Coal Combustion Byproducts and Environmental Issues

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Springer

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IN GRATITUDE TO

My family, Maria, Mia, and Joseph Sajwan
Who've been through it all before

and

Dr. George Gobran
Swedish University of Agricultural Sciences, Uppsala, Sweden
For his major contribution in organizing the Seventh International Conference on the Biogeochemistry of Trace Elements, of which the present work is a part.

Preface

The massive accumulation of coal fly ash generated by electric power plants during fossil fuel combustion has become a major environmental health concern in the United States. Even though, stringent environmental regulations have been mandated by the Environmental Protection Agency through the Clean Air Act, Clean Water Act, and the Resource Conservation and Recovery Act, coal combustion products continue to pose serious environmental concerns due to our major reliance upon fossil fuels to meet ever increasing demands for energy production within the United States. The concentrations of trace elements in coal residues are extremely variable and depend upon the composition of the original coal, conditions experienced during combustion, the efficiency of emission control devices, storage and handling procedures, and overall climatic conditions.

The research papers carefully selected for publication within this book were originally presented as a part of the Seventh International Conference on the Biogeochemistry of Trace Elements held at the Swedish University of Agricultural Sciences, Uppsala, Sweden, from June 15–19, 2003. This conference offered the unique opportunity for international scientists and scholars to share the most current knowledge concerning the source, pathways, behavior, interactions, and effects of trace elements in soils, water, plants, and animals. Notably, this book also contains the invited research papers from leading scientists who have conducted significant research within the area of coal and coal combustion products. All of the research papers presented herein have been subjected to a peer review process. The editors have arranged the articles systematically by topic, beginning with introductory chapter entitled "Production of Coal Combustion Products and Their Potential Uses" followed by the sections on Environmental Impact of Coal Combustion Residues, Trace Elements in Fly Ashes, Transport and Leachability of Metals from Coal and Ash Piles, and the Use of Coal Ash as an Agricultural Soil Amendment.

This book addresses the major implications and critical issues surrounding coal combustion products and their impact upon the environment. It provides invaluable information particularly to scientists specializing and conducting research in coal and coal combustion products. Even so, it will certainly appeal beyond this initial target audience to serve a wide variety of scientists, scholars, academicians, and professionals within the fields of public health, engineering, energy industry, and a wide realm of environmental science related disciplines. It is our sincere endeavor that this volume of work will serve as a valuable resource tool for those engaged in fossil fuel energy research to benefit both our economy and environment to assure quality of life for future generations.

The editors wish to generously express their genuine appreciation and gratitude to all of the contributing authors for their professional insight and scientific contributions to this body of knowledge, along with their diligence and patience throughout the publication process.

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Contents

Part I Introduction

Part II Environmental Impact of Coal Combustion Residues

Part III Trace Elements in Flyashes

Part IV Transport and Leachability of Metals from Coal and Ash Piles

Part V Use of Coal Ash as Agriculture Soil Amendment

I

Introduction

1

Production of Coal Combustion Products and Their Potential Uses

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Abstract

Coal Combustion Products (CCPs) arise from the combustion of coal for energy, with fly ash (FA), bottom ash (BA) and flue-gas desulfurization residues (FGD) the most abundant. Our reliance on fossil fuel for energy is set to continue into the 21st century, and research into the environmental safety of beneficial re-use options, as well as novel re-use options, must continue. Since previous editions of collected CCP research[1], significant changes have been made to both the New Source Review and the Clean Air Act that directly impact CCP production figures. New techniques such as x-ray absorption spectroscopy are increasingly being used to reveal micron-scale elemental characteristics of CCPs, and aid our understanding of the distribution and chemical form of the metallic constituents. This chapter summarizes production and use covering the period 2001–2003, new trends in reuse applications and discusses new research on the environmental safety of CCP re-use.

Introduction

Coal Combustion Products (CCPs) predominantly consist of fly ash (FA), bottom ash (BA), boiler slag (BS) and flue gas desulfurization residue (FGD or synthetic gypsum). In 2003, approximately 110.4 million metric tons (Mt) of CCPs were produced[2], an increase of about 8% on the previous year. Continued disposal of material on this scale is no longer considered feasible, and beneficial re-use is essential. Re-use in various construction applications, by far the most common avenue, now stands at 38.1% of the total CCP produced, although clearly the scope of CCP re-use can be expanded in the future. The focus of this volume is to collate information that will promote environmentally safe CCP re-use and foster this expansion.

The environmental hazards associated with CCPs are posed by the content of potentially toxic trace metals and metalloids which readily leach out when they enter soils[3–5]. While the metal (loid) content of CCPs reflects that of the parent coal, the most commonly found elements of concern are boron (B)[6], molybdenum (Mo)[7,8], arsenic (As)[9–11] and Selenium (Se)[12,13]. A variety of other metals have also been reported in CCPs, such as nickel (Ni), cadmium (Cd), mercury (Hg) and lead (Pb)[12]. The waste from coal and lignite burning power stations can also be enriched with radionuclides, such as uranium (^{238}U), radon (^{226}Ra), lead (^{210}Pb), thorium (^{232}Th) and potassium (^{40}K)[14]. Lasting environmental damage has been attributed, at least in part, to Se from CCP release in to settling lagoons, because this metalloid has a tendency to be transferred through the food chain[15,16]. For instance, developmental abnormalities in the mouthparts of amphibians living in FA disposal ponds are thought to be due to elevated Se[17], and there is also evidence of direct toxicity[6,18,19].

It is the major elemental properties of FA and FGD residues, such as the presence of calcium (Ca), potassium (K), sodium (Na), and sulfur (S), that has led to their application to soil in the hope that they can be safely used as amendments for various soil problems. Adding FA and FGD to nutrient poor soils has been reported to increase short term crop yield[20], correct nutrient deficiencies[21], and change the physical structure to alleviate compaction[22]. Nonetheless, the presence of metals and metalloids in CCPs is a significant impediment to their agronomic use and it is now believed that CCP application to soil should only occur after rigorous elemental analysis of the CCP, the soil and the crop requirement[21].

In addition, the input of mercury (Hg) into the atmosphere and aquatic ecosystems from coal combustion is currently receiving attention. Coal combustion is one of the most significant sources of Hg input into the biosphere[12,23–26], and Hg is currently unregulated in the U.S. The recent fish consumption advisory by the U.S. Environmental Protection Agency[27] has raised the profile of atmospheric Hg, and has prompted the formulation of a regulatory framework to address monitoring and safe limits[28].

Current CCP re-use rates are at their highest ever, although there is much research needed to address the safe exploitation of CCPs. Our understanding of metal(loid) bioavailability is still developing, and is directly applicable to CCP disposal and re-use issues. This volume brings together key biogeochemical studies, using novel techniques to directly address long-term toxicity and bioavailability. They include analysis of varying types of vegetation cover on the physical mobility of potentially toxic metals and metalloids leaching from CCPs, novel sorbents for Hg removal from aqueous CCPs, soil sorption characteristics when CCPs are combined with organic waste materials such as sewage sludge, the influence of CCPs on plant growth and elemental composition and the long term bioavailability and speciation of elements of concern in the soil following CCP application.

Coal Combustion Products

Fly Ash

Fly ash is a fine powder made up of hollow ferroaluminosilicate particles enriched with Ca, K and Na[29–31], and is collected by mechanical filters or electrostatic precipitators from the flue gas during coal combustion. Typical FA particle sizes are within 0.1–1.0 μm, and electron microscopy has revealed particles with rough surfaces covered with smaller adhering spherical particles[31]. Composite FA[32] comprises several types of particles, including true hollow particles, smaller aggregations known as microspheres, and opaque magnetite spheres[33]. Trace elements, including potentially toxic metals and metalloids, condense upon the surface of FA particles during combustion[29,33,34]. Fly ash is pozzolanic in nature; a siliceous (or combination siliceous and aluminous) material that forms cementitious compounds when in the presence of moisture[35]. Using x-ray absorption fine structure spectroscopy (XAFS), Shoji *et al.*[11] showed S to be present predominantly as sulfate, with some thiophene and sulfite in larger particle size fractions (>2.5 μm in diameter). X-ray absorption near-edge structure spectroscopy (XANES) showed Cr to be present as the toxic Cr^{6+} valence state in 10–30% of western U.S. coal fly ashes, but only Cr^{3+} was detected within the eastern U.S. bituminous coal FA. They identified As in all FA as As^{5+}, although there were small spectral differences in As speciation between eastern and western coals, which were not clarified. Significant variation in Zn speciation was observed between different FA phases of eastern and western coals, with $ZnFe_2O_4$ the principal form in eastern coal fly ashes. Struis *et al.*[36] found that 60% of the Zn in raw FA was hydrozincite ($Zn_5(CO_3)_2(OH)_6$) and the remaining 40% was inert forms such as willemite (Zn_2SiO_4) and gahnite ($ZnAl_2O_4$). Pires and Querol[37] investigated the composition of Brazilian fly ashes using ICP-MS, ICP-AES, x-ray diffraction (XRD) and scanning electron microscopy, finding that in the leachable fraction the metal classification was B (40–50%)>Mo>Cu>Ge= lithium (Li) =Zn=As>, Ni, tin (Sb), thallium (Tl), U > barium (Ba), Cd, strontium (Sr), vanadium (V)(0.3–2%). Utilization of micron-scale spatial metal analysis techniques to determine metal(loid) species within coal and resultant combustion products[38–40] is a significant development within CCP research; it will allow engineers to adjust the combustion conditions for parent coal type so that toxic species of metal(loid)s do not predominate in the resultant FA, and will allow the potential environmental hazards as a result of FA use to be more fully understood, by understanding the bioavailability and distribution of metal(loid) species within the soil and biota.

Bottom Ash

Bottom ash is uncombusted material that settles to the bottom of the boiler; boiler slag is formed when operating temperatures exceed ash fusion temperature and the slag remains molten until drained from the bottom of the combustion chamber[41]. Bottom ash is granular and is similar to concrete sand[42]. Boiler slag is a shiny, black granular material that has abrasive properties, and is used as grit for snow and ice control, structural embankments, aggregate and as road base material (Table 1). The re-use potential of BA is influenced by its physical characteristics, such as grain-size distribution, staining potential and color[43], which are typically variable properties[44]. In the scientific literature, the BA derived from coal and municipal solid waste (MSW) are frequently confused; and some workers suggest that these materials have considerable similarities[26], or are similar in nature to FA. However, in the present volume, which focuses on the chemical properties of the CCPs, distinctions are made between those arising from coal, and those from the combustion of other solid materials.

Flue Gas Desulfurization Residues

The Clean Air Act Amendments of 1990 (CAAA '90 Public Law 101-549) placed stringent restrictions on the release of sulfur oxide (SO_x) from coal-fired power plants, with a two phase implementation plan, requiring electric utility companies to reduce SO_2 emissions, in an effort to reduce atmospheric pollution and acid rain[45]. The majority of utility companies previously used high-sulfur bituminous coal, which was thought to have significantly contributed to incidences of acid rain in North America. Following the instatement of the act, many companies switched to low-sulfur coal or fuel oil for partial and rapid compliance with regulations, although retrofitting power plants with flue-gas scrubbing systems was ultimately necessary to fully comply. This change effectively resulted in the creation of a new waste stream, termed flue-gas desulfurization residue (FGD).

Flue gas desulfurization residue is the alkaline material produced when SO_x is extracted from coal-fired power plant flue-gases[46,47]. There are several technologies currently in use, differentiated by the type of sorbent (e.g. lime or dolomitic lime) used and the method of SO_xextraction[48], however, FGD typically consists of calcium sulfite ($CaSO_3$), calcium sulfate ($CaSO_4$), unreacted sorbent, and FA particles. Other types of FGD can include magnesium, ammonium or sodium sulfites and sulfates.

TABLE 1. Production and use of category I (dry) and II (ponded) coal combustion products (CCPs) in the United States during the period of 2001–2003 (metric tons).

	2001			2002			2003		
	FA	BA	FGD	FA	BA	FGD	FA	BA	FGD
PRODUCED	*61,841,517*	*17,044,190*	*25,839,153*	*69,399,630*	*17,962,257*	*10,341,906*	*63,639,007*	*16,420,043*	*10,795,498*
		TOTAL	**104,724,860**		**TOTAL**	**97,703,792**		**TOTAL**	**90,854,548**
USED									
Cement/Concrete/Grout	11,213,022	707,170	443,170	11,411,600	368,548	54,981	11,126,774	270,505	59,505
Raw Feed for Clinker	937,470	147,408	27,946	1,739,699	531,138	275,609	2,744,170	447,936	381,057
Flowable Fill Material	729,107	6,749	0	412,785	0	0	123,938	18,440	0
Structural Fill/Embankments	2,911,617	1,052,572	172,330	3,811,067	1,856,594	0	4,986,747	2,216,439	0
Road Base etc.	931,516	553,257	35,474	695,976	1,335,640	0	447,684	1,032,468	0
Soil Modification/Stabilization	668,582	103,022	0	820,771	89,366	0	467,674	61,687	0
Mineral Filler in Ashphalt	96,651	7,423	1,181	93,597	87,287	0	47,725	0	0
Snow/Ice Control	0	774,212	0	2,400	696,223	0	1,749	620,112	0
Blasting Grit/Roofing Granules	0	36,368	0	56,213	124,697	0	0	38,650	0
Mining Applications	743,518	107,452	127,215	1,713,540	728,089	0	620,446	1,074,948	0
Wallboard	0	0	5,647,109	0	0	6,575,144	0	0	7,058,719
Waste Stabilization/Solidification	1,305,808	62,532	42,872	2,891,899	17,319	0	3,556,071	27,676	0
Agriculture	18,603	20,057	103,949	0	6,235	70,488	11,013	3,206	29,500
Aggregate	*na*	*na*	*na*	0	615,170	5,639	124,439	465,176	0
Miscellaneous	406,665	1,603,978	278,387	507767.6059	519,569	66,964	359381.2189	1204557.123	0
TOTAL	19,962,559	5,182,200	6,879,631	24,157,313	6,975,877	7,048,825	24,617,812	7,481,800	7,528,780
% USE	**32.3**	**30.4**	**26.6**	**34.8**	**38.8**	**68.2**	**38.7**	**45.6**	**69.7**

FGD residues are a rapidly changing group of CCPs; research is continually underway to increase scrubbing efficiency[49] resulting in a higher sulfur content of the final product. In common with other CCPs, the quality of the product also depends on the characteristics of the parent coal, the type of scrubbing system used (i.e., wet or dry[47]) and the handling and stabilization procedures. Stabilization usually takes the form of mixing the FGD with FA[20], and this often changes the re-use options of the stabilized material. Fly ash and additional quicklime are usually added to stabilize FGD filter cake prior to landfilling[50].

Production of Coal Combustion Byproducts

The American Coal Ash Association (ACAA) reports the production of 107 million metric tons (Mt) of CCPs in 2001[51]; an increase of 8.4% from the previous year. However, in 2003, CCP production was seven million Mt less than the previous year (Table 1)[2,52]. In February 2002, the U.S. Administration proposed significant changes to the New Source Review (NSR), and the Clean Air Act[53], known as the 'Clear Skies' initiative. The NSR is the section of the Clean Air Act which requires industrial organizations and factories to install modern pollution control devices (such as the flue-gas scrubbers which produce FGD) whenever they make changes in their activities or output that result in an increase in pollution. These changes have been perceived by environmental groups as a weakening of the NSR; widening pre-existing loopholes and allowing some facilities to bypass pollution control installment or upgrade, and in effect increase atmospheric pollution, rather than decrease it. These changes can be clearly seen in the figures reported by the ACAA in Table 1, which shows production and re-use of all classes (wet and dry) of FA, BA and FGD (million Mt)[2,51,52]. The production of FGD in particular has shown a dramatic fall; down by 60% in 2002 and 58% in 2003, despite the previous trend of increasing production concurrent with the total production of CCPs[48] and the increasing consumption of coal which has steadily increased from 961 million Mt in 2001 to 992 million Mt in 2003[54,55].

Potential Uses of Coal Combustion Products

The percentage of FA re-used in the United States has steadily increased from 7% in 1966 to 38.7% in 2003; an average increase of approximately 0.5 million Mt per year. On average the production of FA has increased approximately 4.5% per year between 1966 and the present, or approximately 1.3 million Mt a year[48]. Although re-use rates of FGD residues appear to have increased dramatically (Table 1), this is due to the changes in FGD production.

Fly Ash

Application of FA alone to agricultural land does not meet all crop requirements for essential nutrients such as N and P, but can enhance K, Ca, S, B, Mo levels, as well as other essential micronutrients such as Zn in the short term. Alkaline FA can be effective in neutralizing soil acidity[56], and when mixed with other coal refuse, has effectively controlled acid mine drainage[4]. The presence of potentially toxic metal(loids) in FA limit its potential use for land application[21]. Historically, the use of FA in agriculture has been based on its liming potential and supply of essential elements such as Ca, B, S, and Mo[57], although the metal(loid) enrichment has diverted FA research toward determining leaching potential and minimizing environmental risks of the materials. Many agricultural studies conclude that FA may only be of use in situations where the plants are tolerant to the salinity[58], metal contamination[59] and are nitrogen fixers[59].

The advantages and disadvantages of FA application to agricultural land are well documented, and includes metal(loid) enrichment and toxicity, plant nutrient imbalance such as P deficiency from soils treated with alkaline FA[60], and antagonistic interactions among elements due to of excessive Ca, K, and S[57,61,62]. Research into the agronomic use of CCPs continues, however, although many now focus on using CCPs in a specifically formulated mix with organic matter. For example, Schumann and Sumner[21] used nutrient availability data and linear programming to formulate mixtures of FA and biosolid (sewage sludge and animal manure) to successfully avoid FA-related issues such as B toxicity, excessive As levels and overliming, and derive environmentally safe FA formulations. In addition, Schlossberg *et al.*[63] adopted a similar technique of mixing FA with an organic waste product to successfully establish and manage bermudagrass sod production.

Successful, and perhaps more appropriate use of FA however, has been in the remediation of severely eroded lands[64,65], where FA is mixed with an organic waste material such as poultry litter, to supply nitrogen and phosphorus to plants. In terms of restoration, the combination of FA with other industrial by-products such as sewage sludge, can result in a high quality restoration material [22,66], and applied to eroding soils that require physical stabilization in addition to chemical improvement. Sajwan *et al.*[65] combined FA with sewage sludge (SS) and applied various mixture (ratios of SS:FA mixtures of 4:1, 4:2, 4:3, and 4:4) to *Sorghum vulgaris* var. Sudanese Hitche ("sorgrass") and found stimulating in biomass at rates of 50–100 tons acre-1 of all ratios of SS:FA mixtures.

Flue-Gas Desulfurization Residues

Flue-gas desulfurization residue is increasingly being used in the production of wallboard material, with over 7 million Mt re-used in 2003, amounting to 93% of the FGD re-used for that year. Due to their alkaline nature, FGD residues have potential value as neutralizing agents[50,67] for agricultural soils which suffer from excessive acidity[68], or for the alleviation of excessive sodicity [69,70]. In comparison with FA, considerably more FGD residue is used in agricultural applications; in 2001, 103,949 Mt of FGD was used in agricultural applications compared to 18,603 Mt FA. The use of FGD in agriculture, however, has steadily decreased during the 2001–2003 period; from 0.1 to 0.03 million Mt.

New research into the agronomic application of FGD has similarly applied the material in a mixture with an organic waste material, such as dairy, swine or broiler litter manures; Zhang *et al.*[71] found that co-application of FGD with organic waste reduced the availability of P, from the water-soluble to the bicarbonate extractable, which retained its availability for plant uptake, while reducing the likelihood of environmental losses through leaching. Stout *et al.*[72,73] also used FGD to reduce the bioavailability of P in high-P soils, reducing surface P runoff effectively for a period of several years. This reduction can be attributed to the amount of Ca supplied from both the FGD and organic amendment. High-P soils pose environmental problems from P run-off, which damages water quality by causing algal blooms through eutrophication.

Using an FGD residue without co-application of an organic waste product, Clark and Baligar[74,75] compared its effect on growth[75] and mineral composition[74] of plants grown on an acidic soils (pH 4) to that $CaCO_3$, $CaSO_4$ and $CaSO_3$. They reported growth enhancement of *Medicago sativa*, *Trifolium repens* and *Festuca arundinacea* as a result of FGD addition, and in particular when magnesium (Mg) was co-applied. In this study, only FGD materials high in B and lower in $CaSO_3$ were found to be detrimental to plant growth, and overall increased the growth responses of plants in an otherwise infertile acidic soil. Sakai *et al.*[76] used FGD residues to restore pH balance, without a detectable increase in the metal(loid) concentration (in comparison with FGD-free controls) of the plant material grown on amended soil. In this case, their product was a combination of wet and semi-dry desulfurization.

Conclusion

Although the beneficial re-use of CCPs such as FA and FGD have been impeded in the past by the presence of potentially toxic metal(loids), research is now moving ahead to better understand the distribution and chemical speciation of metal(loids) in parent coals, combustion products and environmental matrices using analytical techniques which have a high resolution, and capabilities for micron-scale spatial analysis. The future of CCP research into finding new and safer re-use applications depends on the information these techniques can provide. Agronomic use of these materials has been advanced a great deal in recent years by incorporation with organic wastes, and by using these more balanced mixtures to fertilize non-food source crops.

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II

Environmental Impact of Coal Combustion Residues

2

Coal and Coal Combustion Products: Prospects for Future and Environmental Issues

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Abstract

At the background of the overview of prospects for coal-based electricity production, the present and projected status and trends of coal combustion products (CCP) management was discussed. According to the latest projections, coal-based electricity share will remain the largest in world's energy balance and is set to double in the first three decades of 21st century. The majority of this growth is forecasted for developing Asian economies, but also for some developed countries not bound by the Kyoto Protocol (USA, Australia). Coal combustion products (CCP) are one of the most abundant high-volume waste materials worldwide that are partially being reused in a number of commercially and environmentally proven applications—both traditional and advancing, some are in the stage of extensive studies. Despite of numerous beneficial properties, their reuse rates are still far from being satisfactory; also statistics on CCP generation is fragmentary. There is also different approach to CCP in terms of its legal definition: ACAA (American Coal Ash Association) considers CCP as a "product" and a mineral commodity equivalent to natural materials; also some other countries—large coal producers and CCP generators adopted this approach (e.g. India). European legislation treats CCP as a waste, though it does not mean that the material is a waste in all circumstances, but only where the definition of waste is met. In view of anticipated CCP generation and growth in the future, a crucial task is to identify and remove obstacles and barriers in the way of increasing CCP utilization, along with developing new application fields. Based on the analysis of regulatory instruments and enforcement procedures compared to the utilization effects, it has been stated that the pro-environmental and pro-recovery CCP recycling policy must be based on the term "waste" and the "polluter pays" principle. The rationale of this statement is that the legal definition in no case should absolve the producer or the holder from the responsibility for the generated waste until it is transformed into an environmentally safe product. The exemplified practice confirms that the efficient regulatory and enforcement mechanisms should comprise a well-balanced system of precepts, prohibitions and charges for CCP disposal (fees, penalties) that would encourage power plants as waste generators to support financially the environmentally safe utilization of CCP by the waste reuse industry on a cost-benefit basis, in order to reduce charges for the disposal and to assure competitiveness of these products in the market.

1. Introduction

At the beginning of the third Millennium coal remains the primary fuel used in generation electricity worldwide—in 2002 coal generated 39.0% of the world's electricity. Total global hard coal production in 2003 has been estimated for 4037.5 Mt and increased 3.3% over the previous year (in 2002 it accounted for 3909.9 Mt). In the past 25 years it showed over 46% growth.

Coal domination in electricity generation is based on coal abundant and widely dispersed resources compared with oil and gas that is also a matter of energy security and minimizes the risk of energy supply disruption. Coal deposits occur in about 70 countries. At present extraction level, the proven coal reserves are estimated to last over 190 years. In contrast, oil and gas reserves are estimated to last for 41 and 67 years, respectively; besides, over 69% of oil and 67% of gas reserves are concentrated in the Middle East and Russia, which makes these resources highly insecure and endangered by supply disruption[1]. This strongly justify use coal incineration in power plants for electricity generation. This process causes formation of large amounts of coal combustion residues that are environmentally problematic, but at the same time display a number of beneficial properties, that might make these materials recyclable in a wide number of efficient and cost-effective applications. Up to now, though, not all the beneficial properties of these materials are well recognized and adequately utilized. At the same time, it should be taken into consideration that these materials are not environmentally safe and might adversely affect the ambient environment, if improperly handled. This chapter is focused on discussion of beneficial and adverse properties of fly ash (FA) that is the most abundant coal incineration residue in a context of potential applications, as well as on regulatory aspects that might optimize its management.

2. Coal as A Source of Electricity

The countries that are major producers are also major consumers of hard coal for electricity generation (Table 1). A number of countries use imported coal as a significant component in a balanced energy mix (Japan, Republic of Korea, Chinese Taipei, Germany and UK). The major steam coal exporters are Australia, PR China, Indonesia, S. Africa, and in lesser amounts (<50 Mt) Russia and Colombia; USA and Poland exported below 20 Mt.

Data presented in Table 1 reflect both temporary fluctuations in coal generation, but also permanent trends connected with growth of electrification rate, particularly strong in Asian/Pacific region. A dynamic increase of coal generation is observed in China, Indonesia and India; The EU and OECD countries show stagnation or even decreasing trend, which greatly depends on the implementation of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC) that sets mandatory targets on greenhouse gas (GHG) emissions for the parties that ratified the Protocol. The Protocol was first negotiated at COP3 in Japan in 1997 and will finally enter into force on 16 February 2005, when it will be legally binding on its 128 parties, 30 of whom are industrialized EU and OECD countries with emissions targets. Refusal to ratify Protocol by the USA that is the world's largest emitter and Australia, as well as the absence of targets for developing countries reduces Kyoto Protocol implementation to countries responsible for only 32% of global emissions[3]. It should be though noted that the US declared the alternative "voluntary targets" program that rely on recommendations outlined by the Council of Economic Advisors.[4]

According to the latest edition of the IEA—International Energy Agency's World Energy Outlook 2004[5,6], coal-based electricity share will remain the largest in world's energy balance. Between 2002 and 2030, coal demand is projected to grow annually by 1.4% and by 2030 will reach the amount of over 7 billion tons that is almost 50% higher than at present. In 2030 coal will meet 22% of energy needs, similarly to the present level (23%). Asian countries will show continuous increase in demand for coal; China and India are estimated to participate for 68% in this growth.

Coal-based electricity is set to double in the first three decades of 21st century, from 16,074 TWh in 2002 to 31,657 TWh in 2030 and will continue to play a key role in world electricity generation. Despite high nominal growth of coal-based electricity generation, its share in total electricity generation (in %) will remain in 2003 close to the current level showing only slight decrease from 39 to 38%. The strongest increase of coal-based electricity gross generation is projected in developing countries, in particular in China, where a quarter of the total growth will occur[5,6]. By 2030 developing countries will reach almost half of total energy demand. Though the majority of this growth is forecasted for developing Asian economies (China, ASEAN, India), also in some developed countries not bound by the Kyoto Protocol (USA, Australia), increasing competition will favour low cost coal-based electricity generation[7]. The EU and OECD countries with emission targets that ratified Kyoto protocol are tending to reduce share of this kind of energy, mainly by increasing gas use and developing alternative renewable electricity sources (Table 2). Nevertheless, having in mind almost double increase of electricity generation, similar or even reduced share of coal as a source of electricity, means significant nominal increase of incinerated coal.

In the cited outlook, IEA for the first time has used an Energy Development Index that is a composite measure reflecting commercial energy consumption per capita, share of commercial energy in total energy use and share of population with

TABLE 1. Coal production and major producers in 2001 (after WCI—World Coal Institute, 2004[1,2]).

	Production					
	Mt		% of Total		Coal-based electricity % of total	
Hard coal	2002	2003e	2002	2003e	2002p	2003p
World	**3837.0***	**4037.5**	**100**	**100**	**38.7**	**39.0**
China	1326.0	1502.4	34.5	37.2	76.2 (2001 data)	77.5
USA	916.7	891.9	23.9	22.1	49.9	52.2
India	333.7	340.4	8.7	8.4	78.3 (2001 data)	70.1
Australia	276.0	274.1	7.2	6.8	76.9	76.9
S. Africa	223.0	239.3	5.8	5.9	93.0	92.2 (2002 data)
Russia	163.6	188.4	3.5	4.7		
Indonesia	101.2	120.1	2.6	3.0		39.7
Poland	102.6	100.4	2.7	2.5	94.8	94.7
Kazakhstan	70.6	74.8	1.8	1.9		69.9 (2002 data)
Ukraine	82.9	56.8	2.2	1.4		

*Data from 2003 edition of Coal Facts; after 2004 edition the world coal production in 2002 was 3909.9 Mt; e—estimated; p—preliminary;

TABLE 2. Projections of world's electricity generation trends over the period of 2002–2030[6,7]

	Share in electricity generation (%)					
	OECD		Transition economics		Developing countries	
Electricity source	2002	2030	2002	2030	2002	2030
Coal	**38**	**33**	**22**	**16**	**45**	**47**
Oil	6	2	4	2	12	5
Gas	18	29	37	54	17	26
Nuclear	23	15	18	11	2	3
Hydro	13	11	19	15	23	16
Other renewables*	3	10	0	2	1	3

*Solar, wind, biomass, waste incineration etc

access to electricity. According to IEA projection, electrification rates in developed countries will increase from 66% in 2002 to 78% in 2030; the total number of people without electricity will account for 1.4 billions in 2030, while electrification rates in developing countries vary significantly—from over 98% in China to an average 23% in Sub-Saharan Africa, where there is a number of countries with electrification rate <5% (Figure 1).

This shows that in the future (after 2030) further increase of coal use as a source of energy can be anticipated unless novel energy sources are developed by that time.

3. Coal Combustion Products (CCP) Generation, Use and Disposal

Coal combustion products (CCP) are one of the most abundant high-volume waste materials worldwide. Their proportion in the total waste stream highly depends upon the role of coal in power production, and is as a rule the highest in coal producing countries. Despite the omnipresence of CCP, the statistical data concerning its generation and managing in the different countries of the world are fragmentary[9].

American Coal Ash Association (ACAA) regularly publishes in its web site CCP generation and use annual surveys based on a representative sampling of several hundreds of coal-fueled power plants in the U.S.[10,11,12] (e.g. 2002 data are estimates based on a sampling survey of nearly 600 utilities)[10]. These data show distinct increase of CCP generation and use in the last eight years covered by ACAA reports (1996–2003) (Table 3). The last available data for 2003 estimate total CCB amount for 110.44 Mt. that means an extrapolated increase of about 19.5% compared to 1996. It should be noted that total CCP generation can vary distinctly from tear to year depending on the amount and ash content of coal burned, though the general trend is distinctly increasing since 1996[10,11,12]. Its category structure in the last reported years 1996–2003 remains practically stable and consists predominantly of fly ash (ca. 58%), bottom ash (ca.15%), boiler slag (1.5–2.5%), FGD solids (23–25%) and FBC Ash (<1%, 0.7% in 2003), fly as being invariably the largest by mass component of CCP. Though in 1966–1996, along with growth of CCP generation, also its use was growing, an overall CCP utilization for this period remained at almost unchanged level at around 25%. An observed significant and regular upward trend of overall CCP utilization rate at 13.4% in 1996–2003 in parallel with an increase of CCP generation evidences an unquestionable success of utilization industry in the field of coal combustion products usage.

The growth of CCP use under the conditions of a slow economy and a relatively flat construction industry ACAA tentatively explains by possible local material/mineral

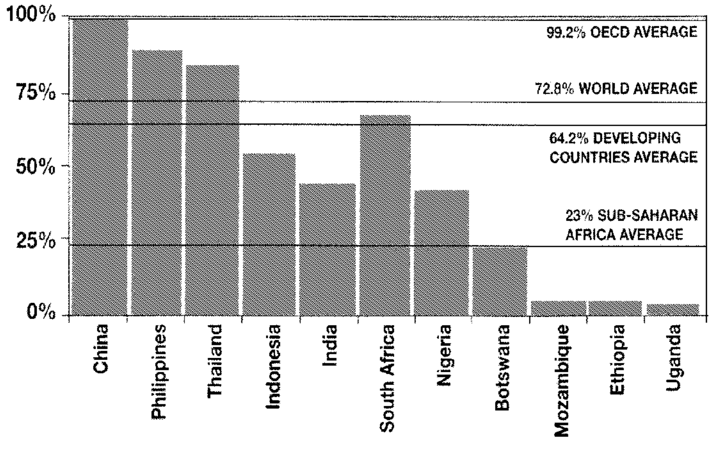

FIGURE 1. Electrification rates for selected developing world countries (after World Energy Outlook, IEA)[8].