

## PV ON LANDFILLS – A DUTCH CASE STUDY USING FLEXIBLE PV MODULES

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**ABSTRACT:** Un-doubtedly, there are great benefits from building PV systems on capped landfills and other waste containment sites. These projects revitalize otherwise unusable property at lower land costs. In this paper the authors describe a field test and case study for capping a Dutch landfill with a solar capping layer. Technical feasibility of the capping could be demonstrated in the field test. Scenarios for economic feasibility were calculated. Results show that the exposed geo-membrane solution is very promising in terms of performance, applicability and financial sustainability.

**Keywords:** Landfills, a-Si, Integrated system

### 1 INTRODUCTION

Spread over the Netherlands there are more than 4,000 landfills, with a total area of approximately 9,500 ha. Since 1980, only so-called IBC landfills (Isolate, Control and Monitor) are active. These landfills are covered by the Environmental Management Act and comply with strict environmental requirements. For example, pollution dusts should not leak from the landfill into the groundwater, and the landfill sites will be provided with both a bottom seal (at the beginning) and a top seal (when closed). These IBC landfills together comprise an area of approximately 1400 hectares, of which 850 hectares have to be sealed in the future. The decrease in the number of active landfills does not mean a decrease of the problem: landfill sites require perpetual care. The Environmental Management Act sets the province responsible for the perpetual after-care of landfills which have been landfilled after 1 September 1996. The closed landfills can be considered as 'lost space': because of the contents of the landfill, a new destination is only in very limited cases possible. Most closed landfills do not get a new destination, the scarce land can no longer be used for any other purpose.

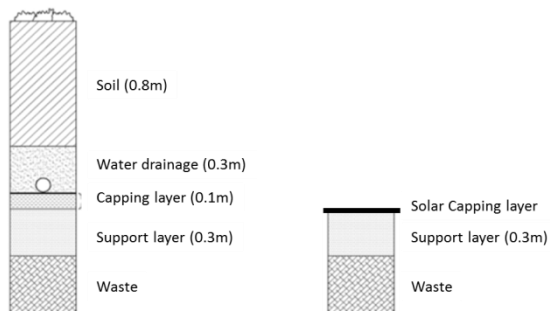


Figure 1: Traditional landfill sealing (left) compared to exposed geomembrane solar capping landfill sealing (right)

### 2 CONSIDERATIONS WHEN DESIGNING A PV SYSTEM ON A LANDFILL

The following constraints make the installation of solar PV on top of a landfill a challenge. For each landfill, its characteristics have to be evaluated and studied for feasibility. Finally the limited experience of

PV in landfills is crucial since the first systems were installed relatively recently around 2010.

#### 2.1 Challenges for installing solar PV on landfills

Despite the great potential of integrating PV on landfills, there are certain constraints that limit this application:

a) **Puncturing of the capping membrane:** The first priority for any landfill is that it should remain eternally covered. This is achieved using a high quality sealing of certified HDPE geomembrane and soil cover on top. The roots of grasses and other vegetation on the soil cover prevent the soil from washing away and exposing the HDPE geomembrane. Installing solar panels on top of the landfill causes the plants to die and the ground beneath it washes away. Additionally, the foundations and fastening frames for the panels can pierce the geomembrane film. This is a risk and hence the PV panels have to be mounted in such a way that it does not damage the HDPE geomembrane.

b) **Waste settlement:** Another common problem is that the surface of the landfill is not well defined. Depending on the type of waste material composition, the waste may decay at different rates throughout the landfill resulting in uneven surface of the landfill. This surface will be difficult to deal with when installing regular solar systems. The uneven surface causes stress on the mounting systems which may result in misalignment of arrays and hence decrease the energy production.

c) **Slope, orientation and stability:** Many landfills have steep slopes ( 15-30 degrees ), and as the slope increases, the complexity of the PV system design increases, resulting in increased system costs. Installing PV arrays on steep slopes can lead to system design challenges associated with wind loads, soil erosion and foundation stability. These challenges often lead to increased system costs for traditionally anchored PV systems. The orientation (or azimuth) of the slope is also important. Generally the developers prefer south facing slopes to provide sufficient exposure to the sun over the course of the year. Slopes with orientations outside of 20-30 degree range of due south typically result in lower annual energy production from the PV system and will require additional design work and system layout modifications. The soil stability of the slope is another relevant engineering consideration. The soil has to withstand both the construction and operation of the PV system. The installation of the solar arrays on steep slopes can be

challenging as the weight of the system places additional force on the slope and can lead to failure if the system is not properly designed.

## 2.2 An overview of PV integration methods on landfills

Various research and commercial projects have been conducted worldwide covering landfills with PV. In these projects, the following techniques were implemented to integrate PV on landfills.

a) **Solar panels mounted on the ground:** This technique has been used on majority of the projects worldwide. The landfill seal utilizes a HDPE foil and on top is covered with a thick soil layer. The PV system is mounted on top of the soil layer. For this technique, there are numerous examples worldwide. Figure 2 shows an example of the ground mounted PV system on the Canton landfill, Massachusetts. This technique, however, can only be applied to flat surfaces or surfaces without significant slope. If the slope is too steep, the soil will erode causing the HDPE foil to be exposed. Hence this technique is not suitable for landfills with steep slope.



Figure 2. Aerial view of 5.75 MW Ground-Mounted Solar System installed on the Canton landfill, Massachusetts

b) **Solar panels mounted top on top of an erosion protection layer:** To counter the problem of erosion of top soil layer, an additional erosion protection layer is applied. This additional erosion protection layer can be, for example, concrete or an anti-root geotextile. The advantage of this technique is that it ensure that rain water can easily drain from the surfaces thus ensuring that water does not drain into the landfill body. However the disadvantage is that there are additional costs for placing this erosion protection layer. An example of PV system using this technique is shown in Figure 3.



Figure 3. 3.8MWp PV system in Lunenburg landfill

c) **PV integrated geomembrane:** PV integrated geomembranes are emerging PV technology solutions for landfill applications. A PV integrated geomembrane is a landfill cover, typically made of a TPO (Thermoplastic

polyolefin) material, which can be used in place of a vegetative or final cover on the landfill. The PV integrated geomembrane provides good cover stability, reduces maintenance costs of the landfill cover, reduces erosion and infiltration of rainwater into the landfill body. A famous example for this technique is the PV integrated geomembrane in Hickory Ridge Landfill shown in Figure 4. Here, the thin film solar panels are glued on top of green colored TPO geomembrane covering the landfill. The geomembrane is made of high strength material for outdoor exposure. The geomembrane covered landfill slopes provide an ideal, clean and stable surface for the thin-film panels to be directly glued on top of it.



Figure 4. PV integrated geomembrane at the Hickory Ridge landfill in Georgia

## 3 FIELD TEST AND CASE STUDY

### 3.1 Field test

In this project the consortium has developed a landfill PV approach based on an exposed geomembrane solar capping. In figure 5 the installation of the solar capping can be seen, on an active landfill slope situated in Maasvlakte, the Netherlands.



Figure 5. Installation of the exposed geo-membrane solar capping phase I

The field test was installed in two phases, with two adhesion methods used.

Table 1. Summary of the two phases of the field test

Parameter	Flexible module v1	Flexible module v2
System rated size	1,1 KWp	3 KWp
PV module technology	a-Si single junction	a-Si single junction
Temperature coefficient	0,20%	0,20%
Inverter type	Fronius Symo 4.5 3-M	Fronius Symo 4.5 3-M
Inverter rated efficiency	97,2%	97,2%
Installation time	Oct-15	May-16
Number of modules	20	60

Precision shunts and voltage transducers were used to measure the DC currents and voltages respectively. DC power was then calculated using the measured voltage and current. AC power was measured with the help of AC power meters. Module temperatures were measured using thermocouples located at the back of the panels. In plane-irradiance was measured using a pyranometer installed in the same plane as that of the PV panels. Additional information such as the ambient temperature and wind speed was imported from the weather station “Hoek Van Holland” which is the closest located station to the site. Data acquisition was done by means of a data logger. A sampling interval of 5 minutes was chosen for all the DC parameters. The energy on the AC side was recorded every hour by AC power meters. Important performance metrics were calculated such as the Performance Ratio and specific yield.

3.2 Case study

The wealth of data acquired during the field test period was utilized to perform a case study simulation based large scale PV plant, covering the entire south slope of the landfill which is approximately 7 hectares. To get an estimate about the usable area for the PV plant, a 3D model of the entire landfill was made with the help of SketchUp. The side view of the landfill model is shown below in Figure 8 with the south slope indicated by the white region. The roads are indicated by the brown region and the green region represents grass.

The total installed capacity assuming a-Si single junction solar modules is around 1.1MWp with an annual yield of 1110 MWh/year (PVsyst) or around 76% PR. The energy produced from the PV plant can be utilized for the operation of the waste and water treatment plants on the landfill site. There water purification unit is a water purification facility that runs continuously for 24 hours, 7 days a week consuming approximately 760 MWh per year. The Ashes Immobilization unit runs 9 hours daily except weekends consuming around 490 MWh per year.

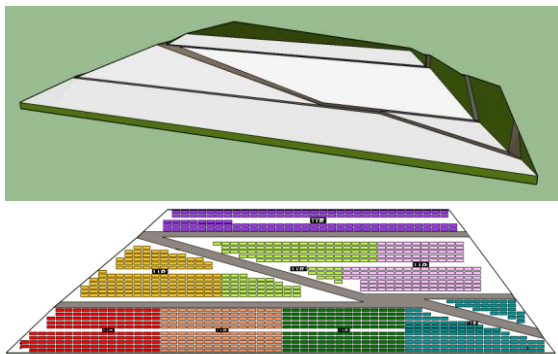


Figure 6. South slope of the landfill designed in SketchUp (top) and array layout including module groups and inverters (bottom)

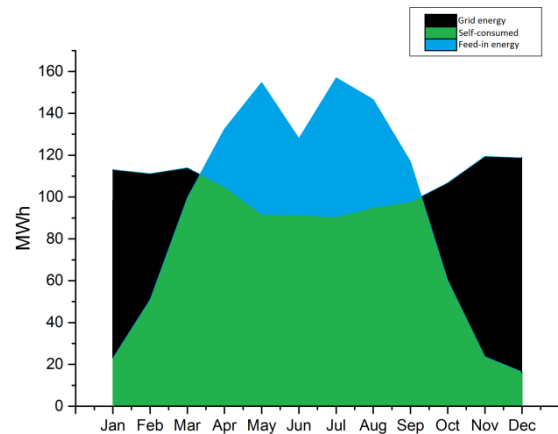


Figure 7. Comparison of monthly PV produced and consumed energy by the facilities of the landfill

Figure 7 shows the correlation of produced and consumed energy throughout the year for this layout. While the consumption is lower during summer months due to less water pumped for purification the PV production is higher. The excess energy can be then fed back to the grid. The produced energy during winter months cannot fulfill the energy needs of the water purification units and thus extra energy has to be supplied by the electricity grid.

3.3 Scenario modeling

Finally, we performed cost scenario modeling to explore the performance and economics of the landfill capping in various boundary conditions. Based on publicly available data and in-house calculations we estimated the investment costs required for the PV plant in the layout of section 3.2 to be above 1.50 €/Wp, which does not make it an attractive investment yet. We used scenario modeling to explore possibilities to get the costs down. Figure 8 shows the effect of the scenario calculations on projected PV plant capacity and investment costs.

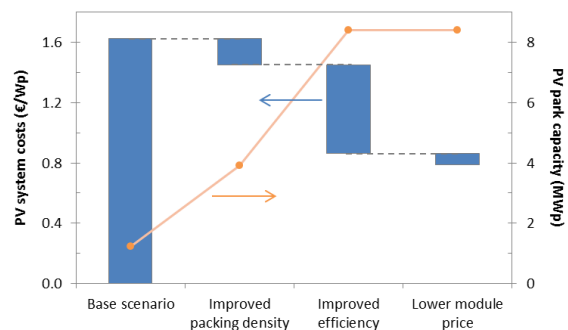


Figure 8. Scenario calculations for investment costs (left axis) and PV plant capacity (right axis) in the base case, and with scenarios of higher packing density, improved efficiency and lower module price.

- (1) Higher packing density. As can be seen in Figure 7 the packing density of modules on the geomembrane was quite low. By using larger modules and packing them more closely together, the PV capacity could increase from 1.2 to 4 MWp.
- (2) Higher efficiency. We used single junction amorphous silicon modules in the field test and case

study. By adopting a higher efficiency cell architecture the capacity of the PV plant could increase to 8 MWp. If the module manufacturing costs per m<sup>2</sup> remain similar a significant cost reduction could be reached as well.

(3) Lower module price. By increasing the market for flexible PV modules a further cost reduction of flexible modules towards the level of glass based modules can be foreseen.

#### 4 CONCLUSION

We have investigated the use of a solar capping layer on Dutch landfills, and can draw the following main conclusions:

- Landfills can be a good opportunity for PV deployment. It is 'waste-space' without other possible uses and requires perpetual care that could be paid for by the revenue stream of the PV plant.
- There are many challenges in applying PV on landfills, such as settlement of the waste, erosion on the top layer and avoiding puncturing of the capping layer.
- A solar capping layer is a good option to overcome the challenges. On top of that it provides a potential cost advantage by making the landfill capping thinner. A solar capping layer consists of an exposed geomembrane with integrated PV modules.
- We have demonstrated the technical feasibility of a solar capping layer on a landfill in Maasvlakte, The Netherlands.
- The economics of the solar capping are promising, but also need further attention. It is a highly attractive investment if packing density can be increased, the efficiency of the flexible PV modules can be increased, and the cost of the flexible PV modules can be lowered.

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