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COAL ASH MANAGEMENT - RETROSPECTIVE AND PERSPECTIVE

Coal - this inconspicuous mineral has accompanied mankind throughout its existence – from ancient times when people were but an idea in some higher entity's mind up till now. What is more it is surely going to be a part of our lives much farther into the future [12]. This black "rock" provided our ancestors with heat and electricity and even nowadays it is still one of main energetic resources known to us. Burning this fossil fuel satisfies 30, 3% of world's total energy consumption as well as contributes to 40, 2% of world's electricity demand.

Burning coal in order to produce heat and electricity runs in boilers especially designed for this purpose. The process of burning coal generates residues often referred to as "coal ashes"[2]. These Coal Combustion By-Products consist of *fly ash, bottom ash and slag* [12]. Coal ash is mainly made up of minerals and other non-combustible natural materials mixed in with the coal when it is mined from the earth. In some cases, the ash might include nitrogen or sulfur compounds captured by air emissions-control equipment, these air emissions compounds may be collected and managed separately or co-mingled with coal ash. Depending on the plant and process, these ashes have different but manageable properties [13].

Miscellaneous physical and chemical characteristics of Coal Combustion Byproducts, negative social approach towards "secondary" materials emerging usually from peoples ignorance and lobbing from producers of traditional materials such as cement and lime makes management of CCP'S as well as the process of implementing certain solutions to introduce them to market economies an interesting and complex problem [9]. This lecture is about to bring the issue of Coal Combustion Byproducts vertically integrated development to the fore.

1. Management models

Ash management can be studied through a variety of different management perspectives, each and every single one of them valid depending on what one wishes to gain throughout the process. For the purpose of this lecture we shall examine two significantly differing approaches towards ash management – scientific as well as practical

1.1. *Science perspective*

Scientific approach towards the issue of ash management tends to focus on the aspects of technology needed to manage Coal Combustion By-products (CCP'S) as well as productivity processes leaving more mundane aspects like profitability or economic justification of the scientific aspect to others. Although it may seem that science when it comes to ash management is detached from reality, there is nothing farther from the truth. Without scientific basis (technology) for ash economic development as well as periodic lab tests to check and maintain quality of coal ash and production processes, effective management of ash would not be possible [9]. Furthermore science in coal ash management through empirical studies of microeconomic environment helps in identifying potential chances.Scientific perspective aims especially to increase productivity and efficiency eliminating waste by turning individual skill sets into processes and procedures.

1.2. *Practice perspective*

Practical approach focuses especially on turning technology into profit by selling products based on coal ash. This perspective includes most aspects of vertically integrated ash management – from transportation of raw ash to production facilities up to selling final product to customers. By using scientific achievements of R&D departments practical management of coal ash is progressively improving due to development of new products [10], market advantages gained with new production techniques etc. Practical approach towards ash management uses best available techniques on the market to achieve measurable outcome – as high a profit as possible.

2. Reasons for ash usage

2.1 Main reasons

There are countless reasons for using coal ash. We can divide them into certain groups depending on the advantages that using ash-based products instead of traditional techniques provides and on the other hand, requirements and regulations that have to be fulfilled while

using coal ash [4]. Main reasons for ash usage can be of economic, social, environmental and technical nature.

Coal combustion by-products (CCP'S) have a wide variety of uses depending on physicochemical properties of indigenous coal burned [13]. Therefore CCP'S are utilised in the building material industry, geotechnical engineering, road constructionand underground works including geotechnical injections [1]. What is more ash can be used for reclamation and restoration purposes in open-cast mining as well as other heavily degraded industrial areas. Ash is a secondary material that can successfully replace traditional substances widely used so it has to meet certain technical and environmental standards and regulations [4][5][11][13].

2.2 Environmental factors

Environmental factors can also be divided into some logical aspects, for the purpose of our lecture we are going to focus on benefits from using coal ash and certain requirements essential to fulfil while managing coal ash [5][11]. Nowadays monitoring aquatic environment in close proximity to ash landfills is usually limited to taking measures and doing various lab tests. Storage of coal ash on ash landfills can be potentially threatening to the aquatic environment. However years of tests conducted on many different ash landfills have verified that there is no negative impact on aquatic environment. In the vicinity of "moist" ash landfills there tends to be a minor, local increase in mineralization of surface as well as ground waters [3]. Impact on the local aquatic environment is limited to the immediate vicinity of the given landfill. Increase in content of trace elements and substances especially dangerous for aquatic environment hasn't been found.

Meeting international as well as local regulations and requirements is vital to maintain top-down control in ash management and its impact on the environment [5]. That is why periodic control checks are indispensable in order to maintain quality of the final CCP based product as well as to verify both environmental and social approach towards CCP development [3].

- ***Carbon footprint***

One of the main environmental benefits from using coal-ash in different building materials and surely the most vital is a lesser carbon footprint that ash-based materials leave in comparison to Portland-cement based materials [2]. Skyscrapers, highways, most residential areas along with massive water retaining structures are mostly built with concrete produced using Portland-cement as a binder [8].This is far from environmentally friendly. Production of one tonne of Portland cement clinker emits about one tonne of CO2 into the atmosphere.

Portland cement production stands at nearly 2,5 billion tonnes/year thus emitting about two billion tonnes of CO2 which constitutes to about 7% of total yearly CO2 emissions worldwide. According to *P.K. Mehta* and *M. Wallace* 50% of Portland-cement clinker in concrete blends can be successfully replaced with fly ash as a binder, thus reducing CO2 emissions substantially [6]. Portland-cementclinker production process emits 10 times the amount of CO2 that fly ash does.

- ***Secondary first***

Economic development of coal ash in road construction helps in preservation of natural landscapes. Coal ash based products are produced using secondary materials therefore the more ash we use the less natural resources we shall need. Using secondary material in the production process makes production less costly and our landscape undisturbed with numerous excavation sites. Due to increasing ash storage fees power plants, main producers of coal ash, grow more and more interested in managing their ashes – making ash usage even more rewarding and less costly, especially in comparison with substitute technologies – Portland-cement and lime usage [1][7].

- ***Meeting requirements***

Coal ash development is an environmentally friendly process [12], especially in comparison to production of substitute technologies - Portland-cement or lime [2]. Unfortunately to be able to use coal ash to produce different materials there are numerous requirements to be met [4]. Natural minerals just like fly and bottom ash contain a certain amount of trace elements. For some of the trace elements, concentrations may even be higher in fly ash than in natural minerals or products used for a certain application. To prevent negative impact on the environment, regulations have been developed by the EU member states for different uses of industrial by-products [3][11]. As a result of the environmental regulations no negative impact on the environment or on human health by the utilisation of CCP's has been reported so far – the regulations have been met.

- ***European regulations***

Government policies and therefore national legislation are influencing management of coal combustion by-products and are essentially important to power producing entities [5]. Due to various benefits – technical, environmental, economic as well as social the total use of CCPs has developed over the last years [4]. Based on national experience in coal ash management scientific along with practical environments came to a conclusion -environmental testing has to be considered transnationally [4][5]. With the latest generation of harmonized European product standards, environmental aspects are being addressed as well [5]. The EU Waste

Framework Directive, or Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste concludes years of experience with waste management in European Member state countries.

In order to be able to produce CCP's (waste) an economic entity needs a permit. In power and thermal power stations permits are usually obtained within a ruling on an integrated permit. Those CCP producers tend to transfer CCP (waste) utilization on smaller, highly specialized entities holding a permit to utilize a specific type of CCP (waste). Along with CCP (waste) transfer the final entity holds responsibility for proper CCP utilization turning CCP (waste) into CCP (product).

The ongoing EU Project on "waste" legislation that is about to be a transpose of the EU Waste Framework Directive 2008/98/EC is going to introduce the concept of by-products. Certain types of waste are going to be treated as waste no more if through salvaging therein recycling they meet certain conditions to be classified as a by-product.

2.3 Technical factors

There are many different technical factors that have to be taken into account while developing coal ash into final product. Taking those factors into consideration can make coal ash based products highly competitive in comparison with traditional substitutes such as cement and lime.

Production process of coal ash products used in road, rail as well as geotechnics and mining is substantially more cost-effective than production of substitutes. Process is limited to only a few energy efficient stages that unlike cement or lime take place in ordinary temperatures [2].

Simplified production offering products of corresponding technical parameters make coal ash development an economical solution to compete with traditional products using natural resources and irreversibly changing natural landscape [1].

In order to develop coal ash into product an economic entity has to make an investment in a salvaging plant where coal ash is processed into final product. These investments are essential but nevertheless financial outlays in comparison to building a cement production facility are substantially lower. Various sizes as well as production efficiencies of coal ash salvaging plants available for purchase on the market make production a flexible process with an option for mobility making it possible to compete on local specialised markets.

Many different options to finance initial investments like leasing or investment credits, not to mention EU subsidies help economic entities limit the initial impact on financial fluency. The

amounts of financial resources needed to purchase a salvaging plant are substantially lower due to its smaller size and fewer production stages.

One of the main technical limitations of coal ash based production is the geographical dependency on coal ash. Transportation of coal-ash is cost effective only to a certain, very limited distance. For consolation cement and lime producers are limited to resourceful areas as well.

Another problematic factor concerning production of coal ash-based products are fluctuating parameters of coal ash that force R&D departments to render periodic, sometimes even daily checks on quality of CCP produced by the power plant. As a result, production process has to be as flexible as possible, coping on a constant basis with differing, but predictable to some extent, parameters of basic production material [7].

2.4 Economy factors

Economy factors concerning CCP development are inseparably intertwined with technical factors of CCP utilisation. The economical side of CCP development is an outcome of technical conditions governing the process. For the purpose of this paper we shall focus on economic range of CCP development along with financial aspects globally.

Geographical range for economic development of CCP's is limited mainly by resource availability. Where there is coal available and burned for electricity and heat there is coal ash to be processed. The more coal extracted and burned the more attractive a market to invest in seems to be. Another important factor concerning geographical area of CCP's development is the collocation of coal ash producers – evenly located net of power plants makes CCP's development more profitable.

Apart from resource constrains it is highly beneficial when there is a regional plan for infrastructure development present on a given market, detailed plan for the nearest future and a strategic document for a farther perspective. Such a document makes it substantially easier to anticipate and implement the investment process and makes it possible to minimize potential risks and maximise potential profits.

Attractive markets for coal ash development are those of developing countries, especially the ones starting high-volume investments in transportation infrastructure. Far East due to substantial coal resources and reserves, proceeding development in infrastructure as well as flood preservation – monsoon threatened areas - has great potential in coal ash development. Another potentially rewarding market for coal ash utilisations is South America.

Up till now subsidies for fossil fuel producers have substantially outweighed those for secondary and renewable. However future perspective for coal ash management presents in bright colours due to oncoming possibilities. Global policies gradually shift from subsidising traditional technologies towards innovative and ecological ones. Benefits through trade of emission rights seems to be another vital chance for products based on coal ash which are energy efficient, leaving a trace of carbon footprint in comparison with cement and lime production.

2.5 Social factors

Coal ash economic development, even though perfectly safe and environmentally friendly, has a social reception which is far from positive. Serious financial outlays are allocated for informational campaigns, conferences as well as expert panels on popularization of CCP's usage in infrastructural investments and especially to raise social awareness when it comes to environmental impact of CCP's utilisation which is beneficial rather than destructive [7].

Environmentally friendly approach

Increased usage of coal ash-based products replacing cement, thus decreasing the amount of cement produced and energy consuming clinker used in the production process can effectively decrease the amount of carbon dioxide emitted into the atmosphere. Carbon footprint of coal ash based products is more than ten times lesser than in cement [2].

By using secondary materials strained landscape can finally catch a breath, no more predatory economy holding no esteem for future generations and their comfort and wellness of living. Recycling "waste" when processing CCP's into final product limits the amount of land needed for ash storage, those areas can be used for other purposes [1].

Mineral properties of coal-ash make it a great solution to re-cultivate industrially polluted lands, introducing them to future investments.

Various environmental factors concerning coal-ash based products have a beneficial impact on local societies [12]. Using CCP's corresponds with EU's environmental, social and economic policies and sustainable development strategies [1]. Although CCP's utilization is compatible with global development policies, sometimes on local, national level entities developing CCP's lack governmental financial support and assistance in implementing energy efficient and environmentally friendly solutions. Few innovative policies are economically viable without external support due to massive competition (cement and lime) and lobbing towards traditional techniques, thus undermining investor's confidence in financing innovative projects.

3. Innovation as a success driven aspect of coal ash management

3.1. Traditional approach towards coal ash management – 3 steps

Traditional approach when it comes to coal ash management derives from scientific interest in various properties of coal-ash through costly research and laboratory testing process up to delivering a product to the market. This is a classic example of implementing the push/pull management model. Historically speaking scientific breakthrough had been the most important motor for developing new coal-ash based products. Traditional approach towards coal ash management can be characterized in 3 different stages.

- ***1st stage:ENGINEERS' INSTINCT***
  – exciting technical properties of CCP and profound knowledge of them as a starting point
- ***2nd stage:GOOD HUSBANDRY***
  – a drive to overcome the barriers imposed by the stigma of waste
- ***3rd stage:ENTREPRENEURIAL INSTINCT***
  – a mature product approach based on the sound understanding of markets

3.2. Product oriented approach

With progressing experience in CCP's utilization tendency shifts toward product orientation based on market research and thorough analysis as well as global and local demand for certain solutions. Products have a limited lifecycle according to current and foreseeable demand and management focuses on complementary efforts in product development (demand based) and product marketing at each and every stage of the product's lifecycle.

3.3. Push and Pull model – benefits and risks

Adopting Push/Pull management model in CCP's utilization is viable due to complementing scientific and marketing factors. These factors if managed properly have the most significant impact on entities condition and market competitiveness.

Traditional approach focused mainly on scientific aspects of CCP's management adopting a dominant role of the push management strategy. Costly scientific and technical advances with an irreplaceable role of R&D departments in isolation from economic reality has turned out to be a nail to a coffin for many coal-ash developing companies including FLUBET and GREENBET Jaworzno in Poland. The former invested in technology of disintegrating particles making ash

binding properties even better but without proper economic analysis the project has turned out to be a fiasco burying the company along with it. The latter had an analogical situation investing in ash grinding techniques – costly process without prognosis on demand for the final, expensive product.

To sum up, scientific and technical development along with everyday tasks of R&D departments like ash quality control and even recognition of attractive properties of coal ash materials globally, like trace carbon footprint [2], is important in CCP's management but without a significant role of pulling elements is not economically viable.

Modern and innovative approach towards CCP's management tends to focus on aspects of pull management model where market analysis is the basis for scientific development and profitability of developed products is the most important. Current global policies provide some demand for CCP's management. One of the main aspects pulling market demand towards CCP's management are progressively increasing charges for ash storage [7], forcing power and heat producers to offer better conditions for entities receiving ash for utilization. Another important aspect is social dissention for ash landfills [12]. Furthermore construction market is in desperate need for cheaper materials in the face of global economic crisis pulling towards coal-ash based products.

4. Polish experience and approach

Burning coal in thermal power plants constitutes to about 95% of Polish electricity production and over 60% of heat generation. Coal is definitely a strategic resource to Poland especially when it comes to energy security issues. Poland produces over 139 million tons of coal (both hard and lignite) yearly which ranks it on the 9th place of world's coal producers list. Mining local coal satisfies most of national demand; more coal is imported (over 15 million tons – 2011) than exported (under 10 million tons - 2011). Due to coal's substantial contribution to energy production in Poland, coal-ash management is a serious issue. Statistics concerning coal-ash production and utilization in Poland for the period of 2008-2011 are provided below.

Tab.1. Coal-ash production in Poland 2008-2011

CCP	Year	Amountproduced, *1000Mg/year		
		LIGNITE	COAL	SUM
Flyash	**2008**	2 497,40	5 859,90	**8 357,30**
	2009	2 402,30	5 293,50	**7 695,80**
	2010	2 705,30	5 606,50	**8 311,80**
	2011	2 753,80	6 078,50	**8 832,30**
other CCP'S	**2008**	4 555,40	4 026,80	**8 582,20**
	2009	5 632,00	4 318,00	**9 950,00**
	2010	6 007,30	5 284,40	**11 291,70**
	2011	6 114,80	5 729,30	**11 844,10**

Developed on the basis of: „Raport o potencjalnych skutkach wprowadzenia przez KE zmiany tzw. „List of waste" a w konsekwencji zmiany w klasyfikacji odpadów z grupy 10 wg katalogu odpadów na odpady niebezpieczne- Etap I"

Fundamental conclusion that arises from the statistics above is that the amount of coal-ash produced by Polish energetic companies is steadily rising and the tendency due to increasing amounts of coal as well as governmental investments to increase power capacity should be maintained. Data provided below describes coal-ash utilization in Poland through 2008-2011.

Tab.2. Coal-ash utilization in Poland 2008-2011

CCP	Year	Amountutilized, *1000Mg/year						
		Construction Materials	Cement	Road Construction	Mining	Other	SUM	%
Flyash	**2008**	1 391,50	754,90	273,60	1 749,20	3 866,10	**8 035,30**	**96,15**
	2009	1 886,40	1 141,70	275,40	1 307,80	801,40	**5 412,70**	**70,33**
	2010	1 706,10	968,90	292,50	1 496,40	1 107,00	**5 570,90**	**67,02**
	2011	1 837,80	1 042,60	308,00	1 585,70	1 176,60	**5 950,70**	**67,37**
other CCP'S	**2008**	1 705,90	332,60	375,30	297,00	1 329,10	**4 039,90**	**47,07**
	2009	2 583,10	273,00	762,70	406,80	1 298,90	**5 324,50**	**53,51**
	2010	2 600,30	252,30	1 423,50	292,70	1 297,00	**5 865,80**	**51,95**
	2011	2 723,20	263,60	1 515,20	315,50	1 367,10	**6 184,60**	**52,22**

Developed on the basis of: „Raport o potencjalnych skutkach wprowadzenia przez KE zmiany tzw. „List of waste" a w konsekwencji zmiany w klasyfikacji odpadów z grupy 10 wg katalogu odpadów na odpady niebezpieczne- Etap I

With increasing amount of coal-ash produced, problems with utilization of surplus material arise. CCP developing companies in cooperation with energetic companies burdened with increasing storage fees are forced to seek new markets for coal-ash utilization. This particular situation requires financial outlays for complex market analysis as well as research and development of new products. On the other hand it is an opportunity for pioneering solutions that can bring significantly better financial outcome.

Perennial experience in CCP's utilization in Poland has paved the road to many different economic applications as well as future directions for development such as:

- **CCP's utilization as concrete additives** – increase in the amount of CCP's utilized this way - prognosis
- **Cellular concrete** – no predicted increase in CCP intake
- **Cement additives –**no important changes projected
- **Ceramics –** without any significant changes in CCP utilisation possibilities
- **Transportation construction –** important direction for CCP usage both at present and in the future
- **Aggregates –** small increase predicted
- **Underground mining –** no change projected
- **Ground injections -** this particular direction of application should be treated locally as an outcome of local demand, however amount of CCP's used can be substantial
- **Mineral-organic composites –** great potential for further development in this area

Case Study: EKOTECH Group – *Potential commercial partner*

EKOTECH Ltd was founded in 1992 and from then on the company's mission has been to utilize as many CCP as possible. First years of economic activity through cooperation with thermal power plant "Dolna Odra" focused on local market of north-western Poland. Proceeding years brought meaningful change – amplification of conducted actions resulted in coverage of national CCP utilization market. Product oriented approach cultivated in companies' management structures helped in creating a variety of competitive products used in transportation construction, geo-engineering projects as well as macrolevelling grounds and landfills.

EKOTECH's success on the Polish market wouldn't be possible without research-based, product oriented approach supported by thorough market analysis along with many complementary services as well as benchmarking partners. Adopting ISO quality standards made the companies' offer even better,warranting product's and service's quality.

Product oriented approach with complementary vertically integrated techniques and services

- **CCP based binding product –** complete product used as a substitute for traditional techniques like lime and cement for ground drainage, improvement, conditioning or stabilization
- **Complementary techniques –** construction techniques used by project contractors complementing EKOTECH's technology, transmission grids for coal ash transfer from ash producer to ash developer, technical know-how arising from specific properties of offered products together with production techniques
- **Vertical integration of management process –** precise integration of production processes along with logistics and strategic management at every stage – from the beginning of production up to delivering final product to customer's satisfaction
- **Implementation –** adapting best available techniques available on market supported by years of experience in aspects of production and logistics; periodic quality checks based upon research to ensure client's satisfaction; creating formal product documentation adjusted to local and global legislation; flexible market adaptation – national and international
- **Coaching and conference –** organizing training seminars and conferences for the purpose of popularizing usage of secondary materials in construction market, informative activity concerning technology used, raising competence of training participants for building techniques using CCP

- **Technical support –** individual technical approach to each and every project, professional technical support for contractors *in situ*
- **Standards and procedures –** standardization of vertically and horizontally integrated processes in the company, procedural approach towards ongoing tasks, adaptation of current actions to norms and standards of construction markets – local as well as national, international

Future plans

- Seeking and implementing innovative applications for CCP in construction materials
- Development of further possibilities of CCP utilization in road construction, especially motorways
- Utilizing other mass waste like: phosphogypsum, sewage sludge, bottom sediments from deepening actions
- Practical application of ash-cement mixtures in embankment construction

5. Conclusions and recommendations

- ***Future of ash market development***

As of greenhouse gas emissions, particularly CO2, coal production globally is at its best. Energy produced whilst burning coal is still one of the cheapest there is. Only atom-based energy is less costly. Without consistent global policies towards CO2 emissions coal production all over the world is steadily rising so it may seem that the amount of coal-ash will not diminish in the foreseeable future [12][14]. Burning more coal provides more coal-ash. There are two possible outcomes of this particular situation – either we process and develop more coal ash or dispose of the surplus increasing overall amount of ash stored on landfills.

Currently existing consumer markets for CCP utilization cannot possibly use all of the ash produced so new markets will emerge dealing with the issue. Nowadays most of CCP's are utilized as commodity components, or in large quantities for infrastructural investments, flood protection or mining [1][6][9][13]. Retail market seems completely unexploited, though potentially attractive and rewarding. Coal-ash based pre-packaged products could constitute to a serious amount of utilized coal-ash, successfully alternating consumer construction materials market with products environmentally friendly, using recycled, thoroughly checked and certified material, offering analogous technical properties. There lies great potential in retail sales of coal-ash products but the process of introducing them to global economies will be a long and bumpy road demanding substantial investments in order to develop new products according to market demand.

Emerging markets for coal-ash based products will probably create a demand for specific types of coal-ash with particular properties [8]. To utilize CCP's efficiently, power and heat producers in order to avoid increasing storage fees will be forced to provide supply for future demand offering consistent quality product – beneficiated coal-ash[14]. It is already being done in some facilities but should become more and more common in the future [10].

Heat and power production techniques through burning coal develop constantly. Technological progress focusing especially on emission reduction will probably result in new properties of coal-ash produced and new types of coal-ash. Modern energy production techniques like gasification or clean coal technologies while reducing emissions substantially produce large quantities of by-products [13]. Developing new products based on different coal-ash properties may take serious research effort from utilizing companies.

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