Proceedings of the 9ICEG
9th International Congress on Environmental Geotechnics
25-28 June, 2023 | Chania, Greece
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https://doi.org/10.53243/ICEG2023-235

Solar on Closed Landfills: Engineering Solutions and Case Studies

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ABSTRACT

After a landfill has reached its capacity, it is required to be closed in accordance with regulatory requirements to protect the environment. There are three main groups of final covers: soil-only, soil-geosynthetic, and geosynthetic covers. The soil-geosynthetic covers have been widely used in landfill closures. One of the geosynthetic covers, the engineered turf cover, has also gained significant acceptance in the past decade. The large space of a closed landfill can be beneficially reused for solar energy development. A traditional solar solution utilizes a racking-supported solar panel system installed on a soil or soil-geosynthetic cover. An alternative solar solution utilizes the engineered turf cover as the foundation for a low-profile solar panel system. This paper provides an overview of landfill closure and solar development solutions. Case studies of solar projects on closed landfills are presented too.

Keywords: Landfill closure, geosynthetic cover, engineered turf, solar development, beneficial reuse

1 INTRODUCTION

A landfill is required to be closed in accordance with regulatory requirements after it has reached its capacity. The final cover system isolates the underlying waste to protect the environment and therefore, is the most critical component of a landfill closure system. The large space of a closed landfill can then be beneficially reused to develop a solar farm that generates a clean source of renewable energy. Using the closed landfill for solar development can prevent disturbing a natural grassland or “greenfield”. Construction of a solar farm on a closed landfill also saves costs, because the facility already has infrastructures built at the site, for example, the access roads, stormwater management system, security fences, electricity connection system, etc. Development of renewable energy is also a demonstration of the site owner’s commitment to sustainability, which can help improve public relationships. Furthermore, the solar farm can generate revenue to offset landfill operation and maintenance costs and transform the closed landfill into a renewable energy asset.

2 LANDFILL CLOSURE SOLUTIONS

Requirements of the landfill final cover system are prescribed in the solid waste management regulations by the federal and state governments. For example, the final cover system prescribed by the United States Environmental Protection Agency (US EPA) for municipal solid waste (MSW) landfills is illustrated in Figure 1.

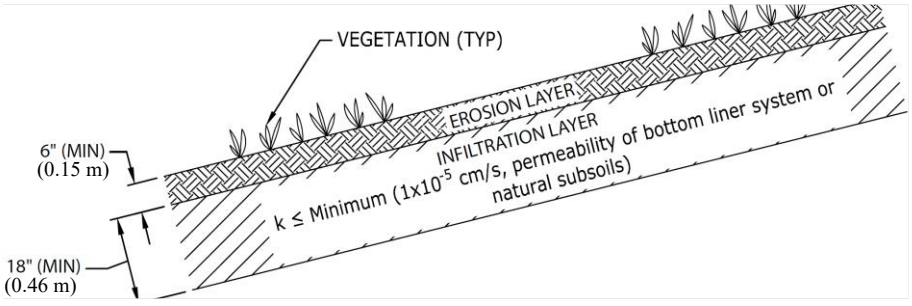

Figure 1. *Final cover system prescribed by the US EPA for MSW landfills*

Typically, the regulations also allow for the use of an alternative final cover system, provided that it performs equivalently to the prescriptive system in terms of infiltration reduction and erosion resistance. Soil-geosynthetic final covers, which meet the performance requirements, have been widely used for landfill closures. Figure 2 illustrates a typical soil-geosynthetic final cover that consists of both soil and geosynthetic components, including a geomembrane barrier layer and a geocomposite drainage layer.

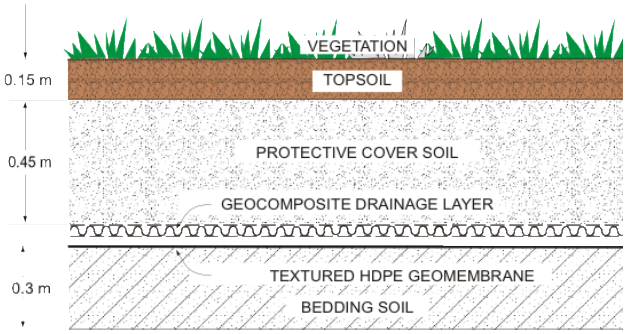

Figure 2. *A typical soil-geosynthetic final cover system*

Other alternative landfill covers, including the exposed geomembrane cover and the evapotranspiration (ET) cover, have been used in landfill closures too. The exposed geomembrane cover comprises a geomembrane barrier layer that is usually anchored with trenches or point-anchoring mechanisms (e.g., sandbags or percussion driven earth anchors) to protect the geomembrane from wind uplift. However, its acceptance as a final cover is limited due to direct ultraviolet (UV) exposure that affects long-term performance of the geomembrane. The ET cover, also known as the water balance cover, relies on multiple soil layers to store percolated water when it rains and then release the water to the air through plant transpiration and surface evaporation processes. The effectiveness of the ET cover is dependent on weather patterns, soil properties, and plant conditions (Alam et al., 2023).

The engineered turf final cover system (e.g., ClosureTurf®) has gained significant acceptance in the US in the past decade as an alternative final cover system for landfill closures (Zhu et al., 2019; Zhu et al., 2021). The engineered turf cover consists of, from bottom to top (Figure 3): (1) a structured geomembrane layer that performs as the hydraulic barrier to control infiltration, (2) an engineered turf layer made of synthetic grass fibers tufted into a double-layer woven geotextile backing that protects the geomembrane from UV exposure and wind uplift, and (3) a specified infill layer (13 mm thick minimum) buried in the engineered turf fibers that provides additional UV protection and ballast against wind uplift. It has been applied to overcome some of the major challenges associated with traditional soil covers, including soil erosion, geotechnical instability of cover slope, and post-closure maintenance.

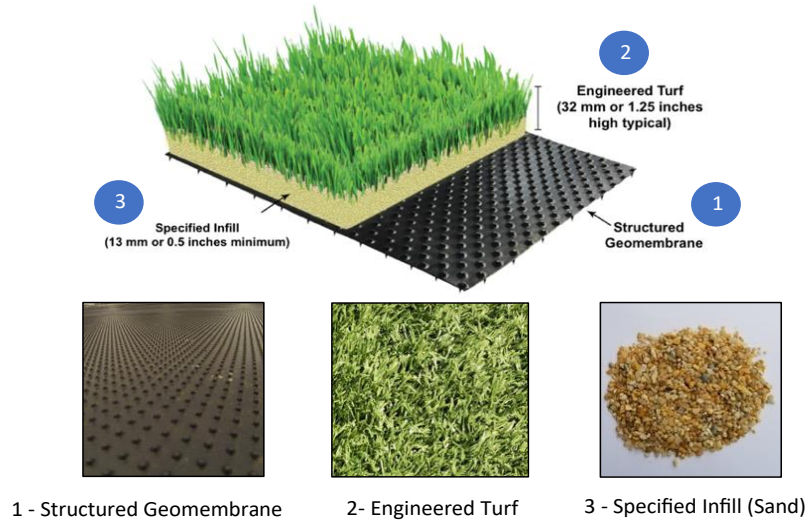

Figure 3. *Illustration of Engineered turf final cover system*

Table 1 lists the above-mentioned five types of landfill final cover systems, which are grouped into soil-only, soil-geosynthetic, and geosynthetic covers. The major advantages and disadvantages of each cover are provided in the table.

Table 1. *Comparison of landfill final cover systems*

Final Cover Systems		Advantages	Disadvantages
Soil-Only Cover	Prescriptive Soil Cover	Low cost	High infiltration; risk of waste exposure due to soil erosion
	Evapotranspiration (ET) Cover	Low cost using local soils	Effectiveness dependent on weather, soil, and plant conditions; limited to relatively dry climates
Soil-Geosynthetic Cover		Widely accepted; minimal infiltration	High cost; potential cover instability due to weak interfaces
Geosynthetic Cover	Exposed Geomembrane Cover	Better runoff quality; minimal infiltration; low cost	UV degradation of exposed geomembrane; limited acceptance as a final cover
	Engineered Turf Cover	Better runoff quality; minimal infiltration; low maintenance cost	Relatively high construction cost; relatively short application history (i.e., 10+ years)

3 SOLAR DEVELOPMENT SOLUTIONS

3.1 Traditional Solar Solution

The traditional solar solution utilizes a soil-only or soil-geosynthetic cover for closure and a racking-supported photovoltaic (PV) solar panel system for power generation. The racking system is usually connected to concrete foundations, which serves to ballast the solar panels and protect them from uplifting and overturning by wind loads. Pile foundations are typically not allowed due to penetration of the landfill final cover barrier layer (e.g., the geomembrane or compacted clay layer).

Designing and permitting a landfill solar project typically involves geotechnical investigation, stormwater management study, solar panel and electrical system design, and demonstration that development and operation of the solar system is not expected to negatively impact performance of the final cover system. The major operation challenges with the traditional solar solution are related to soil erosion, vegetation management, and differential settlement induced by loading from the solar panel system.

Installation of solar panels changes stormwater flow patterns on a landfill cover surface. Instead of falling directly onto the ground, rainwater is intercepted by the solar panels, falls off panel edges, and then hits the ground as a concentrated flow. The impact and hydraulic shear forces can cause erosion of the soil cover along the drip line, especially when the vegetation condition is poor. Soil erosion affects runoff water quality and increases maintenance and repair costs. It can undermine the foundations of solar arrays and integrity of the final cover system too. To control soil erosion, it is important to design an adequate stormwater management system, establish good vegetation on the final cover, and perform regular maintenance and repairs, as necessary.

On the other hand, overgrown grasses, weeds, and plants need to be trimmed because they affect not only final cover performance (e.g., potential blockage of the drainage layer by roots), but also solar panel efficiency by blocking the sunlight with shadows. Because of narrow access between solar panels, the vegetation often needs to be cut manually, requiring intense labour work for large sites. In addition, workers need to operate equipment carefully to avoid cutting cables and conduits or damaging solar panels.

Last but not the least, potential impact of loading from heavy concrete foundations and gravel leveling pads on performance of the final cover needs to be evaluated during the engineering design and monitored after construction, because it can create differential settlement that may cause localized ponding of stormwater on the landfill surface.

3.2 Engineered Turf Solar Solution

The engineered turf solar solution utilizes the engineered turf cover for closure, which serves as a stable foundation of the solar panel system since it is not subject to soil erosion. It requires significantly less post-closure maintenance. For example, no mowing, fertilizing, or revegetation is required. Furthermore, since vegetation overgrowth is no longer a concern, clearance between solar panels and the final cover surface can be reduced for the engineered turf cover. Therefore, a low-profile solar panel system without a heavy racking system can be installed directly on the engineered turf cover, minimizing potential impact on the landfill cover system due to heavy loading.

3.2.1 Performance evaluation of engineered turf cover

The engineered turf cover has been demonstrated as being equivalent to the prescriptive soil covers in terms of infiltration reduction and erosion resistance. Case studies examined by Carlson et al. (2019) indicated that the calculated infiltration rate through the engineered turf cover was less than or equal to the calculated infiltration rates through two different prescriptive soil-geosynthetic cover systems. In terms of erosion resistance, an indicator of erosion performance of the engineered turf cover is the improved runoff quality. De Abreu and Franklin (2014) reported a measured turbidity of 11 nephelometric turbidity units (NTU) for the runoff from a landfill area installed with the engineered turf cover, whereas runoff generated from another area installed with the clayey soil cover at the same landfill produced a turbidity of 371 NTU.

Because the engineered turf cover is a three-component system, longevity of the engineered turf cover depends on the longevity of individual components. The structured geomembrane is covered by the engineered turf and specified infill and therefore, the unexposed geomembrane has an anticipated service life of at least 200 years under most climatical conditions (Koerner et al., 2011; Scholl et al., 2023). The engineered turf geotextile backing has an expected service life greater than 100 years, provided that it remains covered with the specified infill (Scholl et al., 2023). The specified infill (granular sand) will not degrade appreciably from weathering for centuries. The most critical component with respect to longevity is the exposed engineered turf fibers forming the “grass” matrix that hold the specified infill in place.

An extensive UV testing program has been carried out to evaluate the service life of the engineered turf fibers. Outdoor weathering testing was initially conducted on samples of turf fibers placed at the test field of Atlas Material Testing Solutions located in New River, Arizona. Samples of the weathered turf fibers after approximately 1, 5, 7 and 10 years of exposure were sent to a geosynthetic testing laboratory and tested for remaining tensile strength. Based on the evaluation results, the half-life of the turf fibers was projected to be more than 100 years (Geosyntec, 2015). The test results are plotted in Figure 4.

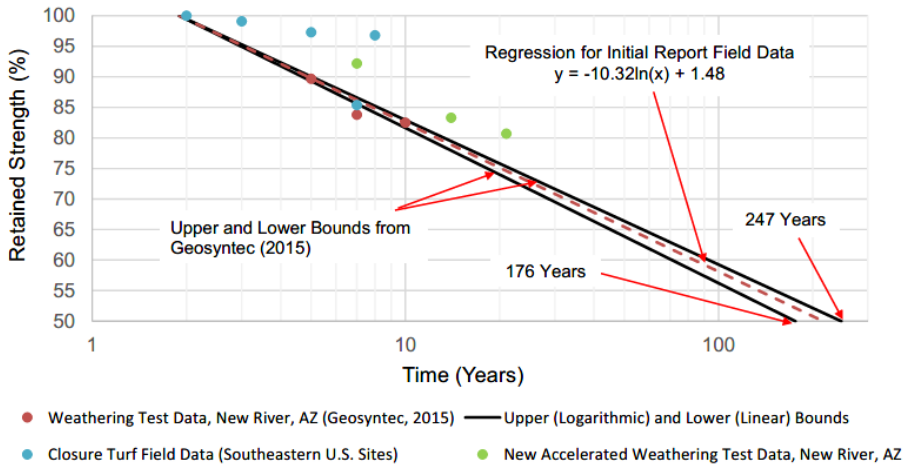

Figure 4. *Half-life projection of engineered turf fibers*

Subsequently, field samples of the turf fibers were collected from multiple sites to evaluate the real-world performance. In addition, an accelerated natural weathering program has been undertaken on samples of the turf fibers at the same facility in Arizona using Fresnel Solar Collectors. The accelerated results

equivalent up to 21 years of UV exposure have been obtained to date. The new data from the field samples and accelerated weathering tests are plotted in Figure 4, along with the data points from the initial 10-year weathering test. The new data points clearly validate the previously projected half-life of more than 100 years for the turf fibers, as they are located at or above the projected trend lines (Geosyntec, 2022). It is noted that the service life of the turf fibers is longer than the half-life, because the turf fibers still have sufficient tensile strength to perform in the field after reaching the half-life (Scholl et al., 2023). Based on the UV longevity evaluation results, the engineered turf cover is projected to have a service life of more than 100 years, provided that it is installed and maintained appropriately in accordance with engineering design drawings, technical specifications, and post-closure care procedures.

3.2.2 Low-Profile Solar Panel System

Low-profile solar panel systems have been developed for direct installation on the engineered turf cover, one of which is called PowerCap™. It is a three-component system that consists of solar panels, mounting rails, and friction strips (Figure 5). It does not require penetrations through or mechanical connections to the engineered turf cover. The friction strips attached to the underside of the mounting rails provide interface friction and maintain stability of solar panels on slopes. The low-profile solar panel system is easy to install due to its simple configuration. It allows installation of solar panels on landfill side slopes in addition to top decks, increasing the footprint of a solar farm for more power generation. Because of the panels are close to the ground, shading and inner row spacing are reduced and therefore, panel density is increased for more power generation. As a light-weight system compared to the traditional system with heavy racking and foundations, the low-profile solar panel system is not expected to impact performance of the underlying engineered turf cover in terms of creating differential settlement.

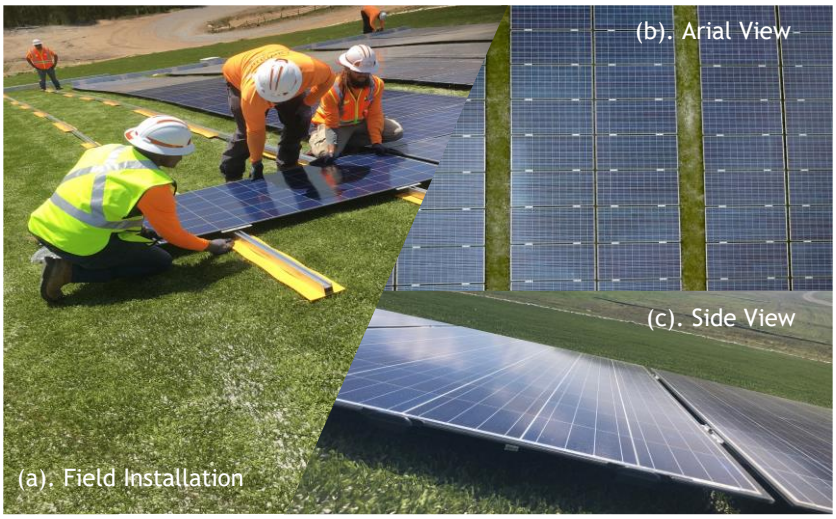

Figure 5. *Low-profile solar panel system, PowerCap™*

4 CASE STUDIES

4.1 Cranston Sanitary Landfill, Cranston, Rhode Island, US

The Cranston Sanitary Landfill is an MSW landfill located in Cranston, Rhode Island. It is also a formal USEPA Superfund site owned by the Cranston Sanitary Landfill Remedial Action Group. A total of approximately 9 hectares of the engineered turf cover, ClosureTurf, was installed on the landfill in 2015. A 3.5-MW community solar farm was installed on top of the engineered turf cover in 2021. It has turned the site that is otherwise undevelopable into a renewable energy resource, setting up an example of brownfield redevelopment. The solar project consists of more than 9,700 low-profile, ground-mounted solar panels. The solar panel frames are ballasted with concrete blocks for wind uplift protection (Figure 6).



Figure 6. *Solar farm installed on engineered turf cover at the Cranston Sanitary Landfill*

4.2 A confidential coal ash impoundment, Southeastern US

A formal coal ash impoundment located in the Southeastern US was closed with the engineered turf cover, ClosureTurf. A solar demonstration project was completed on the closed impoundment in January 2019. The solar project features the low-profile solar panel system, PowerCap. It consists of 120 solar panels with a total capacity of 39 kW installed on a portion of the 3 horizontal to 1 vertical (3H:1V) side slope of the closed impoundment (Figure 7).



Figure 7. *Solar panels installed on side slope of engineered turf cover*

Field inspection conducted in December 2022 indicated that after almost four years, the solar power generation system installed at the site had performed as expected. There were no signs that the underlying engineered turf cover had been affected by the solar panel system. An up-close review of the system (Figure 8) shows the intimate contact between the friction strip (shown in the black colour) and the engineered turf cover. No localized sand infill movement was observed in the area adjacent to the solar panels.



Figure 8. *Up-close view of solar panel after four years of installation*

4.3 Testanlage Deponie Leppe Landfill, Lindlar, Germany

The Testanlage Deponie Leppe Landfill (Leppe Landfill) located in Lindlar, Germany has been used as a research site to test innovative solar solutions since 2009. The test field where a PV solar panel system was installed on an exposed geomembrane cover was destroyed in a storm in 2018. The test field was rebuilt with the engineered turf solar solution in March 2023. The area of the test field capped with the engineered turf cover, ClosureTurf, is about 2,000 m^2 with a slope of 2H:1V (Figure 9). A total of 112 solar panels were installed with a total capacity of approximately 40 kW. The high interface friction between the friction strips and the engineered turf keeps the solar arrays stable on the steep slope. The simple configuration of the low-profile solar panel system made installation on the steep slope much easier and faster than other solar systems.



Figure 9. *Solar test field at Leppe Landfill*

5 SUMMARY

After a landfill has reached its capacity, it is required to be closed in accordance with regulatory requirements to protect the environment. The large landfill space can be beneficially reused for solar energy development. There are three main groups of final covers: soil-only, soil-geosynthetic, and geosynthetic covers. The traditional solar solution for landfills consists of a soil or soil-geosynthetic cover and a racking-supported solar panel system. The engineered turf solar solution consists of an engineered turf cover and a low-profile solar panel system. The engineered turf solar solution is developed to address challenges faced by the traditional solution, including soil erosion, vegetation management, and potential impact on final cover performance. It can save construction and post-closure maintenance costs, increase power generation, and transform closed landfills into renewable energy assets.

REFERENCES

Alam, M.J.B, Aggarwal M., and Ray, R.L. (2023). Performance comparison of evapotranspiration and engineered turf covers. Proceedings of Geosynthetics Conference 2023, 25-32.

Carlson, C., Zhu, M. and Ebrahimi, A. (2019). Hydrologic performance of synthetic turf cover systems and their equivalency to prescriptive cover systems. Geosynthetics Conference 2019, Feb. 10-13, 2019, Houston, TX, USA: 843-850.

De Abreu, R. and Franklin J. (2014). Design and installation of a geosynthetic final cover utilizing artificial turf in Louisiana. 7th International Congress on Environmental Geotechnics, ICEG 2014, Barton, ACT, Engineers Australia: 1397-1404.

Geosyntec Consultants (2015). Literature review and assessment of ClosureTurf UV longevity. Letter Report Prepared by Geosyntec Consultants for Watershed Geo, 15 May 2015.

Geosyntec Consultants (2022). Assessment of ClosureTurf UV longevity. Letter Report Prepared by Geosyntec Consultants for Watershed Geo, 22 November 2022.

Koerner, R.M., Husan, G.Y., and Koerner, G.R. (2011). Geomembrane lifetime prediction: unexposed and exposed conditions. GRI White Paper No. 6, Geosynthetic Institute, Folsom, Pennsylvania.

Scholl, B., Zhu, M., and Yuan, Z. (2023). Engineered turf landfill closure: how long will it last? Proceedings of Geosynthetics 2023, 143-151.

Zhu, M., Isola, M., and Zornberg, J. (2019). Advances in geosynthetic solutions for sustainable landfill design: geosynthetics really do last. GeoStrata: November/December 2019: 60-65.

Zhu, M., Scholl, B., and Joshi R. (2021). Landfill closure with engineered turf cover. Proceedings of Geosynthetics Conference 2021, February 22-25, 2021: 517-528.