (excluding bound crystal water) is between 5 and 12%.
5. The finished FGD gypsum, which may be dried first, goes to an on-site interim storage facility (silo, hall). From there it is transported to the user by water, road or rail. (A certain amount of the FGD gypsum produced in Germany goes to raw material depots to ensure continuous long-term supplies to the gypsum industry.)

The quality of the gypsum is monitored daily. The samples are taken immediately before the on-site interim store. The laboratory tests are performed in accordance with the instruction sheet "FGD gypsum – Quality Criteria and Analytical Methods"[13] and any additional parameters agreed between producer and customer.

2.6.2 Properties

FGD gypsum is a moist, fine-grained material with a residual moisture content of 5 to 12 % and at least a 95 % concentration of $CaSO_4 \cdot 2H_2O$. Depending on the production conditions, the gypsum crystals are needle-shaped to compact and plate-like.

The composition and properties of FGD gypsum are identical to those of natural gypsum, as has been proven by extensive basic scientific research[14].

2.6.3 Use and requirements for use

The amount of FGD gypsum produced in Europe (EU 15) was approximately 11 million tonnes in 2008. More than 80 % of the total FGD gypsum produced in Europe is utilised in the gypsum and cement industry. In total, about 3 % of the FGD gypsum produced was temporarily stockpiled as a raw material base for future utilisation, mostly for plasterboard production, and about 7 % was disposed of.

FGD gypsum is used as a raw material for a number of gypsum products by the gypsum industry because of its purity and homogeneity compared to natural gypsum. 5.6 million tonnes of FGD gypsum was used in 2008 for the production of plaster boards. Other applications include the production of gypsum blocks, projection plasters and self levelling floor screeds (see figure A6 in Annex I).

Like natural gypsum, FGD gypsum has to be dewatered by thermal means before being used for building materials, and in this process the crystal water is completely or partially removed. Before the gypsum product is used on the construction site or at the gypsum works, water is added to it again, starting a controlled setting process.

FGD gypsum is also used as a retarder in cement production and as a filler in the production of paints, adhesives and plastics. Further application exist in agriculture, where FGD gypsum is used as a source of lime and sulphur in fertilisers, composts and soil improvers.

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[13] EUROGYPSUM: FGD Gypsum - Quality Criteria and Analysis Methods (status: April 2005).

[14] Becker, J., Einbrodt, H.-J., Fischer, M.: Vergleich von Naturgips und REA-Gips, Bericht und gutachterliche Stellungnahme, VGB Forschungsstiftung und Bundesverband der Gips- und Gipsbauplatten-industrie e.V., 1989.
(see also: Becker, J., Einbrodt, H.-J., Fischer, M.: Comparison of Natural Gypsum and FGD Gypsum, Abridged version of VGB Research Project 88, VGB Kraftwerkstechnik 1/1991, p. 46-49

Typical uses for FGD gypsum, together with details of the quality requirements it must meet for these uses, include:

- for use as a raw material for the gypsum and cement industry: FGD Gypsum Quality Criteria[15]
- for the use as fertiliser: national regulations.

3. Conclusion

In Europe (EU 25), more than 100 million tonnes of by-products were produced in coal-fired power stations in 2008; of this total, about 56 million tonnes was produced in the EU 15 countries. The by-products include boiler slag, bottom ash and fly ash from different types of boilers as well as desulphurisation products like spray dry absorption product and FGD gypsum. Out of the total production of 56 million tonnes of by-products in EU 15, the amount of ash produced was around 44 million tonnes, while around 12 million tonnes are products obtained from flue gas desulphurisation processes.

The by-products are mainly utilised in the building material industry, in civil engineering, in road constructions, for construction work in underground coal mining as well as for recultivation and restoration purposes in open cast mining. Most of the hard coal fly ashes are used in cement and concrete.

In the majority of cases by-products are used as a replacement for natural materials and therefore offer environmental benefits by avoiding the need to quarry or mine these resources. By-products also help to reduce energy demand as well as emissions to atmosphere, for example CO_2, which are needed for - or result from - the manufacturing process of the products which are replaced.

All by-products are produced in a fully controlled combustion and/or desulphurisation process. The majority of the by-products is produced to meet certain requirements of standards or other specifications with respect to utilisation in certain areas. To meet the demand of the customers by-products may have to be stored for a certain interim period or processed. Interim storage is necessary because by-products are produced in wintertime when construction work is rare. Storage facilities guarantee stable product qualities until final use. For special products also processing of by-products may be required to allow the benefit of specific by-product use also in products with special properties.

[15] EUROGYPSUM: FGD Gypsum - Quality Criteria and Analysis Methods (status: April 2005)

Annex I

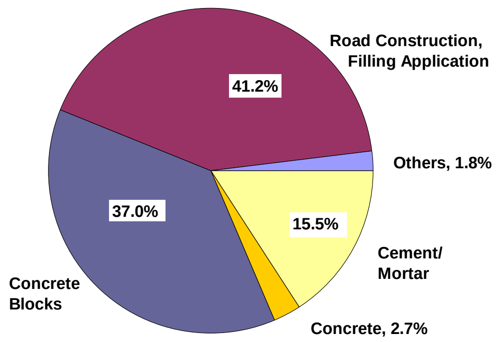

Figure A1:
Utilisation of Bottom Ash in the Construction Industry and Underground Mining in Europe (EU 15) in 2008.
Total utilisation 2.4 million tonnes.

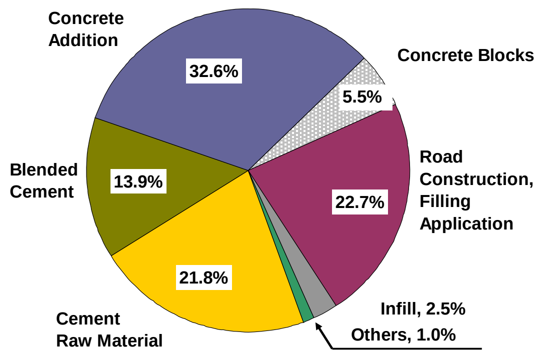

Figure A2:
Utilisation of Fly Ash in the Construction Industry and Underground Mining in Europe (EU 15) in 2008.
Total utilisation 17.7 million tonnes.

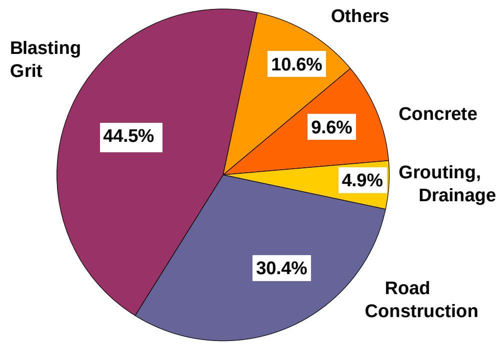

Figure A3:
Utilisation of Boiler Slag in the Construction Industry and as Blasting Grid in Europe (EU 15) in 2008.
Total utilisation 1.4 million tonnes.

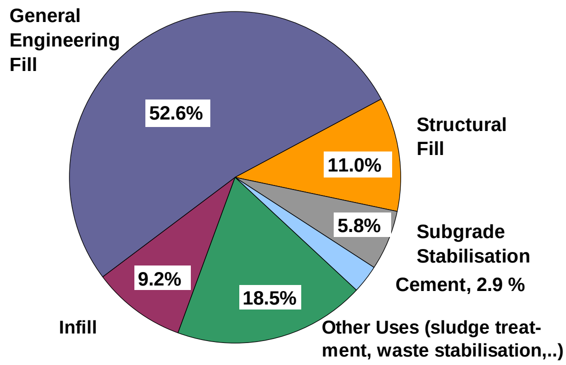

Figure A4:
Utilisation of FBC Ash in the Construction Industry and Underground Mining in Europe (EU 15) in 2008.
Total utilisation 0.2 million tonnes.

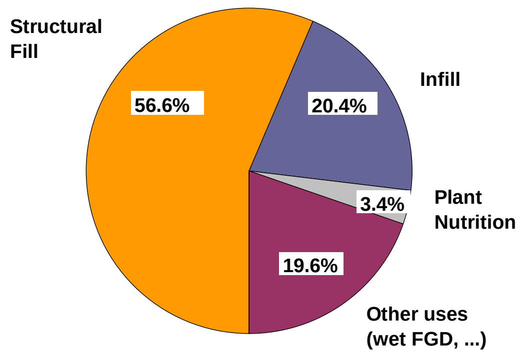

Figure A5:
Utilisation of SDA-Product in the Construction Industry and Underground Mining in Europe (EU 15) in 2008.
Total utilisation 0.3 million tonnes.

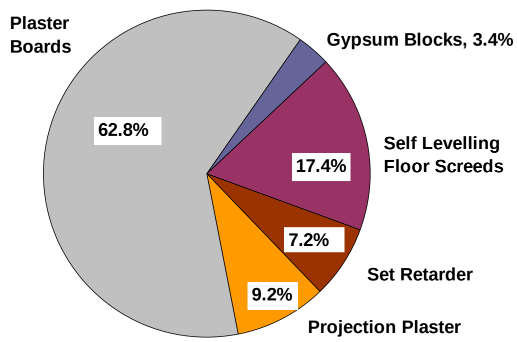

Figure A6:
Utilisation of FGD gypsum in the Construction Industry in Europe (EU 15) in 2008.
Total utilisation 8.8 million tonnes.