UNION OF THE ELECTRICITY INDUSTRY
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European Coal Combustion Products Association

Joint EURELECTRIC/ECOBA Briefing:
Case Study for the Commission's Communication on By-products and for Guidance on the Revised Waste Framework Directive

Each year, more than 90 million tonnes of coal and lignite ashes and desulphurisation products are produced, in addition to the main product electricity, by power stations throughout the European Union. These by-products, which can be described collectively as coal combustion products (CCPs [1]), are either inevitable, are produced in power plants as a result of requirements to meet air emission standards set in EC Directives, and by plant design to meet product standards, or both [2]. Each of the by-products have 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 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 reduce energy demand and emissions to the atmosphere (for example CO_2) which result from the extraction or manufacture of the substituted product [10]. The use of by-products in these ways is consistent with the aims of the existing Waste Framework Directive and with waste hierarchies, which put waste prevention and avoidance before options such as recovery, recycling and re-use.

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' [11]. In each case where they are utilised, they are suitable for use in their existing form and without undergoing any transformation process. We therefore believe that 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 should be included within the forthcoming Commission Communication as examples of industrial by-products which should never be considered as wastes.

In countries where production levels exceed demand or where demand varies temporally, some CCPs, 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, we believe that the materials have ceased to be wastes at the place of recovery and have become secondary products once they are suitable for use. We therefore believe that recovered CCPs are an example that the Commission should include within their implementation of a revised Waste Framework Directive as a waste stream which, when recovered, ceases to be waste.

In some European countries, CCPs are now being classified as wastes even when they are going for beneficial use. This classification stigmatises them as undesirable materials, hampers the development of markets for these products and thus restricts their use. It also puts an administrative burden on companies who still decide to use them (both the producer of the by-products and the potential end-users) through more complex regulation and licensing procedures. This is the reason why it appears more cost-effective, for smaller companies at least, to use primary materials despite their higher overall environmental impact. These problems would be circumvented by appropriate guidance; without this, much more effective education is needed, since end-users and the general public are very reluctant to use a material which has, at any stage, been labelled a waste. This is currently hampering numerous activities associated with the recovery, recycling and re-use of wastes.

In summary, the production of CCPs is an inevitable consequence of the combustion of coal in 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, can find use either immediately or, in the longer-term, after recovery from mono-landfill sites. In the former case, producers believe that 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 secondary products at the place of recovery (Figure 1). Eurelectric and ECOBA believe that, in both cases, CCPs are very good examples for the Commission to use in the guidance they are producing ahead of and to accompany the revised Waste Framework Directive.

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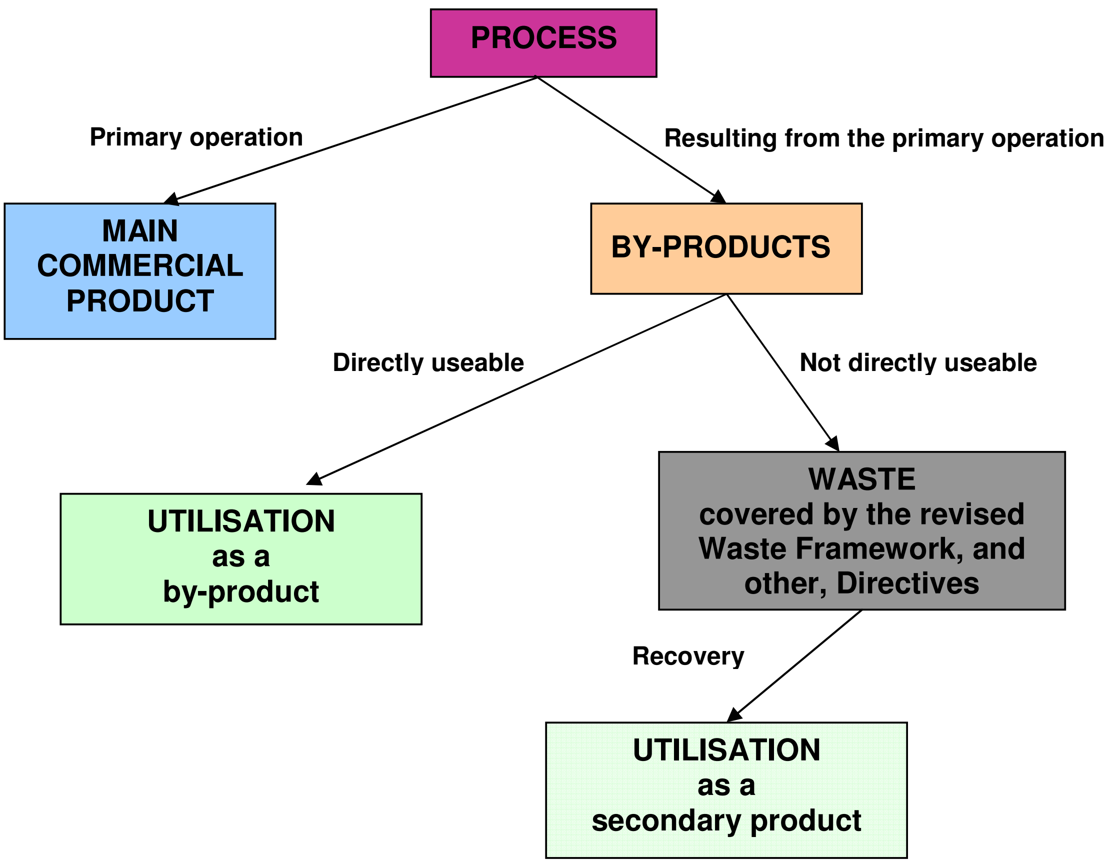
Fig. 1: EURELECTRIC flow chart describing definitions



[1] For the purposes of this Note, coal combustion products (CCPs) are bottom ash, boiler slag, fluidised bed combustion (FBC) ash (i.e. bottom ash, slag and boiler dust according to EWC Code 10 01 01 and 10 01 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.

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 fly-ash cement, fly 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 fly 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, requirements and quality control. Fly ash according to EN 450 is CE-marked.

[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. The products have to meet the requirements of European Standards, e.g. EN 771. 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 fiber resin systems and refractory panels.

[9] Most of the FGD gypsum produced in Europe is utilized in the gypsum and cement industries as a raw material for the production of e.g. plasterboards, 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. A particular 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 EU (EU 15) it is estimated that the use of fly ash in production of blended cement and as addition to concrete results in a reduction in CO_2 emissions of about 5 million tonnes 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.

[11] According to Council Directive 75/442/EEC on waste (as amended by Directive 91/156/EEC), 'waste' means any substance or object, which the holder discards or intends or is required to discard.

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Annex

Coal Combustion Products (CCPs)
- Generation and use -

Content **page**

1 Introduction

In coal-fired electricity generating power plants solid minerals are produced during and after the combustion of finely ground coal in a fully controlled process. The materials under consideration are the ashes i.e. the unburnable mineral matter in the coal (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 furnace 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.

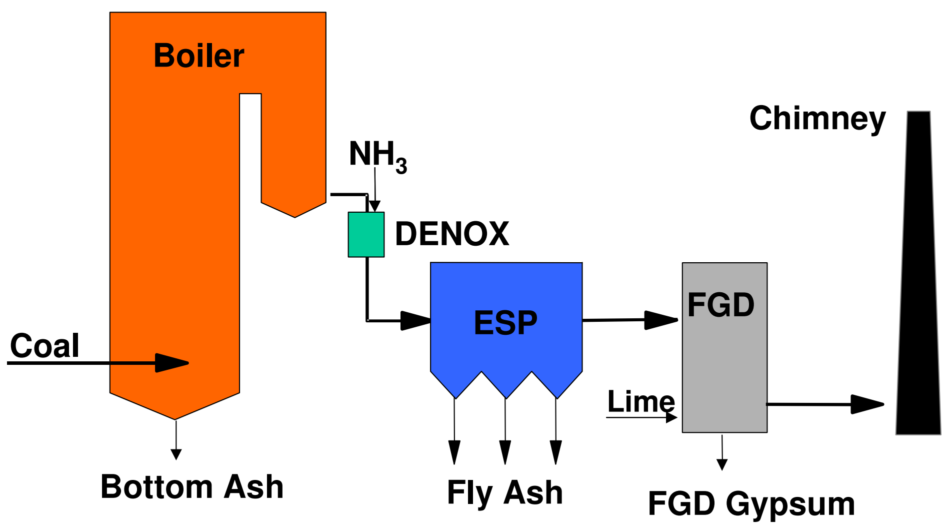

Fig 1 Production of coal combustion products (CCPs) in coal-fired power plants

Comment: This chapter can be removed as the single CCP chapter contain the same information.

A similar process (wet-bottom furnace) is used for production of boiler slag. Within this combustion process the furnace 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 or semi dry flue gas desulphurization.

2 CCPs: Production, use and requirements for the use

In 2003, the amount of CCPs produced in European (EU 15) power plants totalled 65 million tonnes and in the larger EU of 25 member states the total production is estimated to be about 95 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 (52.4 %) or for restoration of open cast mines, quarries and pits (35.9 %). In 2003, about 8.0 % was temporarily stockpiled for future utilisation and 3.7 % was disposed of[1].

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 of coal as well as the type of coal feed. A constant product quality is the major prerequisite for utilisation. Regarding this, residues from coal combustion have more favourable prerequisites than most residues 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 residues from coal.

2.1 Bottom Ash

2.1.1 Generation

During the combustion of finely ground coal 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 directly 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/or national rules (application standards). In earthworks and civil engineering it often has to satisfy national regulations of the road authorities. In additional, 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.

[1] ECOBA- Statistics on Production and Utilisation of CCPs in Europe (EU 15) in 2003

2.1.3 Use and requirements for use

In Europe, about 6 million tonnes per annum of bottom ash are produced following the combustion of coal and lignite. Whereas bottom ash from lignite power plants is almost entirely used for filling worked-out opencast 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 2003, about 2.7 million tonnes of bottom ash were used in the construction industry. Out of this 48 % was used as a fine aggregate in concrete blocks, 33 % in road construction and about 14 % in cement and concrete (see figure A1 in the annex).

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[2] 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] including requirements for conformity evaluation.
- as a raw material for cement clinker production: site specific requirements
- as filler for cement: EN 197-1[3]
- for brick production: national regulations
- for gardening and landscaping: national regulations

2.2 Fly Ash

2.2.1 Generation

The pulverized coal is blown with air into the combustion chamber of the power plant boiler. Combustion (oxidation) of the coal components 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 (see figure 1, page 2).

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.
2. In the electrostatic precipitator 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.

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[2] EN 13055-1: Lightweight aggregates for concrete, mortar and grout, 2004

[3] EN 197-1: Cement - Part 1: Composition, specifications and conformity criteria for common cements, 2000

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 waterway. (sentence might be removed as it's a technical specification)

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[4] .

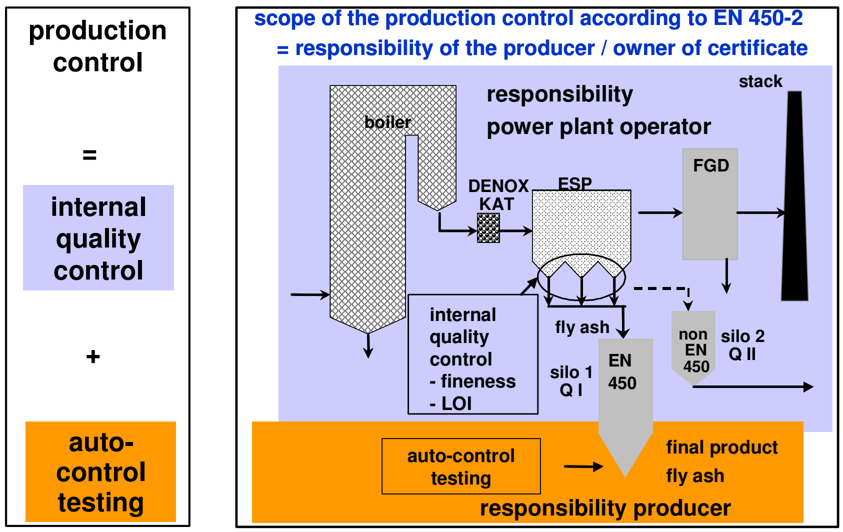

Fig 2 Production control for the production of fly ash for concrete according to EN 450-2[4]

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

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

2.2.2 Properties

Fly ash is a fine powder consisting mainly of spherical, glassy particles. 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 fly 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 2003, about 44 million tonnes of fly ash from lignite and coal combustion were produced in EU 15. Most of the fly ash from lignite combustion (22.7 million tonnes) is used for reclamation of open cast mines, pits and quarries.

About 21 million tonnes of fly ash was used in the construction industry and in underground mining, e.g. 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 the annex).

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[5]
  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 and 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[6] and EN 450-2[7].
- in road construction according to European Standards and national regulations.
  In addition to its use in concrete layers, fly ash is used in bituminous surface layers, hydraulically bound mixtures and in unbound 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. prEN 13282[8], EN 14227-4[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. For the use as raw material component site specific requirements of the cement producer has to be met, for the production of blended cement the requirements in EN 197-1[10].

[5] EN 206-1: Concrete – Part 1: Specification, performance, production and conformity, 2000
[6] EN 450-1: Fly ash for concrete - Part 1: Definition, specifications and conformity criteria, 2005
[7] EN 450-2: Fly ash for concrete - Part 2: Conformity evaluation, 2005
[8] prENV 13282: Hydraulic Road Binders, Composition, specifications and conformity criteria, 1998
[9] EN 14227: Unbound and hydraulically bound mixture - Part 4: Fly ash for hydraulically bound mixtures - Definition, composition, classification: 2003
[10] EN 197-1: Cement - Part 1: Composition, specifications and conformity criteria for common cements, 2000

- for concrete blocks: national regulations
- 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 temporarily stockpiled 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. 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 directly from the loading equipment at the temporary storage facility. The nature and extent of the quality monitoring depend on the intended use of the 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 bulk 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.

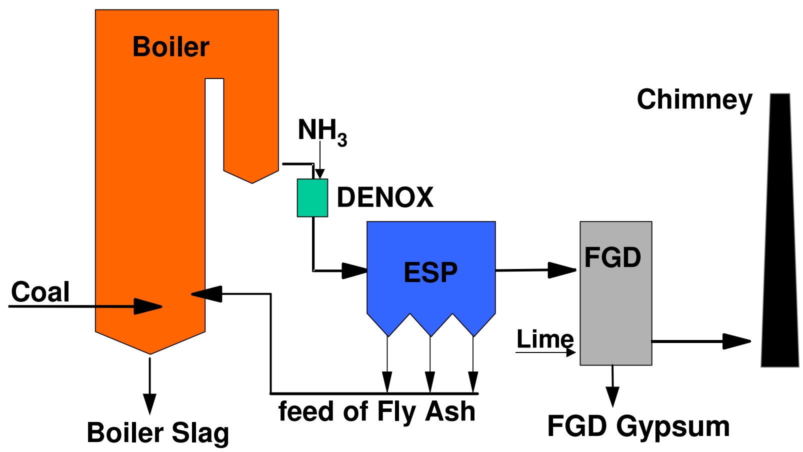

Fig. 3 Production of Boiler Slag

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 2003, about 2.1 million tonnes of boiler slag were produced in Europe (EU 15). The utilisation rate was 100 %. About 55 % was used in road construction, e.g. as a drainage layer. Another 26 % was used as blasting grit and smaller amounts as aggregates in concrete and grouts (see figure A3 in the annex).

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 grit 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

[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, 2001

- 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

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. The individual process steps are:

1. Ground coal and milled limestone for desulphurization 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.
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 adsorbents. 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.

2.4.2 Properties

Depending on the desulphurization 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 desulphurization process. Other main chemical consitutents are silicon, aluminium and iron oxide.

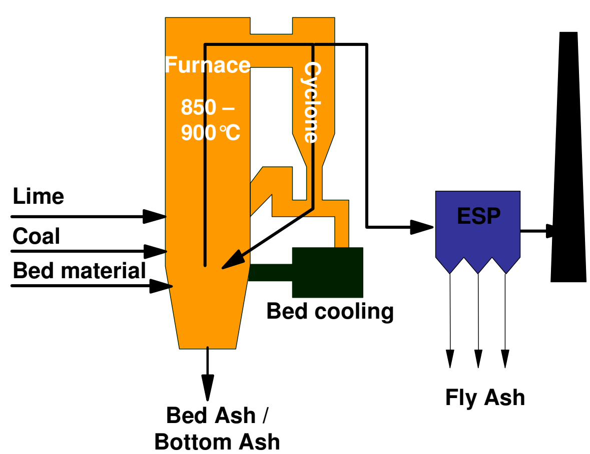

Fig. 4 Production of FBC ash

2.4.3 Use and requirements for use

The amount of FBC ashes produced in Europe (EU 15) was about 1 million tonnes in 2003. Out of this 0.5 million tonnes were utilised in the construction industry and for mining purposes. About 52 % of the total FBC ash was used for infilling purposes, which means filling of enclosed voids, mine shafts and subsurface mine workings. About 13 % was used with the production of pavement base course as foundation material or as drying agent for wet soils and about 11 % was used for structural fill (see figure A4 in the annex).

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 desulphurization of flue gases in European power plants using spray dry absorption techniques spray dry absorption product (SDA product) is generated. The desulphurization 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). 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.

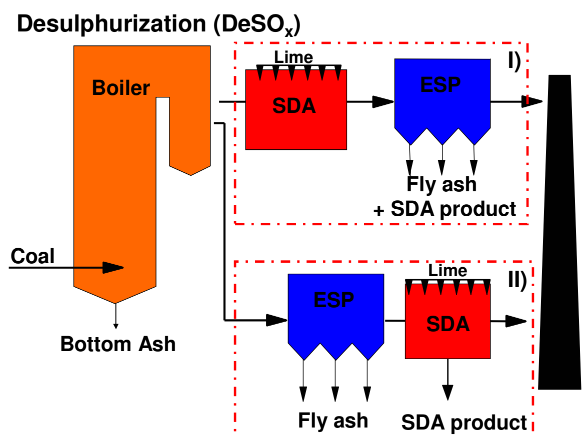

Fig. 6 Production of SDA Product

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/without 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 2003, about 0.5 million tonnes of spray dry absorption product (SDA product) were produced in European power plants.

SDA product is utilised in the mining industry as a component of mining mortar for stabilising underground cavities. In the building material industry it can also be used as an addition in the production of sand lime bricks. About 5 % of the total is used for plant nutrition. It has been proven that SDA product can be used without any harm to the environment as a sulphur fertiliser or as a component of a fertilizer in agriculture. SDA product is increasingly used as sorbent in the wet FGD process in power plants (see figure 2.6).

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.

Other areas of application for SDA product are backfill in underground mining, fill/recultivation and fill construction.

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 (see figure 1) and a refining process 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 slurry, the solid components of which are calcium sulphite and the calcium sulphate circulated in the scrubber cycle.
2. Calcium sulphite is oxidized by entraining defined quantities of air into the scrubvber sump, 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 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 fine-grained material with a residual moisture content of 5 to 12 % and with a minimum content of 95 % 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 11.3 million tonnes in 2003. Nearly 70 % of the total FGD gypsum produced in Europe is utilised in the gypsum and cement industry. In total 14 % of the FGD gypsum produced was temporarily stockpiled as a raw material base for future utilisation, mostly for plasterboard production, and only 0.7 % 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. For the production of plaster boards 4.9 million tonnes of FGD gypsum were used in 2003. Other applications include the production of gypsum blocks, projection plasters and self levelling floor screeds (see figure A6 in the annex).

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.

[13] EUROGYPSUM: FGD Gypsum - Quality Criteria and Analysis Methods (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 Gipsbauplattenindustrie 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

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 fertilizers, composts and soil improvers.

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 fertilizer: national regulations.

3. Conclusions

In Europe (EU 25), more than 95 million tonnes of by-products were produced in coal-fired power stations in 2003; of this total, about 65 million tonnes was produced in the EU 15 countries and more than 30 million tonnes in the ten new member states. The by-products include combustion residues such as boiler slag, bottom ash and fly ash from different types of boilers as well as desulphurization products like spray dry absorption product and FGD gypsum. Out of the total production of 65 million tonnes of by-products in EU 15, the amount of ash produced was about 53 million tonnes, while about 12 million tonnes are products obtained from flue gas desulphurization processes.

The by-products are mainly utilized in the building material industry, in civil engineering, in road constructions, for construction work in underground coal mining and for recultivation and restoration purposes in open cast mining.

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 the 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 desulphurization 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 reduced. Storage facilities guarantee stable product qualities until final use. For the production of special products also processing of by-products may be required.

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

Data on CCP utilisation

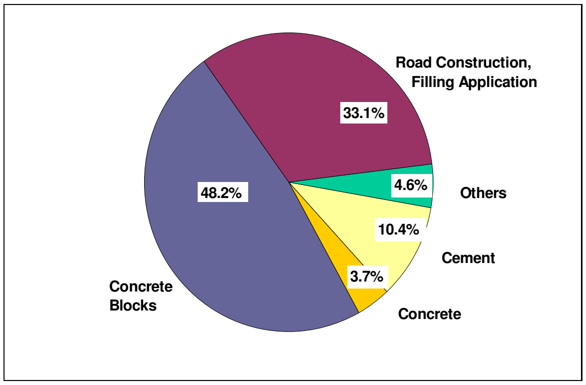

Figure A1:
Utilisation of Bottom Ash in the Construction Industry and in Underground Mining in Europe (EU 15) in 2003 (total utilisation 2.7 million tonnes).

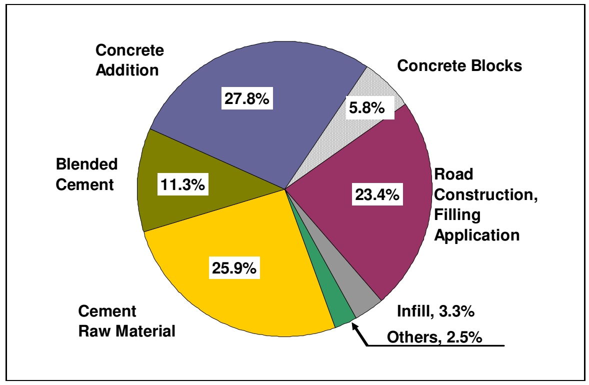

Figure A2:
Utilisation of Fly Ash in the Construction Industry and in Underground Mining in Europe (EU 15) in 2003
(total utilisation 21.1 million tonnes)

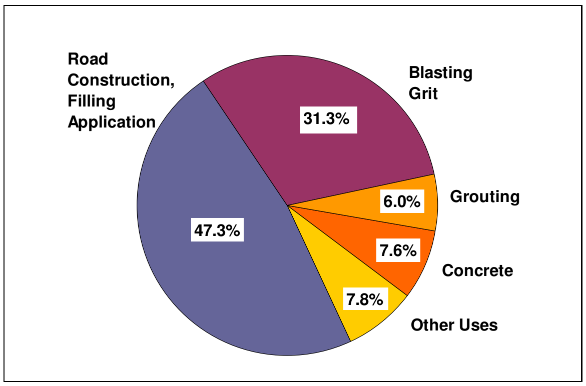

Figure A3:
Utilisation of Boiler Slag in the Construction Industry in Europe (EU 15) in 2003
(total utilisation 2.1 million tonnes)

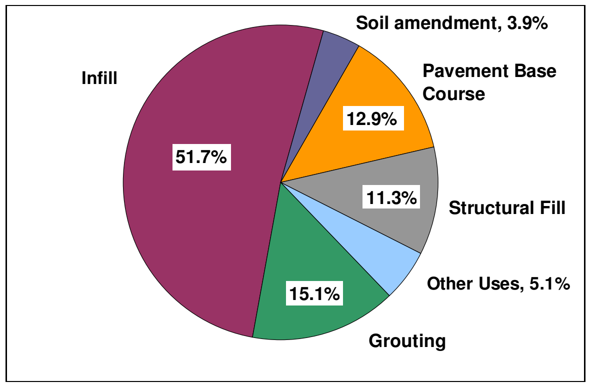

Figure A4:
Utilisation of FBC-Ashes in the Construction Industry and in Underground Mining in Europe (EU 15) in 2003
(total utilisation 0.5 million tonnes)

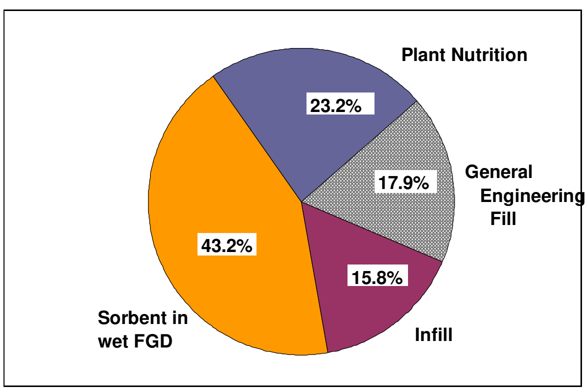

Figure A5:
Utilisation of SDA Product in the Construction Industry, in Underground Mining and for plant nutrition in Europe (EU 15) in 2003 (total utilisation 0.1 million tonnes)

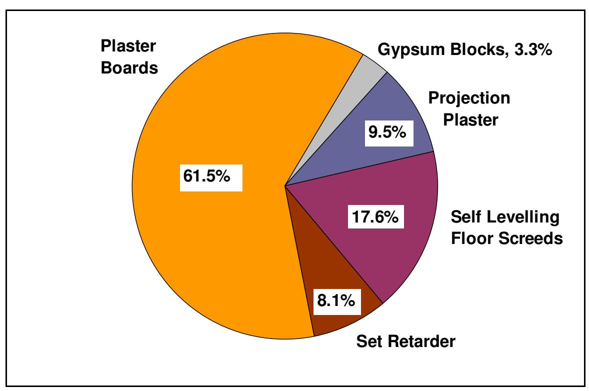

Figure A6:
Utilisation of FGD Gypsum in the Construction Industry in Europe (EU 15) in 2003
(total utilisation 8.0 million tonnes)

Production and Utilisation of CCPs in 2003 in Europe (EU 15) [in kilo tonnes (metric)]

		Fly Ash	Bottom Ash	Boiler Slag	FBC-Ash	Other	SDA-Product	FGD-Gypsum		Total	%
		1	2	3	4	5	6	7			
CCP Production		44.217	6.045	2.110	1.089	76	490	11.276			
Subtotal 1 - 5						**53.537**					
Subtotal 6 - 7								**11.766**			
Total 1 - 7								**65.303**			
CCP Utilisation										Total	%
Cement raw material	1	5.460	151						Cement raw material	5.611	8,5
Blended cement	2	2.377	125						Blended cement	2.502	3,8
Concrete addition	3	5.872	98	161					Concrete addition	6.131	9,3
Aerated concrete blocks	4	845	16						Aerated concrete blocks	861	1,3
Non-aerated concrete blocks	5	380	1.264			5			Non-aerated concrete blocks	1.649	2,5
Lightweight aggregate	6	93	0						Lightweight aggregate	93	0,1
Bricks + ceramics	7	133	23			16			Bricks + ceramics	172	0,3
Grouting	8	481		126	84				Grouting	691	1,0
Asphalt filler	9	158							Asphalt filler	158	0,2
Subgrade stabilisation	10	184	98		1				Subgrade stabilisation	283	0,4
Pavement base course	11	387	258	998	72				Pavement base course	1.715	2,6
General engineering fill	12	1.777	377		0	35	17		General engineering fill	2.206	3,3
Structural fill	13	1.911	145		63				Structural fill	2.119	3,2
Soil amendment	14	37	1		22				Soil amendment	60	0,1
Infill	15	689	94		288		15		Infill	1.086	1,6
Blasting grit	16	0		660					Blasting grit	660	1,0
Plant nutrition	17	3					22		Plant nutrition	25	0,0
Set retarder for cement	18							642	Set retarder for cement	642	1,0
Projection plaster	19							760	Projection plaster	760	1,2
Plaster boards	20							4.897	Plaster boards	4.897	7,4
Gypsum blocks	21							261	Gypsum blocks	261	0,4
Self levelling floor screeds	22							1.401	Self levelling floor screeds	1.401	2,1
Other uses	23	329	6	165	27	9	41	5	Other uses	582	0,9
Reclamation, Restoration	24	18.964	2.686	0	178		180	1.645	Reclamation, Restoration	23.653	35,9
Temporary stockpile	25	3.507	128	0	40			1.581	Temporary stockpile	5.256	8,0
Disposal	26	1.207	613	0	314	11	215	84	Disposal	2.444	3,7
Total utilisation 1 - 23	27	**21.116**	**2.656**	**2.110**	**557**	**65**	**95**	**7.966**	**Total utilisation 1 - 23**	34.565	52,4
Utilisation rate in %	28	**47**	**44**	**100**	**51**	**86**	**19**	**71**	**Utilisation rate in %**		
Average utilisation rate in %	29							**52**	**Average utilisation rate in %**		
Total utilisation 1 - 24	30	**40.080**	**5.342**	**2.110**	**735**	**65**	**275**	**9.611**	**Total utilisation 1 - 24**	58.218	88,3
Utilisation rate in %	31	**89**	**88**	**100**	**67**	**86**	**56**	**85**	**Utilisation rate in %**		
Average utilisation rate in %	32							**89**	**Average utilisation rate in %**		
Reuse of stockpiled CCPs	33	**577**	**38**	**0**	**0**	**0**	**0**	**0**	Reuse of stockpiled CCPs	615	0,9
Total production 1 - 26	34	**44.794**	**6.083**	**2.110**	**1.089**	**76**	**490**	**11.276**	**Total production 1 - 26**	65.918	100,0

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