Utilizing Alternative Caps that meet Subtitle D Equivalency Requirements for CCP Landfill and Impoundment Closures to Gain Significant Savings and Secondary Use Opportunities

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INTRODUCTION

Recent developments in alternative cap designs for landfills and impoundments have proven to meet regulatory requirements, significantly lower capital costs and long-term maintenance costs plus they can provide beneficial secondary use opportunities such as a solar energy generation facility. Alternative closure caps are a practical approach to traditional Subtitle D/CCR Rule prescriptive methods and like a modern roofing system which utilizes composite shingles, alternative caps can be deployed on very shallow and steep slopes with rainwater collected in perimeter channels so as to create a system on which rainwater efficiently drains off the cap. For large impoundments, alternative caps can prove highly valuable because large quantities of soils are not required to develop the necessary slopes to avoid saturated soils conditions and/or ponding on the cap liner. Also for alternate capping of lagoons, grading can be accomplished to develop sump areas within the cap to collect storm water and drain it from the cap.

A beneficial secondary use of alternative caps is that they provide a stable surface to install solar arrays. These arrays provide sustainable and environmentally friendly energy, becoming a valuable asset and revenue generator offsetting future maintenance cost. Solar arrays can be implemented easily utilizing crystalline and/or laminate photovoltaic modules, and can be installed on both sloped and crowned areas. As of 2016, a new generation of laminate solar panels have been developed facilitating easy installation even on steep sloped caps producing similar power on landfills equivalent to earlier as heavy ballasted crystalline arrays over similar sized areas. These new laminates can be applied to a wide range of alternative cap designs providing renewable energy on site and becoming an asset to any renewable energy portfolio. Capping systems for coal combustion products (CCP) surface impoundments are an essential component for long-term containment, stability, and environmental protection for many sites. Design of caps for CCP impoundments should
provide a cost-effective, impermeable, and stable protective barrier between the underlying CCP materials and the environment. Capping systems are relatively simple to construct, easy to maintain, and straightforward to inspect to confirm its ongoing performance. New developments in materials for alternative caps that meet EPA requirements provide owners with a long-term, reliable cap system that typically requires lower installation and maintenance costs than traditional caps, along with secondary use opportunities that can add value to closed sites.

New geosynthetic materials are now available for use in CCP capping applications that can provide warranties for 20+ years and be deployed over dewatered or partly dewatered impoundments. Coupled with next-generation laminate solar panels that can be adhered directly to the geosynthetic cap, impoundments can now be closed in a shorter timeline and with less reliance on heavy soil-moving equipment. This solution allows closed sites to be transformed into revenue generating facilities that offer more than just a long-term maintenance commitment.

The potential long-term liability and cost associated with landfill/impoundment closure now has viable alternatives and options countering inherent risk. The addition of energy generation with renewable, clean solar power to any landfill provides compelling financial and environmental benefits. The following technical issues, listed below once restricted the addition of solar (e.g., traditional glass panels) but have now been removed with the development of next generation thin film PV:

- Geomembrane penetration (anchoring racks)
- Weight point loading (ballast to resist wind)
- Steep side slopes not accommodating solar
- Low power density not meeting economic requirements.
- Shifting cap surface / differential settlement
- Panel security (theft and vandalism)
- Hail or potential storm damage

Matching the evolution of geosynthetic materials and technology, thin film PV has also enjoyed recent successes. The lightweight flexible form factor of Copper Indium, Gallium (CIGS) thin films have addressed all of the above concerns. Until now, these barriers have slowed the adoption of solar into the cap systems for CCP municipal solid waste, along with and mine tailings storage and disposal facilities.

Typically, coal ash sites are ideal for this technology and can benefit from the close proximity of grid interconnect opportunities by avoiding the cost of constructing new transmission and power lines.

The main issues and benefits defining the requirement and adoption of solar power to any landfill site include:

Revenue Benefits
- Continuous cash flow beginning with partial closure
- Renewable energy credits (RECs)
- Energy off-take

Cost Avoidance
- Lowest overall cost of closure from geomembrane
- Lowest operational and maintenance costs
- Lowest on-site electricity costs

Incentives
- 30% Federal Investment Tax Credit
- State Investment Tax Credit (e.g., North Carolina offered 35% in 2016)
- Often Property & Sales Tax Relief
  - MACRS (accelerated depreciation)
  - Rebates and/or grants

Perception
- Positive image of sustainability and energy independence

BACKGROUND

On July 26, 2016, the EPA Administrator signed a direct final rule and a companion proposal to extend, for certain inactive CCP surface impoundments, the compliance deadlines established by the regulations for the disposal of CCP under Subtitle D of the Resource Conservation and Recovery Act (RCRA). The Rule is enforced under Subtitle D, and is self-implementing under 40 C.F.R. Part 257. USEPA allows state programs to operate in lieu of the federal program, or to enforce any of the requirements addressing the disposal of CCP. Consequently, USEPA establishes a prescriptive closure cap, but with the opportunity to submit alternate procedures if they can be shown to be equivalent or better than the prescriptive cap shown in Figure 1.¹

The alternate procedures clause provides an opportunity for engineers, designers, and manufacturers to develop alternative methods and materials to help clients reduce the significant capital and maintenance costs required to cap large areas with the prescriptive cap. ¹
A number of opportunities are available to realize savings from utilizing an alternative cap to the prescriptive cap. These potential 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 that can be both hard to identify and expensive to repair.
- The volume of soils needed to create a slope with sufficient lateral drainage for the standard Subtitle D cap is significant for a large site.
- Heavy earth moving equipment is required to haul and place the soil, requiring the impoundment to be significantly dewatered prior to closure.
- 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 and permitted several alternative caps to the prescriptive Subtitle D cap. These caps are engineered for improved performance over the prescriptive cap in terms of stability, maintenance, constructability, and storm water runoff quality. These caps can also provide a beneficial reuse opportunity by incorporating a photovoltaic component directly to the cap itself. A cross-section of a typical alternative cap is shown in comparison to the prescriptive cap in Figure 2. 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 an exposed geomembrane solar cover (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.

**Figure 2: Comparison of a Cross-section of a Typical Alternative Cap and a Prescriptive Cap**

Impoundments and landfills are well-suited for alternate caps that include a solar energy component because they are large open areas, and typically have 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.

HDR's teaming partner, Miasole, has recently developed a highly efficient line of laminate solar panels that provide significant savings to the life cycle cost of alternative caps for CCP impoundment closures. The following sections provide an explanation of the technical and financial aspects of these alternative solar caps as final cover systems for CCP impoundments.

**COST COMPARISON FOR FINAL COVER SYSTEMS FOR CCP IMPOUNDMENT CLOSURES**

HDR performed a cost analysis comparison of different closure designs including a Subtitle D, a synthetic turf/geomembrane, and an exposed geomembrane cover (EGC). The budgetary construction cost of the EGC or a synthetic turf/geomembrane is generally around $100,000 to $115,000 per acre on a CCP impoundment, whereas the standard Subtitle D cap is approximately $160,000 to $175,000. In addition to the construction cost, the reduced annual maintenance cost of approximately $2,500 per acre is realized for the EGC and $500 for the synthetic turf alternative cover system as compared to the standard Subtitle D cap. If the maintenance savings are converted to present worth value for a life cycle cost estimation...
for the CCP impoundment post-closure care, then these values result in a savings of approximately $50,000 per acre for an EGC cap (30-year design life, 3% interest) as compared to a standard Subtitle D cap. These closure and post-closure care cost estimates are general and do not include site-specific details, 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.

THE MIASOLE ADVANTAGE

Today’s thin film solar (CIG’s Copper Indium, Gallium) has matched the power density and performance of more traditional poly silicon (16.5% efficiency). An example MiaSolé’s next-generation laminate solar panels is included in Figure 3. The higher module power is an excellent complement to landfill gas technology increasing overall power density and energy output at the site. The flexible modules can be bonded directly to the membrane cover allowing easy inspection for liner integrity.

Figure 3: Miasolé Flex Series-03W
Membrane covers and flexible modules are a perfect combination for steep-sloped landfill sites where conventional solar arrays cannot be installed due to slope and live-load limitations. The current design with laminate module weight below ½ lb per square foot meets all live point load requirements.

The non-penetrating installation protects the environment (water ingress), while the flexible form factor conforms to the contours of the landfill and accommodates differential settlement. The modules are also easy to install. The ability to simply peel-and-stick the modules onto the capping membrane is substantially faster than the old rack and wire management strategies resulting in labor installation savings.

The earliest generation of solar thin films from 2012 experienced performance limitations and also cost and adhesion issues. These issues have been resolved with the current generation laminates and CIGs technology. The early thin film panels also experienced low energy yields, adhesion issues, and reliability problems. However, as mentioned earlier, the efficiency of CIG’s has almost doubled the output of early generation amorphous silicon technology. In fact, new adhesives developed by Royal Adhesive & Sealants (ADCO) have surpassed performance exhibited in 2012.

<table>
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<th></th>
<th>MiaSolé</th>
<th>a-Si Thin Film 2012</th>
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<tr>
<td>Cell Technology</td>
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<td>aSi</td>
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<td>Ultrawire Technology</td>
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<tr>
<td>Efficiency</td>
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<td>20 year</td>
</tr>
<tr>
<td>Workmanship Warranty</td>
<td>5 year</td>
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While no industry accepted standard for testing PV to membrane attachment existed, ADCO developed several test methods and internal performance standards for the attachment of MiaSolé panels. One of these tests is a lap shear based on ASTM 1002, which pulls the membrane and PV apart in a longitudinal mode. The strip being pulled is 1” wide thus the resulting adhesive strength is reported in pounds per square inch. This is now the test method incorporated and used by UL for adhesive certification under category QOQW2.

Figure 4: MiaSolé Adhesive Shear Strength Comparison
Miasole is the first PV module to test and pass UL 580 “Standard for Tests for Uplift.” Resistance of roof assemblies over TPO (thermoplastic olefin) and metal roof substrates actually surpassing the standard -90 psf with supplemental testing to -135 psf. The roof systems failed, but not the Miasole module attachment to the roof substrates.

Panel reliability has improved tremendously with the incorporation of meticulously tested transparent barriers and redundant interconnect strategies. The current generation laminates have incorporated the lessons learned from the early pioneers on thin film.

In the past, the transmission of water vapor through the front transparent barrier impacted performance resulting in the evolution of new robust materials.

Figure 5: Water Vapor Transmission Comparison
Today, with the development of new materials and incorporation of diligent testing, Miasolé’s current CIGS technology now offers reliable, efficient, and long-lasting solutions.

FINANCIAL BENEFITS FOR ADDING SOLAR TO THE LANDFILL CAP

Traditionally, landfill solar power has been consumed onsite or used by municipal owners to offset their energy usage. Utilities closing CCP sites are typically located near transmission assets, and have a demand for clean (green) environmental energy to offset renewable energy requirements. Another financial option is a power purchase agreement with third parties that have a tax appetite and power demand.

Community Solar, a new financial model for large solar farms, takes large solar arrays and sells power to individuals and companies who may not be able to install solar on their homes or business. Some situations include:

- Renters who may be prohibited from installing solar on the property
- Roofs that are shaded or unable to carry the additional weight of solar
- Roofs where the size or orientation may not be able to produce enough power
- Commercial buildings that are leased or may already have equipment on the roof

Typically, the solar developer sells power subscriptions to individuals and businesses. Once all subscriptions are sold, the developers can unload the paid subscriber base to a utility company that manages and handles the billing. Community Solar power purchases are transportable, so a subscriber can take their power with them to a new location.

Community Solar projects have been completed in 25 states with California, Massachusetts, Minnesota, Colorado, and Florida being the leaders. The U.S. Community Solar market will add an impressive 1.8 gigawatts in next five years, and solar landfill farms can play an important role in this market.
CASE STUDY

HDR and Miasole prepared a conceptual design of a solar energy cap for a CCP land disposal monofill that will be closing in the next year. The utility that owns the CCP land disposal site is determining which closure options best suit this facility. The site is partially closed with some of the side slopes already capped with soil/grass. HDR’s exposed geomembrane cap design is only for the approximate 53 acres that currently remains open as shown in Figure 6 below.

Figure 6: Aerial of CCP Land Disposal Site

The facility intends to optimize the airspace, and therefore, the remaining closure area will be primarily sideslope with insufficient top deck area (shown in Figure 7) is available for traditional ballasted solar. However, the 3:1 side slopes are well-suited for the laminate panels adhered to the geomembrane.

Figure 7: Proposed Closure Area

The optimal location for solar on the side slopes in the northern hemisphere is on the south-facing slopes of the landfill. In this scenario, the design utilizes 11,238 Miasole Flex 03
Modules (490W each) for a system size of 5,551 kWp and a projected energy of 7,361 MWh/year.

Figure 8: Primary Array Location

Additional slope areas can also be utilized for additional energy as shown in Figures 9, 10, and 11 below.

Figure 9: Additional Slope Areas for Potential Array Expansion – Zone 2

Zone 2, shown in Figure 9, utilizes an additional 11,184 panels for an additional 5,480 kWp and a projected energy of 7,385 MWh/year.
Zone 3, shown in Figure 10 above, adds an additional 2,376 panels for an additional 1,164 kWp and a projected energy of 1,534 MWh/year.

Zone 4, shown in Figure 11 below, adds an additional 7,106 panels for an additional 3,482 kWp and 4,140 MWh/yr. If the facility chooses to maximize the solar generation of the site using a solar cap the PVsyst projected maximum total energy from Zones 1 through 4 is estimated to be 20,421 MWh/yr.

Modeling tools are available that now accurately predict (+/- 2 %) possible energy generation for any of the proposed layouts. Insolation (location), orientation, slope angle, and solar technology selected can impact the sites suitability. Once the predicted output for each scenario has been determined, it easy to determine the ROI for any CCP or municipal solid waste closure project.
With the continued evolution of membrane materials and solar efficiency, the cost of sustainable cover systems will continue on their positive trend. This will result in solar becoming common as a secondary benefit with many Subtitle D closures as well as for impermeable covers for industrial sites looking to re-purpose the property rather than simply maintain it.