An Innovative Design for CCP Impoundment Capping and Closures with Significant Cost, Performance and Environmental Co-Benefits – Soilless Solar Caps

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ABSTRACT

Closure caps for coal ash impoundments typically require large volumes of earthen materials combined with geosynthetics to form an impermeable barrier to prevent future storm water infiltration into the impoundment. However, the continued success of exposed geomembrane caps (EGCs) and other soilless caps as a highly efficient and cost effective method for long-term environmental protection to reduce leachate generation and provide for a stable low-maintenance cap system for sludge lagoons and waste landfills is leading to their utilization at CCP (Coal Combustion Products) facilities where they can be deployed on impoundments and disposal areas to address long-term capping solutions with an EPA approved alternative method to meet Subtitle D closure equivalency.

This innovative, yet practical approach to capping CCP impoundments has a number of cost, performance, and environmental co-benefits over traditional Subtitle D prescriptive methods. Like a modern roof system which utilizes composite shingles, EGCs and other soilless caps can be deployed on very shallow slopes, with rainwater collected at the perimeter. For large impoundments this can prove to be highly valuable because large quantities of soils are not required to develop the necessary slopes to shed storm water on earth covered cap systems. Also, like lined lagoons, grading can be accomplished to develop sump areas within the cap to collect storm water and remove it from the cap.

By adding laminate solar panels to the cap, an EGC can give the site a built-in beneficial secondary use which allows the closed impoundment the option to double as a renewable energy source. The design of exposed geomembrane caps with solar panels can provide renewable power generated on-site that can be used on site or be added to a renewable energy portfolio. In addition, the use of an EGC allows demolition waste from the coal plant demolition to be stored safely, and long-term on-site, thereby reducing cost and liability for the owners. Regulatory agencies and citizens groups are accepting this alternative capping system because it transforms a piece of property with limited alternative re-use options into a solar energy generation facility.

INTRODUCTION

Capping systems for CCP surface impoundments are an essential component for long-term containment, stability, and environmental protection for many sites. Design of impoundment caps for CCP lagoons should provide a cost effective, impermeable and stable protective barrier between the underlying CCP materials and the environment that is relatively simple to construct, easy to maintain, and straightforward to inspect to confirm its ongoing performance. It is also important that CCP surface impoundment caps be designed to accommodate future access to the underlying CCP materials that have potential valuable secondary reuse opportunities. And, as the title to this paper indicates, it is important to examine possible beneficial site uses that can be performed over the capped area. By designing alternate cap designs to Subtitle D that employ soilless systems and coupling them with a solar option, provides a triple play of benefits:

1 Superior long-term and extreme weather performance and environmental protection;
2 Beneficial reuse of the site allows for regulatory and public understanding by converting some of it to “green energy” generation; and

3 A cost efficient system with lower construction and maintenance costs that also, can provide income through energy production and renewable energy credits (RECs).

As regulations for CCP disposal remain in limbo, Subtitle D of the Resource Conservation and Recovery Act (RCRA) provides capping and closure criteria at an appropriate level of guidance for capping non-hazardous disposal sites. Typical CCP basin closure projects require a combination of low permeability soil covers over areas with no groundwater impacts, and geosynthetic cover over areas with groundwater impacts above the regulatory standards.

USEPA establishes in 62 FR 40710 that states have the regulatory authority to approve alternative final cover designs that can meet or exceed specific engineering performance characteristics of the prescribed system. Of the main criteria, it explains that an alternative to the final cover can be approved if the permittee can show that the permeability of the infiltration layer can be met by an equivalent reduction in infiltration.

HDR has researched, designed, and acquired permits in several states for alternatives to the Subtitle D prescriptive final cover system on MSW landfills. These alternative final cover systems can provide similar cost savings and long-term performance for a wide variety of ash basin closure projects. Some of the reasons for the savings include:

- Imported soil can be costly when a suitable soil source is not located near the project site.
- Saturated soil conditions can occur on top of the geomembrane creating stresses both to the barrier system and the subsurface drainage system.
- Placing and compacting low permeability soil cover materials over saturated coal ash basin materials will frequently result in near surface instability. This temporary construction instability requires additional dewatering, geogrid stabilization layers or soil material that must be accounted for in the overall construction cost.
- Over flatter areas of an ash basin closure project, a head build-up will occur on the liner which can be both hard to identify and expensive to repair.
- The volume of soils that are needed to create a slope with sufficient lateral drainage for the standard Subtitle D cap is significant for a large site.
- The cost of the annual maintenance of a typical Subtitle D final cover system during the post-closure care period can be significant. The cost of ongoing turf and soil maintenance must be accounted for in the life cycle cost of the ash basin closure final cover alternative.

HDR has designed, permitted, and constructed several Subtitle D alternative soilless caps including the exposed geomembrane solar cap (EGSC) system on several sites in the Eastern United States. These are providing substantial financial benefits and reduced maintenance for landfill owners and operators. The Haley & Aldrich coal ash team has evaluated the life cycle cost of the solar cover and conventional methods for ash basin closures and found that an EGC with solar panels make sense from both a technical and financial perspective. The following sections provide an explanation of the technical and financial aspects of EGSC final cover systems.

BENEFITS OF CCP IMPOUNDMENT CLOSURES WITH A SOLAR RE-USE OPPORTUNITY FOR UTLITIES

Soilless caps with the capacity to incorporate solar energy generation represent a different and more effective design than the typical and traditional Subtitle D prescribed closure systems. This is particularly evident for ash basin closures, with the physical characteristics of large drainages areas with long flow lines and shallow slopes. Another important application is the use of a EGSC on sections of the ash basin with down gradient groundwater impacts. For most ash basin closures it is a valuable option to examine installing a soilless alternative cover system that incorporates a lightweight impermeable and high-strength cap that can be installed, maintained and inspected with relative ease, and one which also allows for potential future access to the underlying materials for future CCP beneficial reuse.

By adding a solar component as part of an alternate capping system, it allows the CCP impoundment area to gain a beneficial reuse application with strong public and

regulatory support. CCP impoundments and/or ash basins set for closure can be seen as large Brownfield areas that are not likely to be reused for industrial activity in the near future. Incorporating solar energy into a soilless cover system offers owners the opportunity to show a beneficial use of the area while providing long-term environmental benefits as well as immediate and long term economic benefits.

Impoundments and landfills are well suited for alternate caps that include a solar energy component because they are large open areas generally with good access control and proximity to the electricity grid. Solar caps can incorporate as many solar panels as the owner chooses and are easily expandable to incorporate more panels without additional detailed design or permitting.

The solar energy cover system design takes advantage of the strength and flexibility of the geomembrane material to provide a final cover that is engineered to encapsulate the underlying CCP. A traditional cover system uses soil to act both as a ballast for the underlying geomembrane and also as a material to support the overlying vegetative growth. However, continuous turf maintenance in order for the cap to continue to perform as designed is difficult because of inconsistent weather patterns and severe weather events, which can directly lead to conditions not suitable for long-term cap performance and stability.

In addition to realizing the financial benefits of soilless caps with the reduced construction and maintenance costs, incorporating solar panels to the cap can be partially offset by applying for renewable energy credits (RECs). Overall, the general cost for PVLs installed on an engineered soilless cap is roughly $3.75 per watt including the PVLs themselves, the wiring and the inverter. Although, the initial costs of the solar may not be completely offset with RECs and revenue, the solar system can be installed in stages depending on future needs. These RECs vary from state to state, but a cost benefit analysis indicates that the solar cap can help pay for a portion of the EGSC cover system. Depending on the state renewable portfolio standard (RPS) the RECs can easily provide 10 to 12 cents a kilowatt hour.

Conversely to a conventional Subtitle D cap, a non-ballasted soilless cap, with or without a solar energy component, is designed for both long term outdoor exposure and specific design weather events. These systems use pins or anchors directly into the underlying material that strengthen the overall liner system by limiting the stresses and strains the material encounters during a design storm. This design provides a stable cover system that can protect the impoundment during storms and wind events for a specific area.

Using a solar energy cover creates a solar park from a CCP impoundment in a single closure construction project and is typically constructed with less uncertainty and less risk to the affected power utility. This can be especially important when the CCP impoundment is located in a densely populated area that has a lot of visibility and a high level of citizen input. Most citizen groups in urban areas are favorable to use of solar energy, and the closure of coal combustion plants. Installing an attractive exposed geomembrane solar cover system over a portion of ash basin closure project helps to convince citizens that the electric power utility is both practical and open to innovative forms of “green” energy. It is also important to note that illustrating to the regulatory agency the positive environmental co-benefits of alternate caps can provide impetus for permit approvals of alternate systems.

EXPOSED GEOMEMBRANE CAP SYSTEMS

Exposed geomembrane cover systems utilize a single high-strength geomembrane designed for outdoor applications. These are installed over a prepared earthen or stabilized CCP subgrade and require no soil or vegetation over the geomembrane, and thus having a cost savings at closure and during the post-closure period of the surface impoundment. EGC’s have been utilized in the United States using HDPE, LLDPE, scrim-reinforced polypropylene, EPDM and other proprietary resin formulas for geomembranes. The EGC system does not have the potential for veneer slope-type failures (i.e. sliding of cover components) that can occur on a Subtitle D or sand ballasted synthetic turf cover systems. The EGC is anchored into the landfill utilizing anchor trenches and/or anchor pins designed to counter balance wind uplift forces.

EGCs have recently been developed which incorporate synthetic turf directly bonded to the geomembrane are similar to EGCs in their deployment, their inspectibility, and their long-term maintenance. In fact, they can be looked at as EGCs with hair, and share many of the same attributes of EGCs with the additional protection and visual benefit of grass-like turf. These systems can

incorporate the lightweight photovoltaic laminate (PVL) solar panels which can generate energy on the cap while not creating any point-loading conditions that may cause differential settlement areas within the capped impoundment.

EGC's have been permitted and installed as landfill closures in Louisiana, Florida, Delaware, Georgia, New York and Texas. The performance criteria of exposed geomembrane caps include UV resistance, seamability, seam durability, chemical resistance, puncture resistance, stress-strain characteristics, and interface friction. UV degradation has been noted as the most important property in exposed conditions. A multitude of UV exposure tests have been performed on geomembranes and the body of work and example projects are more extensive than synthetic turf. In research described in GRI's White Paper #6, HDPE geomembrane that has been exposed to accelerated aging via UV light has performed well. The study has estimated an HDPE lifetime of 36 years and testing at 70°C (158°F) is still ongoing. In other research, standard oxidative induction time and high pressure oxidative induction time tests have been performed to determine the antioxidant properties of the exposed HDPE and LLDPE geomembrane.

Minimum criteria used to evaluate the geomembrane selection for an EGC:

- Compatibility with the underlying materials and its leachate
- Resistance to degradation due to exposure to direct sunlight;
- Strength to handle wind uplift pressures;
- Expansion/Contraction concerns
- Durability to withstand walking or low ground pressure vehicles, hail, birds and falling debris;

The following is a listing of advantages and disadvantages of the EGC cover compared with a prescribed Subtitle D cap:

Advantages

- Accelerated construction time and lower soil requirements
- Can be more easily constructed on lower and steeper slopes without extensive re-grading
- Flexible solar panel arrays have been installed and are currently producing power. Also, fixed-frame solar arrays are possible similar to the synthetic turf solar panels.
- Accelerated aging tests indicate that HDPE manufactured per GRI-GM13 has a predicted lifetime greater than 36 years. GSE recently introduced a line of high-performance geomembranes that have superior endurance properties than typical 60-mil HDPE. EPDM and TPO have also been tested to perform for extended periods of outdoor exposure.
- HDPE and EPDM geomembrane costs are competitively priced and are commercially available from a number of different manufacturers.
- Post-closure costs are significantly less.
- Access to the materials beneath the EGC is less cumbersome
- No veneer slope stability issues.
- Can confirm geomembrane integrity and make repairs relatively easily
- Pro-rated 20+year material warranty available

Disadvantages

- More vulnerable to damage by hail, wind and other externalities than the other alternatives.

- Limited permitting experience within state solid waste regulatory offices and therefore hasn't been approved as an alternate closure system in some states.

- Testing for UV exposure degradation to the geomembrane may be required to confirm that the EGC is conforming to its initial specified values.

- More stormwater runoff may need to be accounted for with a steeper hydrograph

SYNTHETIC TURF/GEOMEMBRANE SYSTEMS

HDR has recently designed alternate Subtitle D closure systems that include synthetic turf weaved into a geotextile and laid over a studded geomembrane. These are ballasted systems in which sand is applied on the

geotextile between the blades of the synthetic turf to provide sufficient weight to the sysem to keep it in place. These types of synthetic turf caps were first installed as a landfill final cover system in 2008 in Louisiana. Since then, the system has been permitted and installed at landfills in Texas, California, Missouri, Pennsylvania, Florida and Georgia.

The following is a listing of advantages and disadvantages of the synthetic turf cover systems compared with a prescribed Subtitle D cap:

Advantages

- Accelerated construction time and lower soil requirements
- Post-closure costs are significantly less.
- Can be more easily constructed on lower and steeper slopes without extensive re-grading.
- The overlying geotextile/synthetic turf layer can be seen as an alternative protective layer.
- The geotextile/synthetic turf provides weathering and UV protection for the geomembrane. Weatherometer ASTM G147(02) tests performed on the exposed portion of the yarn shows less than 10 percent tensile strength loss after 20 years. Additional UV exposure tests on the synthetics turf are ongoing.
- Repairs can be performed more easily
- Pro-rated 20+-year material warranty available
- Can remove for easier access to the underlying materials for future mining for material reuse.

Disadvantages

- PVLs may not be easily incorporated into the existing distributed power system Generally, may incorporate solar arrays comprised of rigid-type panels.

- More stormwater runoff may need to be accounted for with a steeper hydrograph

- Sand ballasted systems may be vulnerable against wind uplift under extreme conditions if sand shifts over time. Pinned and anchored synthetic turf systems do not have this disadvantage.

- Sand ballasted systems incorporate a studded LLDPE geomembrane under the turf/geotextile layer. LLDPE has a lower lifetime under exposed conditions than other geomembrane materials used in other soilless caps discussed in this paper. (Koerner et. al, 2005)

- Installation errors and long-term material creep could occur creating an appearance of "loose carpet" and requiring specialized repairs.

- Synthetic turf is currently a patented technology and therefore not competitively priced.

- Not yet authorized as a landfill final closure in most states.

- Unable to confirm the integrity of the barrier layer (geomembrane) with visual inspections.

COST COMPARISON FOR FINAL COVER SYSTEMS FOR CCP IMPOUNDMENT CLOSURES

HDR performed a cost analysis comparison of different closure designs including a Subtitle D, synthetic turf/geomembrane, and an EGC for a subject landfill in Texas – a state which has approved various alternate Subtitle D final cover systems including an EGSC. The budgetary construction cost of the EGC on a CCP impoundment is approximately $75,000 per acre, the synthetic turf/geomembrane is approximately $95,000 per acre, whereas the standard Subtitle D cap is approximately $150,000 (Beben, 2012). In addition to the construction cost, the EGC will provide a reduced annual maintenance cost of approximately $2,500 per acre for the EGSC and synthetic turf alternative cover system as compared to the standard Subtitle D cap. If the maintenance savings are included as the present worth value of the life cycle cost of the CCP impoundment closure then these values result in a savings of $49,000 per acre for a EGC cap (30-year design life, 3 % interest) as compared to a standard Subtitle D cap. These costs do not include engineering, permitting, quality assurance and certification that will occur during all installations. Additionally, the costs do not incorporate post-closure water quality monitoring, leachate management and

general professional services. **If the estimated 30-year post-closure care costs are incorporated into the total cost, the Subtitle D cap is over twice the overall cost of either of the two soilless caps in the comparison.**

BENEFICAL USE OF A CLOSED CCP IMPOUNDMENT FOR SOLAR ENERGY GENERATION

While the construction and maintenance costs savings are significant, the value of reusing a large industrial area for a secondary use as well as ensuring relatively simple access to the underlying materials for future reuse contributes greatly to the overall logic of utilizing alternative Subtitle D caps. The development of solar power generating arrays on closed surface impoundment caps is an emerging technology. By generating renewable energy on closed sites, owners can reuse the open areas that would otherwise have limited post-closure use while at the same time holding and protecting the underlying CCP for future beneficial reuse.

EGCs can be simply solarized by welding or bonding thin-film PVLs directly onto the EGC. PVLs have been used in roofing, landfill EGC's and other applications. These panels are lightweight, flexible, easy to install and do not require an expensive concrete ballasting structure. The PVL's have been formulated to be exceptionally durable by encapsulation in UV-stabilized polymers. These panels have not been installed with synthetic turf cover systems although they could be incorporated into these systems in future designs. Flexible solar arrays have been constructed for landfill caps in New Yourk, Texas, and Georgia. It is important to note that the PVLs don't have to be installed at the time of cap deployment, but can be added a later time or in a series of additions throughout the post-closure life of the disposal facility.

To illustrate the construction cost and electricity generation from a 250-kW solar panel array welded to a EGC. A Xunlight XR36 PVL is selected with nameplate wattage of 300 watts per panel. Therefore, an array of 860 panels will provide 250 kW of direct current power. Based on previous EGC solar designs with a gentle slope and no liner penetrations, it is estimated that this array will require a 2.5-acre area of EGC. The kilowatt hours provided to the utility grid will vary in the field due to hours of sunlight, temperature, angle to the sun, and the efficiency of the conversion from direct current to alternating current. Given these parameters, material and installation cost of a 250-kW array encompassing a 2.5-acre area will cost over $1.2 million, produce 341 MWh of electricity in the first year.

For the design of the solarized EGC (or EGSC –exposed geomembrane solar cap), the panels of each sub-array are attached to an above-surface raceway that groups the wires before they are connected to combiner boxes positioned at the toe of the slope via flexible enclosed wire-ways adhered to the exposed geomembrane. Also, geomembrane flaps are adhered to the EGC to protect the wire connections to the solar panels. These flexible conduit wire-ways and flaps match the color of the exposed geomembrane and can be detached in order to have future access to the connections and wiring.

The flexible laminated solar panels are connected together in strings to reach the system voltage. The strings are connected in parallel to increase the total amperage. The landfill's solar energy conversion system consists of the solar array and equipment necessary to take the DC power generated by the solar array through either the utility grid or a battery back-up system.

SOILLESS CAPS WITH A SUSTAINABLE RETURN ON INVESTMENT

Soilless solar energy caps can make sense both at current cost and future cost-benefit comparisons with traditional systems with worldwide application potential. Utilizing alternate Subtitle D caps with PVLs is an outstanding example of sustainable investment, with a high benefit to cost ratio, relatively low risk and great potential to add renewable energy on site as part of the overall energy portfolio.

This innovative design of the solar energy cover creates a flexible, durable and stable surface that conforms to impoundment surface variations with long-term reliability for both energy generation and environmental protection. This alternative CCP impoundment closure design utilizing soilless covers with PVLs applies solid science and engineering principles to close an impoundment in an efficient an environmentally responsible manner while providing it with the ability to generate commercial scale renewable solar energy and also the potential to reclaim the CCP for future beneficial reuse. In conclusion, a solar energy cover creates a new source of renewable energy with creative land re-use,

enhanced environmental protection and the potential reclamation of CCP materials for beneficial reuse.

PRACTICAL APPLICATION OF EXPOSED MEMBRANE COVERS FOR CCP IMPOUNDMENT CLOSURES

The use of EGCs with flexible solar panels is a proven technology on other types of landfill closure projects. The financial benefits for a wide variety of landfill and impoundment closure projects suggests that this technology would be applicable for most CCP impoundment closures. The advantage of cost effectively covering industrial disposal sites with known ground water impacts suggest that the use of EGSCs will provide similar benefit for CCP impoundment closures. To effectively apply this technology on CCP impoundments and/or ash basin closure projects the following is recommended:

- Use the EGSC technology over areas of CCP impoundments with known groundwater impacts;
- Conduct a life cycle cost evaluation of the final closure alternatives that includes the cost of materials, installation and post-closure maintenance.
- Consider the available State and Federal incentives and tax deductions for the use of solar technology;
- Incorporate the use of EGSC final cover system as part of an integrated closure strategy that includes adequate consideration for risk reduction, regulatory acceptance and citizen acceptance.

The design concepts and financial evaluation in this paper are offered to provide designers, owners and operators a practical look at an innovative method for CCP impoundment closure. The alternative closure design incorporating an unballasted soilless cap with flexible solar panels is a proven technology for landfills with conditions similar to those at CCP landfills and ash basin closure projects. Site specific conditions, construction cost, and regulatory acceptance of these alternatives is expected to be the deciding factor in most cases. The authors of this paper and presentation are available to assist with interpretation and application of the information in this paper upon request.

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