Macroencapsulation: An Economic and Environmental Framework for Using Coal Combustion Residuals as Beneficial Reuse

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Coal combustion residuals (CCR) have been used for many years in the construction of berms and engineered structural fill applications including embankments for highways, dikes and levees. However, large un-encapsulated structural fill projects have become a focus of environmental concerns due to potential leaching of metals and structural failures. The U.S. Environmental Protection Agency (EPA) recently promulgated national standards for CCR disposal, with specific criteria used to differentiate beneficial use from disposal. As a result, un-encapsulated structural fills could be subject to regulation as disposal. To address these concerns, an economic and environmental beneficial use framework has been developed based on patented macroencapsulation technologies. These technologies fully encapsulate CCR material within a Subtitle D-compliant liner and cover system, which prevents water infiltration and leaching of metals. CCRs can be used in mechanically stabilized earthen (MSE) berms for the creation or expansion of disposal airspace at a lower cost than traditional methods, or in engineered structural fills for a variety of end uses. This framework utilizes CCRs in every facet of the coal ash management strategy, enabling facilities to establish an on-site beneficial reuse program that meets regulatory requirements and controls potential liability. The beneficial use framework consolidates the disposal footprint in an environmentally-protective manner, minimizing risk and compliance costs.

CCR Management and Beneficial Use Challenges

Over 114 million tons of coal combustion residuals (CCRs) were produced in the U.S. in 2013, making it one of the nation's largest industrial waste streams (ACAA 2014). CCRs are suitable materials for the construction of berms and engineered structural fills in a variety of applications, including building sites and foundations, embankments for highways and railroads, road bases, dikes and levees (ASTM 2014). While CCRs have been used in large-scale un-encapsulated structural fill projects for many years, recently these applications have been a focus of environmental concerns due to potential leaching of metals and structural failures.

In December 2014, the U.S. Environmental Protection Agency (EPA) finalized the first-ever national standards for CCRs, establishing disposal requirements and environmental criteria for differentiating beneficial use" from disposal (U.S. EPA 2014). Specifically, EPA acknowledges that some un-encapsulated structural fills could be considered disposal and subject to regulation. EPA's fourth environmental criterion for un-encapsulated uses requires demonstration that "environmental releases to ground water, surface water, soil and air are comparable to or lower than those from analogous products made without CCR." This raises the question:

Macroencapsulation is an innovative beneficial reuse technology that utilizes coal combustion residuals in embankments, berms, engineered structural fills and other construction applications while preventing water infiltration and the leaching of metals.

Advanced Wall Technologies' patented technical solutions use CCRs in every facet of the coal ash management strategy to enhance the structural stability of disposal units, facilitate additional beneficial applications, and provide environmental protection.

Is there a way to use a facility's CCRs on-site to address environmental risks associated with structural fills and satisfy EPA criteria?

AWT Patented Solutions

Advanced Wall Technologies (AWT) patented macroencapsulation technologies[1] allow generators to continue to beneficially reuse CCRs in structural berms and fills. Unlike traditional berms and fills, the AWT solutions have an internal geomembrane envelope that completely encapsulates the fill material. These technologies can be utilized in every facet of the strategic CCR management solution—closing ash ponds in place, converting to dry storage, strengthening existing sloped structures, or relocating ash for beneficial use. AWT technologies utilize a unique drainage system and lined hydrostatic barriers around the boundaries of CCR storage and disposal units, allowing access to highly saturated CCRs by heavy construction equipment.

Beneficial Reuse Framework—5 C's

Commitment to process

Creation of proper, adequate storage

Consolidation into smallest footprint

Compliance with environmental regulations

Clean closure—clean up once!

Advanced Wall Technologies' beneficial use framework utilizes CCRs in berms and engineered structural fills for the closure, retrofit and construction of ash disposal units—consolidating the disposal footprint in an environmentally-protective manner.

AWT solutions enable a utility to create an on-site beneficial use program that controls facility liability and minimizes compliance costs.

Regulatory Drivers

New EPA regulations for coal ash disposal will require many surface impoundments to be retrofitted with liners, converted to dry disposal or dewatered and closed. Some states also have enacted legislation or statutes that establish CCR management and disposal standards. Whether derived from regulatory, legislative, legal or public pressures, coal-based power plants will have to manage active and retired ash impoundments differently than in the past. At the same time, the closure of disposal units places additional pressure on utilities to manage both legacy CCRs and active coal ash production. As a result, operating and compliance costs could increase substantially. Regardless of whether remediation and closure costs will be borne by the rate payers or utility companies, facilities are looking for the most economical solution while meeting or exceeding environmental requirements.

AWT solutions fully encapsulate CCR material within a Subtitle D-compliant liner and cover system, which can be used in mechanically stabilized earthen (MSE) berms for vertical expansion of disposal units, creating additional airspace at a lower cost than a conventional lateral expansion. The solutions can also be used in engineered structural fills, allowing utilities to find new uses for CCRs. Macroencapsulation with a geosynthetic liner prevents water and leachate from entering or exiting the berm, wall or fill, leading to long-term structural stability, safety and reliability (Dudding et al. 2011). Further, by utilizing the facility's CCR materials in construction, potential liability remains on-site and the disposal footprint is reduced.

From Waste to Resource

Using macroencapsulation techniques, AWT has developed methods for perimeter, finger and channeling berms constructed using CCRs with a unique drainage system, enhancing structural stability and minimizing potential environmental impacts. AWT solutions balance environmental stewardship with economics, allowing facilities to create an on-site CCR beneficial reuse program, controlling liability and decreasing costs. In most cases, AWT solutions allow the facility to consolidate the disposal footprint, further reducing risk. This is the core of AWT's conceptual beneficial reuse framework.

Closure and Disposal Solutions

There are a number of options for CCR pond or impoundment closures, each having engineering, cost and risk advantages and disadvantages. In most circumstances, dewatering and/or stabilizing will first have to be undertaken. The end use of the site and the need for additional dry disposal capacity factor into the choice of beneficial reuse options. For example, expansion of disposal capacity can utilize MSE berms, which have been safely utilized for many years at landfill facilities to create vertical airspace for waste disposal. AWT's encapsulated berm technologies use CCRs as fill material in a vertical expansion, lowering construction costs compared to lateral expansion. AWT solutions aim to prevent shipping CCRs for costly off-site disposal.

AWT has developed retaining berm and engineered structural fill designs that provide a unique and economical solution for every facet of CCR management—from cap and closure to retrofit to the construction of new structural fills.

Encapsulated berms can be utilized for the stabilization of in-place structures, impoundment closure or conversion from wet to dry disposal. AWT technology supports a range of closure, new construction and consolidation solutions.

Cap-in-place: An AWT berm is constructed around an existing disposal area using active CCR production as construction material.

Wet basin to dry disposal conversion: AWT's solution allows the wet basin to continue to function until the transition to dry disposal is complete. A composite liner is installed using additional geogrid underlayment.

Retrofit wet basin to Subtitle D standards: AWT berms or curtains are constructed through a basin so a portion of the basin can continue to operate. An AWT berm is constructed around the perimeter with removed CCRs, and a composite liner is installed using additional geogrid underlayment.

Creation of dry disposal capacity: The AWT solution creates landfill capacity using CCR in encapsulated berms, while moving coal ash away from streams, rivers and wetlands to reduce liability and create sustainable containment.

Large-scale structural fill projects: AWT encapsulation allows coal ash to continue to be used as a structural fill material on current and future engineered projects, satisfying EPA beneficial reuse criteria.

The costs for different applications have been estimated with an economic model using standard engineering and construction assumptions. The final approach to any project will depend on site-specific conditions that may require accommodations beyond what is considered typical. The model calculates the estimated costs from implementation to completion of the AWT system. Because site conditions can vary greatly, the cost estimates included herein are for discussion purposes only.

Preventing Berm Failures

AWT is a strong proponent of the utilization of CCRs in the structures we build. However, due to the fine-grained nature of CCRs, their usage requires important engineering considerations, including reducing storm water infiltration and development of pore water pressures. Water removal from an ash pond is critical to constructability, project economics and long-term performance. Without proper dewatering of saturated ash materials before removal, excavations risk caving and slope collapse, creating safety hazards and the potential for costly repairs and environmental remediation (Johnson and Nilsson 2014).

Berm Failures

68% of MSE wall failures were water-related, according to engineering studies

Water removal from an ash pond is critical to constructability, project economics and long-term stability and safety.

AWT berms fully encapsulate CCRs in a liner system equipped with an internal drainage system to prevent water from entering the wall system. No liquids = no liquefaction!

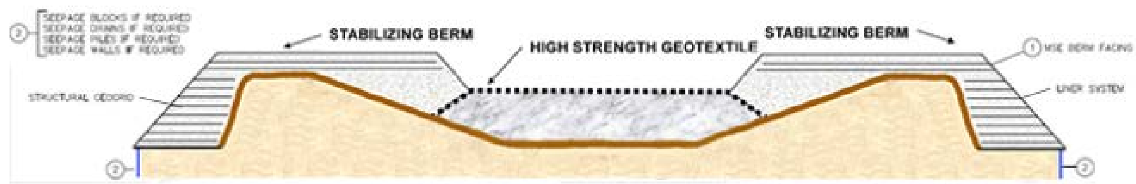
The Geosynthetics Research Institute has studied the importance of drainage control in wall systems (Koerner and Koerner 2011). The guidance detailed the overwhelming necessity to maintain and design for proper drainage control in berm systems. To prevent problems, the guidance concludes, “The entire reinforced soil zone *must be encapsulated* by waterproofing from above the drainage from beneath and behind whatever backfill consists of fine-grained soils. These precautions are felt to be absolutely necessary to prevent wall drainage failures from occurring in the future.” Indeed, the GRI study found that 68% of wall failures were internal or external water-related, 80% of failures were due to moderate to poor material compaction, and 76% of failures were associated with masonry block walls (Koerner and Koerner 2009). As the majority of berms constructed at waste and power facilities are vegetated berms, this eliminates the potential failure mechanisms associated with masonry block walls.

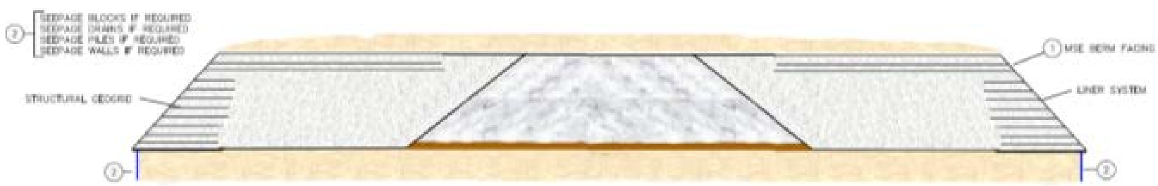
AWT patented designs are based on a wealth of scientific study on all aspects of MSE retaining berms and engineered structural fills, including structural stability (Luettich and Quiroz 2008; Qian and Koerner 2009), construction (Brown and Ballod 2008), and the flexibility of expansion options.

Improving Structural Stability

The hybrid cap will use CCRs to construct a perimeter berm extending well below the ground surface, creating a hydrostatic barrier and natural buttress under the base of the AWT berm system. Each section of the hybrid cap system will extend toward the middle of the existing basin or completely to the center point of the existing basin, creating a pinwheel structure as shown in the figures below.[1]

> By converting to dry storage and combining AWT's encapsulated berm technology with standard geosynthetic capping, existing wet CCRs impoundments/basins could utilize a "hybrid cap." AWT's solution moves liability away from waterways, maximizes on-site capacity while consolidating the CCR footprint, minimizes permitting time, and reduces cost.

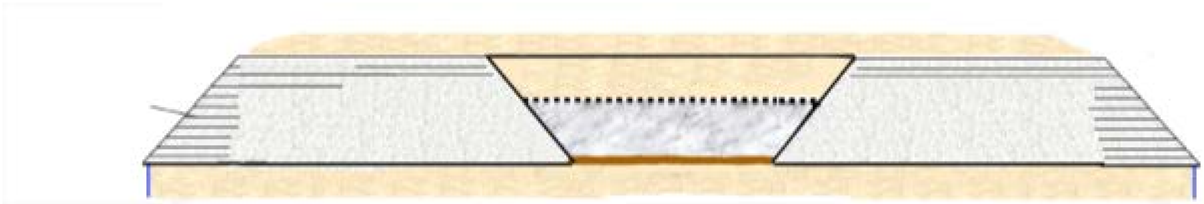




The AWT berm system is a Subtitle D-compliant lined approach that complies with EPA regulation and addresses state regulatory programs. A geomembrane option (GCL or 30-mil FML) is the preferred long-term remedy for areas with groundwater impacts. The berm can be constructed 50 to 75 feet inside of the current CCR waste boundary to allow for future groundwater control methods.

Consolidate Multiple Impoundments

Where there are multiple existing wet basins, the dewatered CCRs from additional wet basins can supply the construction fill material for the AWT berm system utilized in the final capped wet basin. This approach consolidates multiple impoundments into one lined containment area. The perimeter embankment can be replaced with an AWT coal ash-geosynthetic wall using the soils for final cap or used to stabilize "left-in-place" CCRs in the center of a wet basin, as shown in the figure below.[1]



PROJECT COSTS MATTER

The center bowl area can also be lined and capped, with final soil cover graded to provide a developable plateau for other uses. Cost modeling of the awt berm system ranges from **$10.23** to **$11.78** per cubic yard of CCRS handled. This cost assumes proper dewatering of CCRS to approximately 40% to 50% moisture content before utilization in the berm system, and does not include the cost of dewatering or transportation of CCRS.

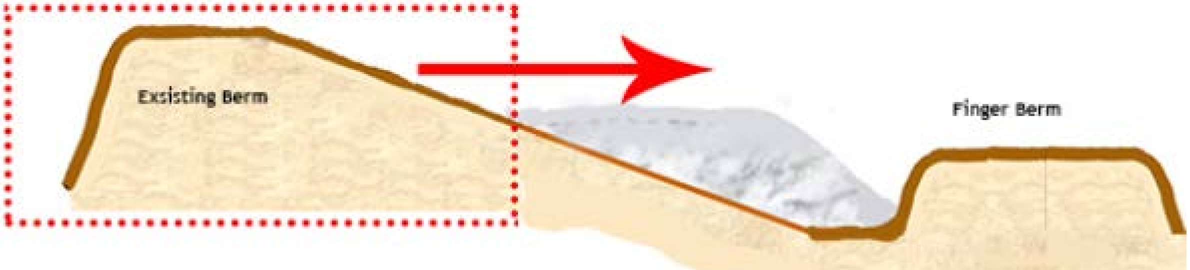
The cost model calculates costs based on “standard” project requirements. However, each facility has its own features and characteristics that could lower or increase costs. The estimated cost does not include base grade preparation costs or final beneficial use costs, such as paving, installation of solar panels or other end-use features.

The Cost-Effective Conversion Solution

Using AWT solutions combined with standard geosynthetic capping, the amount of material needed to fill from below the ground water could be obtained from the existing dirt berms around the basins, minimizing cost. Where there are multiple wet basins, the dewatered CCRs can supply construction fill material. The existing outer embankment can be replaced with an AWT ash-geosynthetic wall using soils to create finger berms for stabilization within the basin, as shown in the figure below.[1]

The ultimate in “clean closure,” AWT’s encapsulated berm technology can cost-effectively convert wet basins to dry lined storage facilities.

The creation of a lined disposal footprint, constructed in phases, could include ALL material at the facility-consolidating multiple wet basins into one lined containment area.

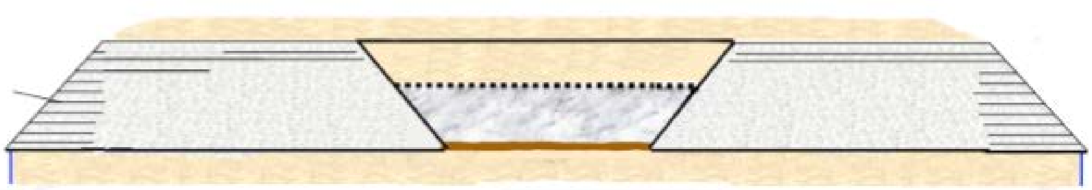


The strength of the geotextile-reinforced finger berm is designed to produce additional bearing capacity to the CCRs, thereby providing enough load-carrying capacity for construction equipment to access the center of the wet basin or to stabilize “left-in-place” CCRs. This solution requires CCRs dewatering to approximately 40% - 50% moisture content before utilization in the berm system.

Construction in Phases

After completion of the AWT perimeter berm, the area excavated to supply CCRs in berm construction can be lined. The remaining CCRs between the perimeter berm and the finger berm can be excavated and placed on top of the lined area, pushing material toward the finger berm, as illustrated in the figures below.[1]

A geomembrane option (GCL or 30-mil FML) is the preferred long-term remedy for areas with groundwater impacts. The top of the disposal unit can be lined and capped for a developable plateau.



PROJECT COSTS MATTER

In most cases, this method consolidates the CCR disposal footprint and optimizes existing footprint utilization. Cost modeling of this wet-to-dry conversion AWT berm system ranges from **$12.32** to **$13.92** per cubic yard of CCRs handled. This cost does not include the cost of dewatering, base grade preparation costs, or any beneficial use costs associated with development above the cap. The cost model calculates costs based on “standard” project requirements. However, each facility has its own features and characteristics that could lower or increase actual cost.

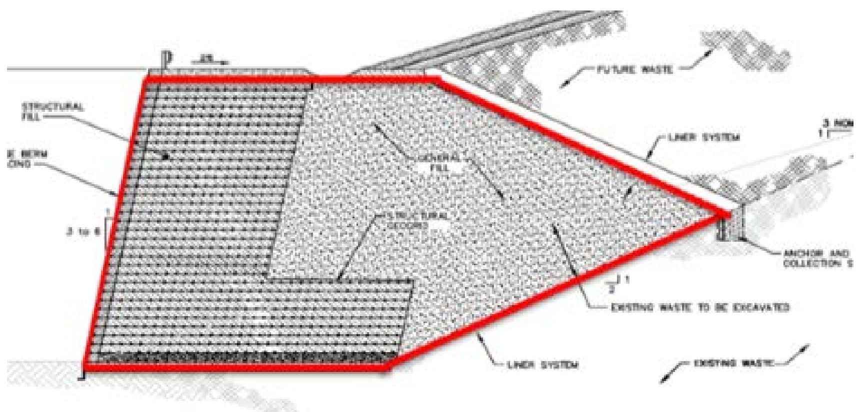
Encapsulated MSE Berms

New dry lined disposal capacity can be created by using encapsulated berm technology at power plants with adequate available property or at nearby solid waste disposal facilities.

The solution moves coal ash disposal away from waterways, thereby reducing liability. By using encapsulated CCRs in the construction of MSE berms, the financial burden of construction is dramatically decreased.

The AWT solution uses CCRs in the construction of MSE berms for dry landfill capacity, reducing the amount of ash that must be disposed of. MSE berms may also be used for vertical, rather than lateral, expansion of landfill space, as shown in the figure below.[1]

Further, the technology can also be used to create a plateau over an existing hill, mound or stockpile by constructing an AWT perimeter berm system around the boundary and extending the top deck into the middle of the structure.



PROJECT COSTS MATTER

The cost model estimates the AWT berm system to range from **$13.43** to **$14.71** per cubic yard of CCRs handled. This assumes that the footprint is flat or has been graded to be flat and at least 20 feet above the underlying water table. The estimated cost does not include dewatering of CCRs or base grade preparation costs. The cost model calculates costs based on “standard” project requirements. However, each facility has its own features and characteristics that could lower or increase costs.

Solid Waste Landfills

MSE berms have been utilized for many years in solid waste facilities for lateral and vertical expansion. Patented AWT technologies have been developed for the beneficial reuse of CCRs to be utilized in the construction of these berms at solid waste landfills. The beneficial reuse material (CCRs) is segregated from other landfill waste, with its own leachate treatment system.

Landfills within a 25-mile radius of the power plant can be identified as potential beneficial reuse opportunities. The 25-mile radius has been determined as the optimal distance economically for a beneficial reuse project.

PROJECT COSTS MATTER

Cost models indicate that full implementation of the AWT berm system at area landfills ranges from **$11.43** to **$12.97** per cubic yard of CCRs handled, offsetting construction costs.

This cost estimate does not include dewatering or preparing CCRs for transport. Since the landfill greatly benefits from the additional disposal capacity created, the power plant can negotiate the freight on board (FOB) rate, reducing the overall cost of disposing of CCRs on-site. The cost model calculates costs based on “standard” project requirements. However, each facility has its own features and characteristics that could lower or increase costs.

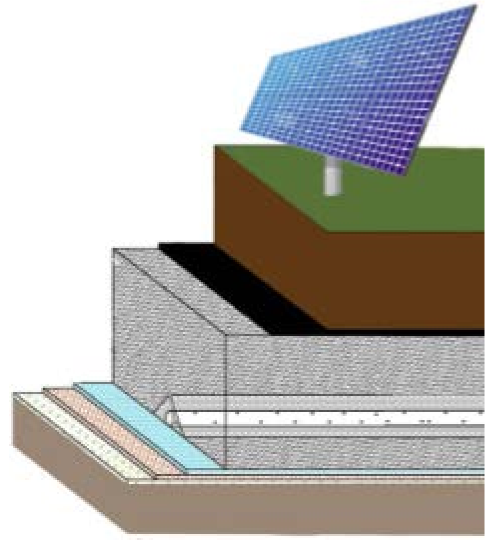
Enabling Continued Use of Structural Fills

Using AWT’s patented methods, developers can continue to use CCRs as a backfill material, creating developable acreage (plateaus) for applications such as solar farms, model airplane parks and sports fields. Final soil cover is graded to fit the end use.

Large-scale structural fill projects have utilized CCRs as fill material for many years. However, due to environmental concerns and new EPA regulations, these projects must now be designed with environmental controls to be considered “beneficial use.”

AWT macroencapsulation technology with internal drainage allows for the continued use of CCRs as engineered structural fill material.

The beneficial reuse material (CCRs) is encapsulated and segregated from other materials, with its own leachate treatment system, as illustrated in the cross section (right).[1]



Experience Matters

Improper design and construction techniques have been cited for the vast majority of wall failures, with improper compaction cited in 80% of berm failures (GRI 2009). When designers do not understand the systems they are designing and when proper construction quality assurance is not performed, the project has a greatly increased likelihood of failure.

AWT-designed MSE berms and engineered structural fills are based on extensive scientific literature and experience with geosynthetic liner systems—essential elements for a successful construction project. Its license agreement, AWT requires an equivalent CQA plan for beneficial reuse projects typical of a stringent landfill CQA program (Dudding and Sheridan 2013).

Experienced construction quality assurance (CQA) personnel are critical for successful berm and engineered structural fill construction. Proper design, construction and water management results in one of the most useful and cost-effective methods for CCR management that has emerged in the last 20 years.

Construction Quality Assurance (CQA)

A robust CQA plan establishes the construction quality assurance observation and documentation activities that will be implemented during construction. The purpose of the CQA plan is to provide specific procedures that will be followed by qualified CQA personnel in order to ensure that the project satisfies technical specifications and will receive regulatory agency approval. Because a CQA plan does not address design guidelines, installation specifications or procurement of materials, a thorough understanding of MSE berm construction by CQA personnel is critical to ensure project success. CQA is best performed by someone independent of the facility owner, contractor or material manufacturer and installers.

Quality First

Through its license agreement, AWT requires a CQA plan for all beneficial reuse projects.

The CQA inspector will monitor:

- Appropriate subgrade preparation
- Relocation and abandonment of existing structures
- Proper fill compaction to maintain stability
- Appropriate moisture conditioning of the fill
- Changes in fill properties that may require additional testing
- Consistent, acceptable facing installation procedures
- Installation of appropriate reinforcement at appropriate locations
- Verification of material properties against design requirements
- Appropriate protection against run-on and run-off

[1] Advanced Wall Technologies, LLC is the sole and exclusive licensee, with the right to sublicense certain intellectual property rights of utility PATENT No. 8,376,657, PATENT No. 8,430,600, PATENT No. 8,727,664, PATENT No. 8,784,008, PATENT No. 8,845,240, PATENT No. 8,961,073 and pending US patent applications held or submitted by AWT IP, LLC

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