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RESPONSIBLE HANDLING AND CONTAINMENT OF COAL COMBUSTION RESIDUALS

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ABSTRACT

Thermal power plant specifically coal fired power plant is the primary energy source for major developing countries such as China, India as well as in South East Asia. Primary energy consumption through coal has also regained its popularity in the U.S. due to emerging clean coal technologies and carbon capture and sequestration (CCS). Whilst the by-product of coal combustion through flue gas emission is well regulated in its content prior to release to the atmosphere, the filtered flue gas residue together with all other un-combusted material collectively termed as coal combustion residue (CCR) which comprises of fly ash, boiler slag, bottom ash and flue gas desulfurization (FGD) products are contained in surface impoundments or landfills depending on whether the CCR are handled using wet method or dry method. CCR is one of the largest waste streams in the U.S. second only to municipal solid waste (MSW). This paper summarizes the risk to human health and the environment from leakage of CCR in unlined CCR containment facilities as well as poorly designed surface impoundments and landfills. Current available information on CCR regulations in the U.S. and around the world are tabulated in the paper together with geomembrane barrier lining systems adopted for CCR containment facilities observed by the authors. Specific design considerations for CCR landfills compared with traditional design for MSW landfill shall be discussed.

Keywords: Coal combustion residuals, geomembrane, landfill, surface impoundment

INTRODUCTION

Coal is the primary energy source for many countries such as South Africa (93%), Poland (92%), China (79%), India (69%) and U.S. (49%) (IEA 2011). Within the Asia Pacific countries, energy consumption is dominated by coal (52.1% of total energy consumption) (BP 2011). Coal is certain to play a major role within the foreseeable future despite growing environmental concerns such as global warming and pollution control as coal remains as the lowest-cost fossil source for base-load electricity generation and coal reserves are widely available throughout the world in both developed and developing nations unlike oil and natural gas which is concentrated in the Middle East region (MIT 2007).

Energy generation through coal fired power plant produces by-products of coal combustion i.e. waste heat, flue gas and coal combustion residue (CCR). CCR is also commonly referred to as “coal ash”, “coal combustion products (CCP)”, “coal combustion waste (CCW)” or “coal combustion by-products (CCB)”. For consistency, this paper adopts CCR unless a direct quotation is referenced from sources which use a different definition.

COAL CLASSIFICATION AND PROPERTIES

Coal Classification

Coal is not a homogeneous material and it differs considerably in chemical composition, structure and properties from one mining location to another within the same country as well as between different countries. In geological terminology, coal is classified into four main categories i.e. Anthracite, Bituminous, Sub-bituminous and Lignite depending on several factors such as amount of heat energy it can produce and the type and quantity of carbon it contains. Coal which originates from peat, is initially metamorphosed into Lignite. Lignite generally contains high moisture content and has the lowest energy content (approximately 25% - 35% carbon) and hence ranked as the lowest amongst all coal categories. As Lignite matures, it becomes darker and harder and is then classified as sub-bituminous which typically contains 35% – 45% carbon. As the metamorphosis process continues, the coal is converted to bituminous which contains approximately 45% – 86% carbon. Coal is classified as Anthracite when it has reached its final maturation at the last stage of metamorphosis. Anthracite is the highest ranked coal as it contains

86%-97% carbon, contains the lowest moisture content and has a higher heating capacity when compared to the other lower ranked coals.

Thermal Coal Properties

Coal suitable for coal fired power plant also called thermal coal are evaluated based on several factors such as its ash content, sulfur content, moisture content and heat content or called Higher Heating Value (HHV). Coal with high ash content is known to cause reduce efficiency in coal fired power plant and generates a lot of CCR which requires greater effort in handling and containing the CCR responsibly to prevent detrimental impact to human health and the environment. Table 1 compares the coal characteristics of Chinese and Indian coal with coal from various coal mines in U.S.

COAL COMBUSTION RESIDUALS (CCR)

In general, the process of a coal fired power plant using pulverized coal combustion technology begins by grinding 2inch coal pieces supplied to the coal fired power plant into powder form and fed into a furnace and air combusted. The coal would heat up and ignite and generate enough heat and pressure to convert water circulating in the Boiler into high pressured steam. The pressurized steam is channeled to the Steam Turbine Generator (STG) to drive the turbine that ultimately turns the electrical generator and produce electricity. The flue gas generated in the Boiler is then released to the atmosphere through the smoke stack after going through modern clean up devices such as Electrostatic Precipitators (ESP) and FGD units commonly called scrubbers to remove unwanted particulates such as Nitrogen Oxides (NO_X) and Sulfur Dioxide (SO_2).

Boiler slag and bottom ash are CCR that are found at the bottom of the boiler. FGD materials and fly ash are CCR that are collected through the smoke stack after the flue gas has gone through modern scrubbers. CCR are generally handled through sluicing into surface impoundments or mechanically transported in its dry state to landfills. The percentages of CCR components comprises of bottom ash (~ 17%), fly ash (~ 57%), flue gas desulfurization (FGD) products (~ 24%) and boiler slag (~2%) (Luther 2010a).

CCR RECYCLING OPPORTUNITIES

Due to the large amount of CCR generated from coal fired power plant, a lot of research has gone into exploring the beneficial uses of CCR. Suitable fly ash as defined by ASTM C 618 is very useful as a concrete additive due to its pozzolanic properties. FGD gypsum is also commonly used in panel products (i.e. wall boards). CCR is used in the geotechnical field for soil stabilization, structural fill and embankments. However, due to the extremely large volume of CCR, not all CCR may be absorbed into recycling opportunities due to imbalance in demand and supply. American Coal Ash Association (ACAA) estimates about 40% of CCR generated in the U.S. is used and 60% disposed.

Other issues on the difficulties in handling CCR for recycling purposes are CCR's chemical composition varies subject to the coal source, coal combustion technology and method of handling and temporary storage of the CCR. Coal fired power plants are also usually located in remote areas away from human settlements where possible. As such, lack of testing and packing facilities and difficulties in transportation are a hindrance to a certain extent on the CCR recycling opportunities.

HUMAN HEALTH AND ENVIRONMENTAL IMPACT

Contamination of Water Bodies

Flue gas emission is generally tightly controlled for most countries worldwide. The advances in clean coal technology have managed to control and reduce the hazardous un-combusted material from being released into the atmosphere. However, the captured hazardous un-combusted material ends up as part of the composition of CCR. As such, the management of CCR needs to mitigate the risk of exposure and detrimental impact to human health and the environment through other means of contaminant transport such as water.

The typical un-combusted heavy metals contained in CCR include arsenic, cadmium, lead, selenium, mercury, chromium and many others. The content and concentration of each heavy metal are dependent on the coal source and coal technology. The risk of effect to human health and the environment is ultimately a function of "exposure x toxicity". These heavy metals are hazardous if they were ingested or inhaled in significant quantities as they can cause cancer and neurological harm to humans. Exposure to these toxicants can also cause heart damage, lung disease, respiratory distress, kidney disease, reproductive problems, gastrointestinal illness, birth defects and impaired bone growth in children. (Lockwood et al. 2009)

Salt minerals and metallic contents found in CCR may leach into the groundwater or water bodies by diffusion through unlined CCR surface impoundments or landfills thus causing contamination to the living organisms in the water and ultimately to humans through ingestion. More than 100 damaged cases due to water contamination

Table 1 General Coal Characteristics of US, Chinese and Indian Coal

	Higher Heating Value (HHV) (kj/kg)	Moisture Content (%wt)	Carbon Content (%wt)	Ash Content (%wt)	Sulfur Content (%wt)
Anthracite	30,000 – 31,500	2.1 – 12	72 – 87	6.9 – 11	0.5 – 7
Chinese Coal	19,300 – 25,300	3.3 – 23	3.3 – 23	28 – 33	0.4 – 3.7
Indian Coal	13,000 – 21,000	4 – 15	30 – 50	30 – 50	0.2 – 0.7
Texas Lignite	14,500 – 18,300	30 – 34	38 – 44	9 – 14	0.6 – 1.5

Note: Data extracted after (MIT, 2007).

from CCR waste that threatens human health level in the US have been recorded. (Stant 2010) Risk assessment carried out by the USEPA in 2010 presents substantial risk to human health and the environment due to exposure to water bodies contaminated particularly with arsenic and selenium from unlined landfills and surface impoundments (Luther 2010b).

Contamination through Air Borne Particles

Another concern of CCR, specifically fly ash, is its very fine consistency similar to powder. When fly ash is caught by the wind, it may travel far by air. Salt minerals and metallic contents found in fly ash such as mercury, lead and arsenic, which are classified as human carcinogens, are hazardous when inhaled in large amounts. When fly ash settles on crops, it would lower the yield of farms that are located surrounding the power plant.

Loss of Land

Rapid growth of coal fired power plant especially those that utilizes coal with high ash content requires large expanse of land area in order to responsibly contain the CCR thus resulting in land loss.

Catastrophic Failure

Catastrophic embankment failure of unlined CCR surface impoundment has also been recorded. Walton and Butler (2009) carried out forensic study on the surface impoundment failure at Tennessee Valley Authority's (TVA) Kingston coal fired power plant where 1.1 billion gallons of CCR was estimated to be released into 300 acres of surrounding land and water bodies including Emory River and Clinch River as well as damaged and destroyed adjacent properties. The following four probable factors were concluded to have acted together in causing the embankment failure:

i. Fill Geometry – Vertical cell expansion of the surface impoundment was carried out following the upstream construction method but setback by 200ft from the original embankment thus resulting in the vertical expansion embankment resting purely on 35ft to 40ft of wet CCR deposits instead of the better foundation conditions under the original embankment;
ii. Increased Loading – Upstream embankment expansion method results in decreasing plan area with each inward step of embankment construction. For a given equal amount of CCR to be contained over a period of time, the rate of vertical expansion increased at a faster speed thus gave rise to increased loading onto the wet CCR and weak slime found at foundation level;
iii. Weak Slime Foundation – Existing thin layer of very weak slime foundation in between the wet CC deposits and the stiff original ground created a deep seated wedge failure instability path;
iv. Sluiced CCR – Sluiced CCR placed underwater resulted in high void ratio that did not consolidate under the weight of newer CCR fill. The wet CCR was therefore susceptible to collapse when placed under rapid loading as well as rapid displacement. The CCR has characteristics of low undrained shear strength and very sensitive structure of low strain at peak strength. The compounded effect of creep in weak slimes, low undrained behavior of the loose CCR at low strain levels led to a failure mode termed static liquefaction which created a knock on effect of very large movements of the failure mass.

CCR DISPOSAL AND CONTAINMENT REGULATION – LINING REQUIREMENTS (CURRENT STATUS)

USA

In general, US waste disposal and containment is governed by the following Resource Conservation and Recovery Act (RCRA):

i. Subtitle C of RCRA for Hazardous solid waste – Where USEPA has direct authority to impose the regulations
ii. Subtitle D of RCRA for Nonhazardous solid waste (similar to municipal solid waste (MSW)) – Where USEPA does not have authority to

enforce its requirements but is dependent on individual states to regulate them

CCR however is presently not regulated by the USEPA under RCRA and is therefore currently subjected to the requirements of each individual state. Survey carried out by USEPA in 2009 presents an alarming data indicating over 60% of states do not require liners for surface impoundments. (Luther 2010b) The two regulatory options as indicated above are currently proposed to manage CCR. However, the main concern for regulating CCR under Subtitle D of RCRA is that it may not be sufficient to protect human health and the environment.

Worldwide

GRI's Second Worldwide Survey of Solid Waste Landfill Liner and Cover Systems (Koerner and Koerner 2007) provides a broad and general indication of the worldwide regulatory status for containment of CCR. Although not specifically defined, Koerner and Koerner (2007) suggested that CCR regulations found around the world in the countries which it has surveyed is likely to be classified under the category of Inert Solid Waste (ISW) at the time of survey. The results of the survey for regulation on liner composition beneath waste mass for ISW presented 4% of the total 52 countries requires compacted clay liner (CCL) alone, 2% requires geomembrane (GMB) alone, 40% requires a GMB / CCL composite and 54% have no designation for ISW.

Requirements on CCR storage and handling in most Asia Pacific countries are neither state nor federal regulated but rely on project specific recommendations from the Environmental Impact Assessment (EIA) report as well as the respective consultant's design. From the authors' experience and observation throughout the Asia Pacific region, the barrier lining systems varies significantly from single 0.75mm high - density polyethylene (HDPE) geomembrane (GMB) liner, single 2.0mm HDPE GMB liner, to composite 2.0mm HDPE GMB liner and geosynthetic clay liner (GCL) and composite 1.0mm HDPE GMB liner and compacted clay liner (CCL) compacted to 95% maximum dry density (MDD).

DESIGN CONSIDERATIONS FOR CCR LANDFILL OR SURFACE IMPOUNDMENT

Location and Area Requirement

Gandhi (2005) provided several criteria for consideration when selecting a suitable location for CCR landfill or surface impoundments and they are summarized as follows:

i. Proximity of the CCR waste containment facility to the coal fired power plant shall be considered in order to reduce CCR handling cost;
ii. To be located away from existing water bodies such as lakes, rivers, groundwater aquifers etc. where possible to minimize risk of pollution from leaching of CCR;
iii. Provisions for CCR waste containment facility's expansion subject to the life and expansion plans of the plant. The CCR waste containment facility may be expanded horizontally if sufficient area was planned in advance or vertically by raising of the dikes. Construction of a CCR landfill on top of an existing CCR landfill (piggybacking) have been done and may be considered where suitable land availability is scarce. (Seymour and Houlihan 2011);
iv. In areas where hilly terrain is available within reasonable distance of the coal fired power plant, a suitable valley may be identified as the CCR waste containment facility to minimize dike construction.

Land area requirement for CCR landfill / surface impoundment is generally planned with the following considerations:

i. Coal ash content subject to coal source. Central Electricity Authority (CEA) India estimates 40% ash content from Indian coal and 10% ash content from imported coal, which generally comes from Indonesia or Australia (Nath 2007). As such, for a plant that uses Indian Coal, a larger landfill or surface impoundment land area would be required;
ii. Coal fired power plant combustion technology;
iii. Designed or regulatory permitted height of embankment – Where a higher height is permitted, the required land area would be smaller;
iv. Coal fired power plant duration – Required land area for landfill or surface impoundment needs to be estimated for the entire plant lifespan;
v. Recycling opportunities – Realistic ash utilization may be estimated based on increasing percentage of utilization, e.g. a low 10% degree of utilization during first year of operation and gradually increasing the percentage to the plant's 10th year of operation prior to stabilization of the percentage of CCR utilization (Nath 2007).

Barrier Lining Systems

The technology for barrier lining of waste containment systems evolved from single CCL to single GMB liner. Single GMB liner further evolved to composite GMB / CCL lining system. GCL was later introduced to replace CCL as an equivalent lining layer motivated by scarcity of obtaining suitable CCL at certain sites. The barrier lining system further evolved to double lining systems separated by a leakage collection and recovery system (LCRS).

Although single CCL is still being adopted for ISW landfills including CCR waste landfills or surface impoundments, the difficulties and tedious process of selecting suitable material, stringent Construction Quality Control (CQC) requirement at site (Daniel and Koerner 1995), and the need to protect the CCL from deterioration prior to waste deposition renders this system impractical to be relied upon on its own. Some of the well known difficulties of ensuring a good CCL are inconsistencies in soil as a non-homogeneous material, differences in soil placement moisture affecting its compaction density and low permeability characteristics, differences in varying soil layer thickness and uniformity, differences in minimum required compaction energy, presence of roots and different particle size, clay lumps required to be pulverized to avoid void formation and preferential flow path due to soil dessication. For storage of wet CCR's, (Koerner and Koerner 2011) further illustrated that CCL is not suitable in tolerating differential settlement and should therefore not be selected as the barrier lining system on its own and the preferred lining system is a GMB liner by itself or a composite GMB / GCL.

As a guide, the minimum technology guidance recommended by USEPA for lining of landfills and surface impoundments under Subtitle C and landfills under Subtitle D is summarized in Table 2.

Geomembranes (GMBs)

GMBs are impervious sheets of polymeric material primarily used to reduce the hydraulic conductivity of in situ soils. They represent a branch of engineering materials called geosynthetics which are specifically designed to enhance the building properties of natural soils which have been deemed deficient from an engineering point of view. GMBs are thus extensively used to provide additional imperviousness to natural soils in order to protect groundwater tables against contamination from industrial activities such as land filling, waste, and more generally, hazardous material storage. GMBs come in a variety of polymers of which polyethylene represents the most significant percentage because of its inherent engineering and endurance properties, including chemical resistance to a wide range of contaminants. In particular, ever since their inception in the early 80's HDPE GMBs have indeed become the material of choice when it comes to waste containment applications including CCR waste.

Furthermore, when compared to natural soils which require specific water contents and compaction energy to achieve proper barrier status, HDPE GMBs are inherently impervious regardless of their environment, unharmed by freeze-thaw cycles and extreme subzero temperatures. HDPE GMBs also constitute great space savers from their essentially bi-dimensional structure, achieving even higher levels of imperviousness in less than a few millimeters rather than several meters thick of natural clay.

The selection and proper design of GMBs is however not a straight forward process. Firstly, it has to be checked based on minimum regulation requirements where applicable. After which, the expected lifetime where the GMB is required to perform needs to be decided based upon respective project requirements. The durability properties of the GMB is then checked for resistances against chemicals in contact with the GMB, temperature levels and UV exposure. Once the durability requirements meets the lifetime performance criteria, the required thickness of the GMB needs to be calculated following mechanics based design as well as checked against installation and maintenance requirements. Given the above, one is likely to end up with several GMB options given the various possible consideration permutations.

Koerner and Koerner (2008) recommends the adoption of Benefit / Cost (B/C) ratio matrix as an evaluation tool for optimal selection of a GMB. The B/C ratio matrix requires the designer to numerically quantify the GMB's benefits for the pertinent site – specific application and normalizing it over the estimated installed cost. From this numerical evaluation, the most optimal GMB may be evaluated from the resulting highest B/C ratio.

Some Specific Design Considerations for Land Filling of CCR Waste

The current design of CCR waste landfills in the US generally adopts the similar concept to a MSW landfill. However, Hardin and Perrotta (2011) pointed out several differences in the characteristics of CCR compared with MSW as well as highlighted the operations and maintenance issues to be considered for a CCR landfill that is different from a MSW landfill. The waste characteristic differences between CCR and MSW and issues faced unique to CCR landfills are summarized in Table 3.

Table 2 USEPA minimum technology guidance for liner system beneath waste

Identification	Component	Requirement
Subtitle C - Hazardous solid waste	Leachate Collection System	Sand - Thickness $\geq$ 300mm; Permeability $\geq$ 1 x 10^{-1}mm/sec
	Primary Barrier Lining System	GMB - Thickness $\geq$ 0.75mm or $\geq$ 1.5mm HDPE
	Leakage Detection, Collection and Removal System (LCDRS)	Sand - Thickness $\geq$ 300mm; Permeability $\geq$ 1 x 10^{-1}mm/sec
	Secondary Barrier Lining System	GMB - Thickness $\geq$ 0.75mm or $\geq$ 1.5mm HDPE CCL - Thickness $\geq$ 900mm; Permeability $\leq$ 1 x 10^{-6}mm/sec
Subtitle C – Hazardous surface impoundment	Primary Barrier Lining System	GMB - Thickness $\geq$ 0.75mm or $\geq$ 1.5mm HDPE
	Leakage Detection, Collection and Removal System (LCDRS)	Sand - Thickness $\geq$ 300mm; Permeability $\geq$ 1 mm/sec or Geonet / Geocomposite - Permeability $\geq$ 3 x 10^{-4}m^{2}/sec
	Secondary Barrier Lining System	GMB - Thickness $\geq$ 0.75mm or $\geq$ 1.5mm HDPE CCL - Thickness $\geq$ 900mm; Permeability $\leq$ 1 x 10^{-6}mm/sec
Subtitle D - Nonhazardous solid waste	Leachate Collection System	Sand - Thickness $\geq$ 300mm; Permeability $\geq$ 1 x 10^{-1}mm/sec
	Composite Barrier Lining System	GMB - Thickness $\geq$ 0.75mm or $\geq$ 1.5mm HDPE CCL - Thickness $\geq$ 600mm; Permeability $\leq$ 1 x 10^{-6}mm/sec

Table 3 Characteristic Differences between CCR and MSW

Characteristic	CCR	MSW
Waste Particle Size	Homogeneous fine material of powder like consistency.	Heterogeneous and inconsistent particle size bounded in plastic or paper bags and sometimes comes in large dimension objects as big as a refrigerator.
Odors and Vector Control	Inorganic, generally inert, has no noticeable odor and therefore not subjected to biodegradation.	Organic and biodegradable, has vector issues and heavy odor from methane gas generation.
Erodability and Moisture Sensitivity	Predominantly silt sized and susceptible to erosion as it loses strength quickly when contact with water if the CCR was placed un-compacted near the optimum moisture content (OMC)	Generally can absorb large amounts of moisture without immediate loss in shear strength and therefore not susceptible to erosion but is susceptible to blowing trash.
Dust Control	Susceptible to rapid surface drying and thus reverting to original dust particle state and susceptible to blowing off – site and creating airborne hazards and difficult to control.	Generally not susceptible to rapid surface drying as it can absorb moisture but susceptible to blowing trash.

Hardin and Perrotta (2011) makes the following suggestions to manage the characteristic differences of CCR in landfills compared to traditional MSW design:

i. Waste Particle Size – Due to CCR's homogeneous fine particle size, it has a tendency to clog the leachate collection system of a landfill that was designed with MSW characteristics. Ponding surface water above leachate collection system was also commonly observed due to the reduced leachate infiltration rate through the densely compacted layers of CCR. In order to prevent clogging of the leachate collection system, different design for the drainage and filter layer for geotextile or aggregate layer needs to be addressed. Chimney drains and interim drainage layers is proposed to address the problem of ponding surface water.
ii. Odors and Vector Control – For MSW, daily cover soils or fabrics is required to control the vector and heavy odor issues. For CCR, it is recommended that daily cover soils or alternative daily cover fabrics is not needed.
iii. Erodability and Moisture Sensitivity – CCR facilities are faced with frequent clogging of storm water management and sediment control structures due to the erosion of CCR fine particles. As such, additional capacities need to be provided for the storm water management ponds and the erosion control devices. It is also recommended that more frequent storm water pond cleanouts and maintenance be carried out.
iv. Dust Control – Blowing trash in MSW generally can be contained through the construction of a fence. However, this would not work for CCR which is predominantly silt size. As such, installation of a full time sprinkling system may be considered. A water layer of 20 – 50cm is recommended by the EIA report to address this issue in the 1200MW Vung Ang Power plant, Vietnam (Lilama Corporation 2006).

SUMMARY

Although CCR is in essence an incinerated waste and therefore somewhat inert, the potential risk to human health and the environment due to contamination releases of toxic constituents, particularly arsenic and selenium, leached from unlined CCR landfills or surface impoundments into water bodies is significant.

Given the fast growing pace of constructing new coal fired power plants around the world especially for fast developing countries as well as the renewed interest of coal power generation in developed nations such as the US, it is therefore important to pay attention to the responsible handling and containment of CCR. Properly engineered embankment formation for the stability of landfills and surface impoundments combined with careful selection of GMB lining which mitigates contamination risk to human health and the environment should be constructed from the start of coal fired power plant initiation as the need for retrofitting of poorly designed CCR containment facilities in future and the possible clean up requirements due to catastrophic failures would be very costly

HDPE GMBs wide industry acceptance through worldwide governmental endorsements such as the USEPA have made it one of the obvious choice for barrier lining systems to responsibly contain CCR in landfills and surface impoundments. HDPE GMBs have been acknowledged for their many advantages when compared to other more traditional waterproofing materials such as natural clayey soils.

CCR exhibits several different characteristics compared to MSW and as such requires different design considerations in order to manage CCR in the landfills.

REFERENCES

American Coal Ash Association (ACCA). Sustainable Construction with Coal Combustion Products: A Primer for Architects. ACAA Educational Foundation. Aurora, CO, U.S.A.

ASTM C618-08a (2008). Standard Specification for Coal Fly Ash and Raw or Calcinated Natural Pozzolan for Use in Concrete. ASTM International, West Conshohocken, PA, U.S.A.

BP (2011). BP Statistical Review of World Energy June 2011. London, UK.

Bradley L.J.N. (2011). Is Coal Ash Toxic? – Questions and Answers About Toxicity and Assessment of Risk for CCPs. World of Coal Ash (WOCA) Conference, Denver, CO, U.S.A.

Daniel D.E. and Koerner R.M. (1995). Waste Containment Facilities – Guidance for Construction Quality Assurance and Quality Control of Liner and Cover Systems. ASCE Press, New York, U.S.A.

Gandhi S.R. (2005). Design and Maintenance of Ash Pond for Fly Ash Disposal. IGC-2005, Ahmedabad, India, 85 – 90.

Hardin C.D. and Perrota N.L. (2011). Operations and Maintenance Guidelines for Coal Ash Landfills – Coal Ash Landfills are not the same as Subtitle D Solid Waste Landfills. World of Coal Ash (WOCA) Conference, Denver, CO, USA.International Energy Agency (IEA) (2011). Key World Energy Statistics. IEA, Paris, France.

Koerner R.M. and Koerner J.R. (2007). GRI's Second Worldwide Survey of Solid Waste Landfill Liner and Cover Systems. GRI Report No. 34, Geosynthetic Research Institute, Folsom, PA, U.S.A.

Koerner R.M. and Koerner G.R. (2008). The Development of a Benefit / Cost Ratio Matrix for Optimal Selection of a Geosynthetic Material. GRI White Paper No. 12, Geosynthetic Research Institute, Folsom, PA, USA.

Koerner R.M. and Koerner G.R. (2011). Geosynthetic Opportunities Associated with Coal Mining Spoils and Coal Combustion Residuals. Presentation, Geosynthetic Research Institute, Folsom, PA, USA.

Lilama Corporation (2006). Environmental Impact Assessment Study for Vung Ang 1 Thermal Power Plant Project – 1200MW. Ministry of Construction, Hanoi, Vietnam.

Lockwood A.H., Welker-Hood K., Rauch M. and Gottlieb B. (2009). Coal's Assault on Human Health. Physicians for Social Responsibility, Washington, DC, U.S.A.

Luther L. (2010a). Managing Coal Combustion Waste (CCW): Issues with Disposal and Use. CRS Report for Congress R40544, Congressional Research Service, Washington, DC, U.S.A.

Luther L. (2010b). Regulating Coal Combustion Waste Disposal: Issues for Congress. CRS Report for Congress R41341, Congressional Research Service, Washington, DC, U.S.A.

MIT (2007). The Future of Coal – Options for a Carbon Constrained World. Interdisciplinary Study, Massachusetts Institute of Technology, Cambridge, MA, U.S.A.

Nath R. (2007). Report on the Land Requirement of Thermal Power Stations. Government of India (Ministry of Power), Central Electricity Authority, New Delhi, India.

Seymour J. and Houlihan M.F. (2011). Advances in design of landfills over CCR Ponds and CCR Landfills. World of Coal Ash (WOCA) Conference, Denver, CO, U.S.A.

Stant J. (2010). Out of Control: Mounting Damages from Coal Ash Waste Sites. Environmental Integrity Project and Earthjustice, Washington, DC, U.S.A.

Walton W.H. and Butler W. (2009). Root Cause Analysis Report, TVA Kingston Dredge Pond Failure – AECOM Project No. 60095742. Vernon Hills, IL, U.S.A.