ClosureTurf™
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Engineering Report

ClosureTurf™ has been extensively tested in the lab and in "real-world" applications for performance and durability.

The goal was to produce a system that performs better than current "Subtitle D" requirements and can resist the many common failure modes of today's closure covers. Traditional approaches to landfill closure have customarily involved the use of a vegetative cover. However, many of these cover systems have failed as a result of excessive erosion, gas pressure buildup, earthquake loads, poor maintenance and inadequate oversight procedures after site closure.

In response to numerous failures of these closure systems and associated rising costs, engineers have looked at new approaches in establishing a more stable and environmentally sound solution. An old solution to address cover failures and the associated environmental impacts is the implementation of exposed geomembranes. However, exposed geomembrane systems are still costly to maintain, are not wind resistant, and do not provide for an aesthetically pleasing solution. For these reasons, many state agencies do not grant final cover status to exposed geomembrane cover systems. After all, the geomembrane is still exposed to the elements for the entire duration of the application. The best approach still involves covering and protecting the underlying geomembrane, however instead of using two feet of soil to do it, it can be done with a specialized tufted geotextile ("engineered turf"), infilled with sand that has been engineered to perform better than the traditional soil cover.

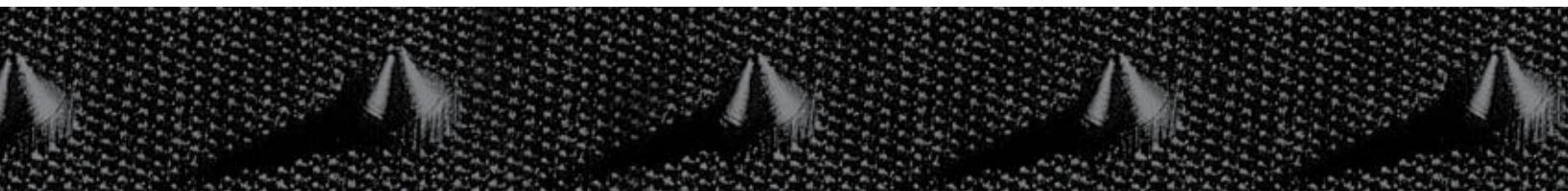
Combining an engineered turf infilled with sand and a highly transmissive structured geomembrane forms a system known as ClosureTurf. The next generation closure system, ClosureTurf has proven to be environmentally protective and more stable than traditional vegetative/soil solutions as a cover system.

The engineered turf technology was originally developed for professional sports venues. Over the last decade the market has expanded greatly and technology has improved dramatically. The latest generation of polyethylene material now provides excellent residual strength and color durability against UV light.

By combining the newest technology of engineered turf with a 50 mil thick geomembrane that has the highest interface friction available in the market, and adding approximately a 0.5 inch of sand for infill, the ClosureTurf system is quickly becoming the preferred choice among the engineering community for covering landfills, mines, industrial waste sites, and CCR storage areas. The product is proven to significantly outperform current closure methods while allowing engineers to deliver a sound solution with net savings to their clients.

The driving performance criteria for the product are stability, transmissivity and durability. These criteria serve to mitigate LFG emissions and liquid infiltration for a duration that extends well beyond the post-closure period. The graphs and charts represent a summary of the performance.

U.S. Patent Nos. 7,682,105 & 8,585,322
Canada Patent No. 2,663,170
Other Patents Pending



Stability

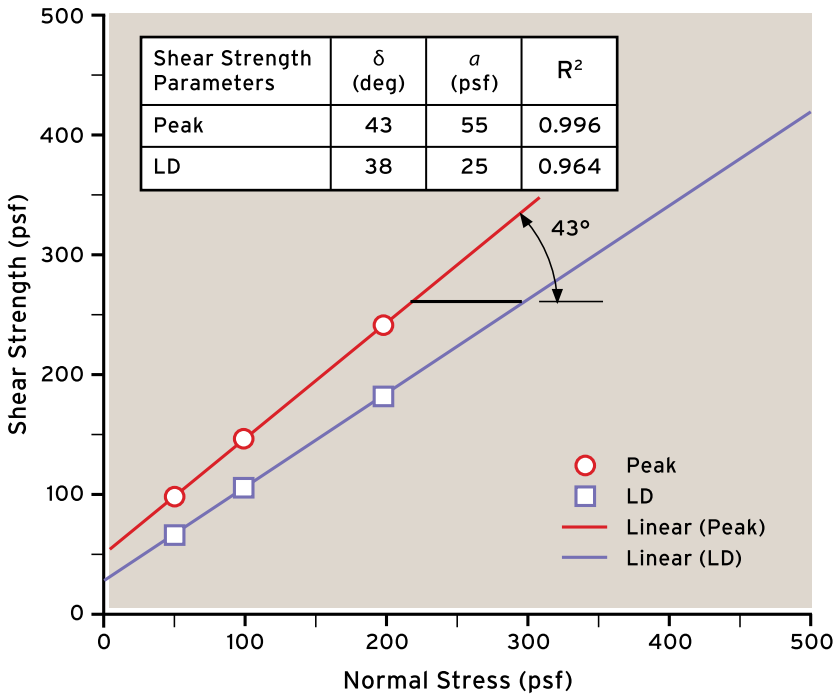
On landfills and mine piles, sliding of the soil cover along steep side slopes is of primary concern, particularly after major storm events. During a rain event, **the rainfall will penetrate quickly through the sand infill and drain directly in the drainage system below avoiding sand erosion and maintaining stability** of the sand infill. "**The infill is also held in place by the unique structure of the engineered turf** that traps the sand to anchor and ballast the engineered turf to the surface it covers. Note that:

- **ClosureTurf™ can be placed on very steep slopes**
- **Tests indicate 43 degrees interface friction value**
- **The slope stability safety factor can be calculated from the chart using the equation:**

  SF= tan φ/tan α

ClosureTurf System Interface Evaluation

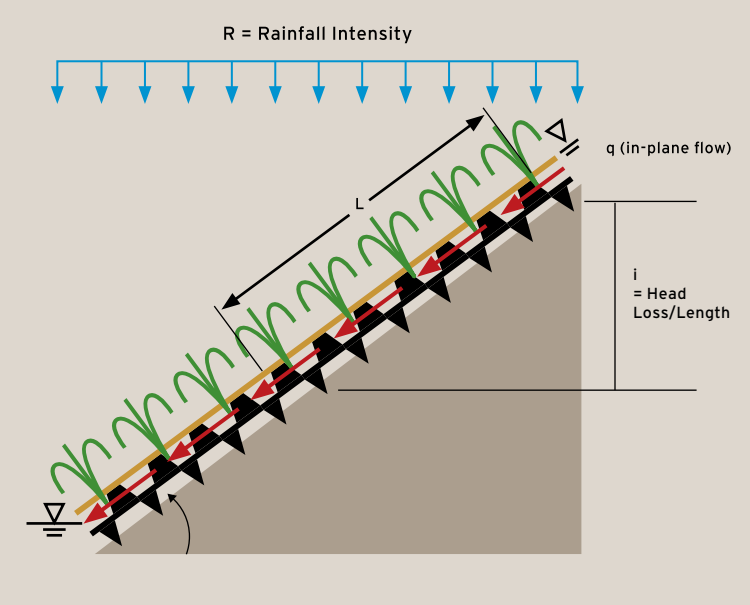
Slope angle	Slope	SF
34	1.5H: 1V	1.4
27	2.0H : 1V	1.9
18	3.0H: 1V	2.8
14	4.0H: 1V	3.7

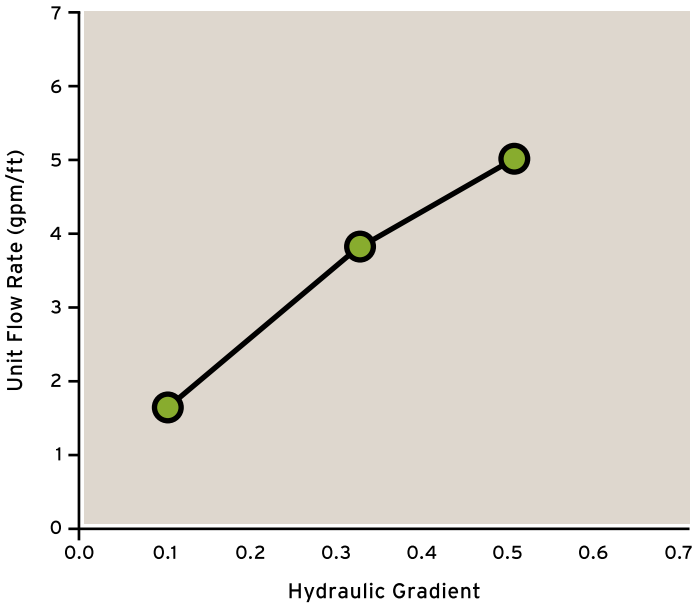


Drainage

ClosureTurf™ sand infill material is **stable on steep slopes under severe weather conditions.** The stability of the sand infill is controlled by the following product characteristics:

- **Percolation/Permeability**
- **Transmissivity**
- **Sand friction**
- **Grass interlocking grid**
- **Sand gradation**



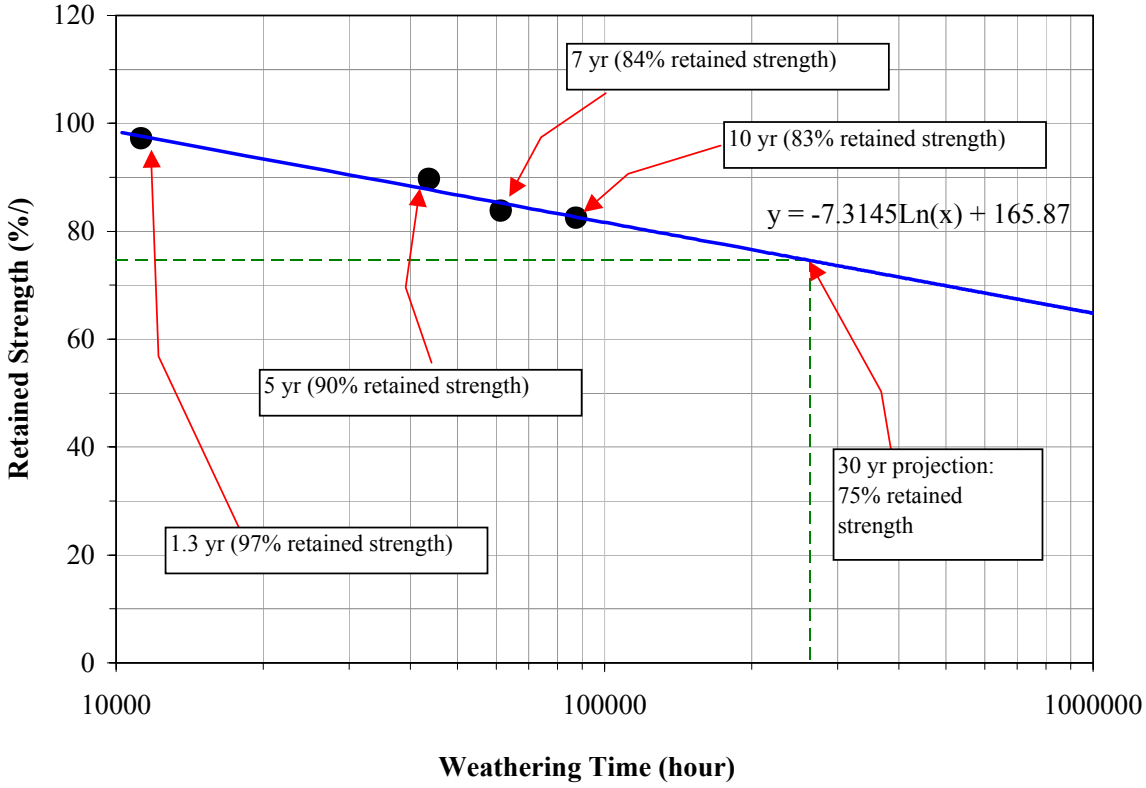


ClosureTurf was designed with the above characteristics in mind. The sand infill can handle **over six inches per hour of rainfall intensity without erosion** when applied on 3H:1V slopes.

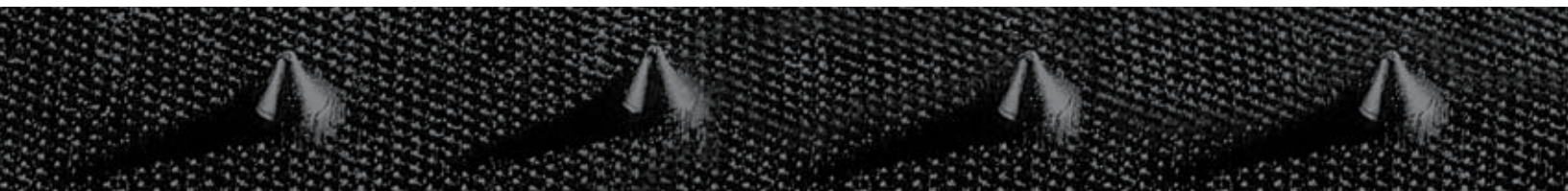
Rainfall penetrates quickly through the sand and into the structured drain liner below which has a very high transmissivity. The energy that could cause erosion is on the structured geomembrane and not on the surface of the sand. The transmissivity is presented in the graphic at left.

Weathering

Weathering Resistance For a Long Life



ClosureTurf™ is designed to provide weathering resistance and geomembrane protection when exposed to the **most extreme conditions**. Based on independent, real-world weathering tests performed at Atlas Material Testing Laboratories in New River, AZ. The tensile strength of the engineered turf fibers is projected to have 75% retention after 30 years. This means that with typical traffic loading forces, the material can provide over **four times the strength required after thirty years of extreme heat and UV exposure**. Based on the testing data collected and shown in the graph above, and data from many existing ClosureTurf projects, the system can **provide decades of reliable performance beyond the standard thirty-year post-closure maintenance period**.

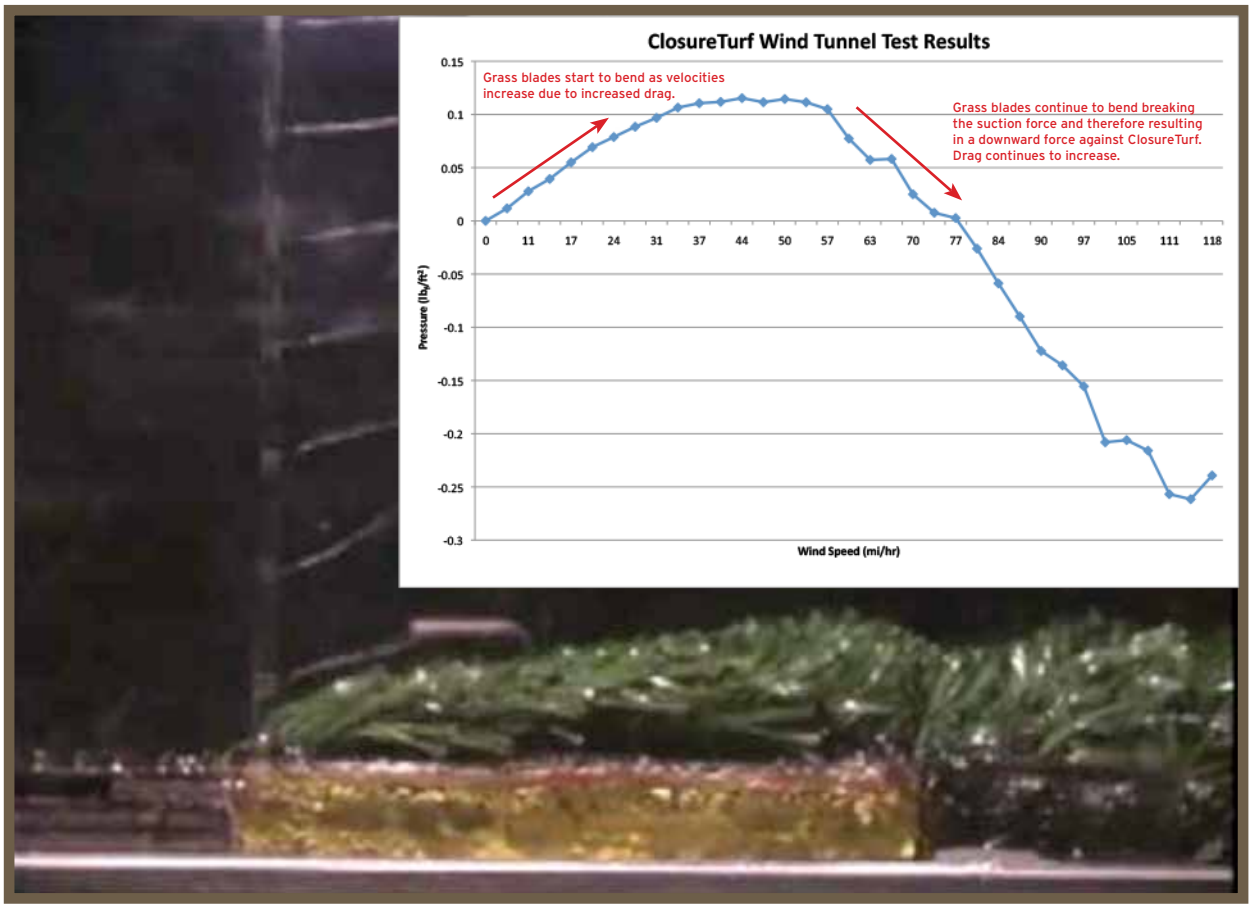


Wind Uplift Resistance

Wind Tunnel Testing at GTRI

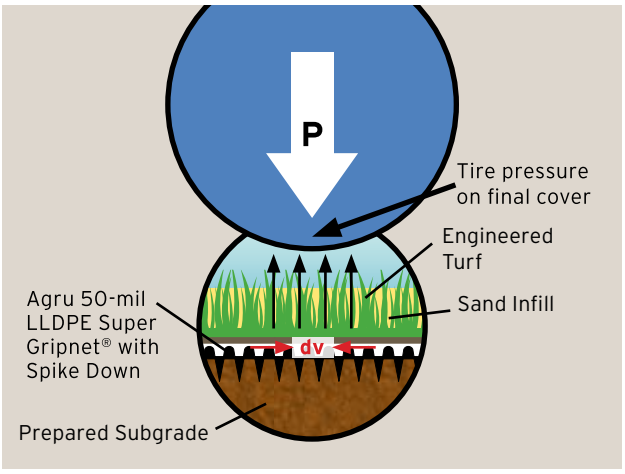
Since all exposed geomembranes are susceptible to damage from high winds, the technology must withstand these forces. A study was performed on the wind uplift reactions by Georgia Tech Research Institute. To complete their evaluation wind tunnel testing was performed. The ClosureTurf™ product indicated no uplift when exposed to 120 mph winds. This is in contrast with exposed geomembrane systems where extensive anchoring is required even for 30 mph winds.

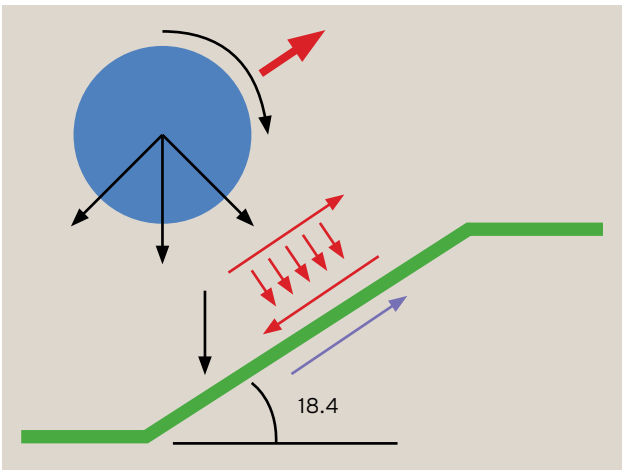
ClosureTurf technology provides features that help mitigate the forces of wind, such as a porous surface to break vacuum and engineered turf blades that will increase the aerodynamic boundary conditions and blades bending and reacting against the wind causing a resistance to the uplift.



Drivability

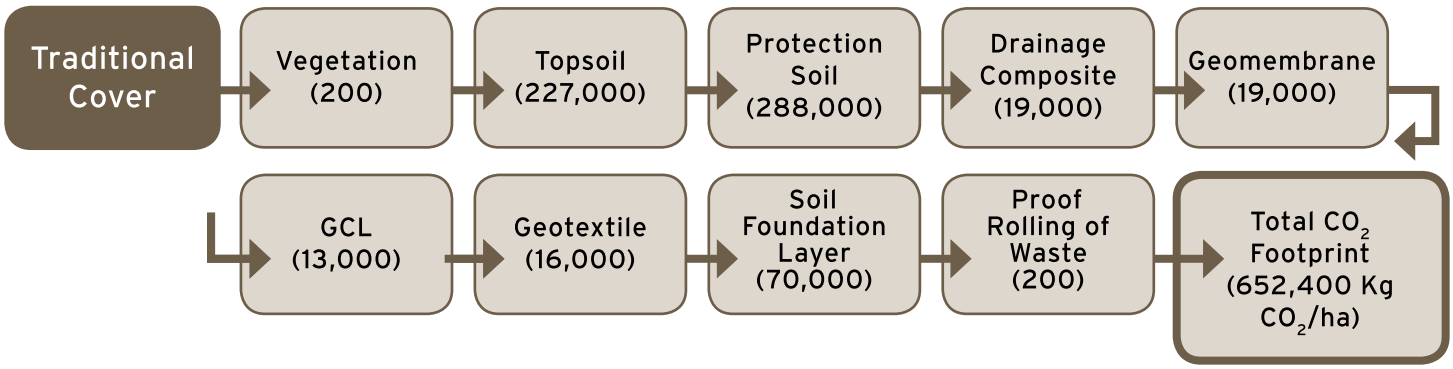
Gas system monitoring locations or wells in the landfill will have to be accessed by persons on foot or in vehicles. The typical exposed geomembrane closures, being fully exposed, would likely be damaged during access. Further, the geomembrane can be damaged by birds or other animals. All such damage to the geomembrane would have to be continually repaired and replaced at additional costs after construction. The ClosureTurf™ is thicker, covered with sand infill that not only ballast the system but also allows for access of a 60 psi tire pressure vehicle on 3:1 slopes and up to 90 psi tire pressure in flatter areas without being susceptible to damage.

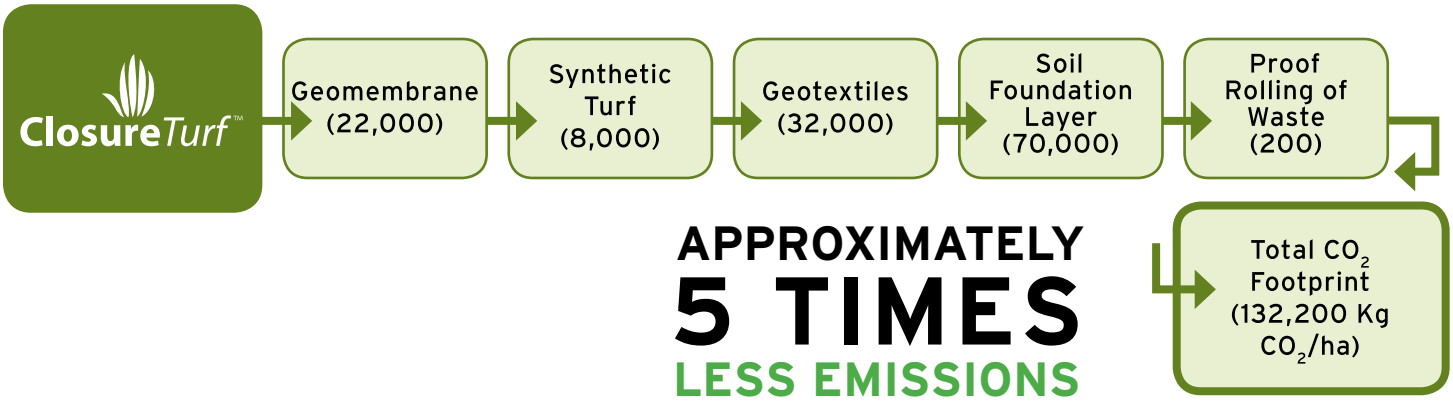




Sustainability

CO_2 Footprint: Traditional vs. ClosureTurf™ *





APPROXIMATELY
5 TIMES
LESS EMISSIONS

* Source; Koerner, R., "Traditional vs. Exposed Geomembrane Landfill Covers–Cost and Sustainability Perspectives," Geosynthetic Magazine, October 2012

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