Feasibility Study of Solar Generation Facilities: Are CCR Landfills A Viable Location

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Feasibility Study of Solar Generation Facilities:

Are CCR Landfills a Viable Location

Beachy, Jaden
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This report will examine the feasibility of constructing and operating a solar generation facility on a coal combustion residual landfill. The total generation capabilities of a generation facility located near Nashville, Tennessee will be compared to the total cost of construction, including but not limited to Photovoltaic panels, construction materials and labor.
Introduction

In 2016, the United States produced 4.1 trillion kilowatt-hours of electricity and all of that production comes from five key forms of electrical generation: natural gas, coal, nuclear, petroleum and renewable sources (1). Natural gas and coal are the foundation of electrical production for the United States power grid producing 64% of all electricity used throughout the country, over four times the output of all renewable energy put together, (1). In most standard fossil fuel generation stations, natural gas or coal are burned to produce large amounts of heat, which is then used to turn water into steam. This steam then used to spin turbines attached to generators that produce the electricity. They are a reliable, cheap and relatively safe way to produce constant amounts of electricity while also being able to increase output in times of high consumption. However, natural gas and coal, commonly referred to as fossil fuels have several major drawbacks. The largest and most discussed drawback of these fossil fuels is the large amount of carbon dioxide and other emissions released by fossil fuel generation stations. For example, in 2014 the United States produced 5,410 million metric tons of carbon dioxide emissions, at 2040 million metric tons, electricity production was the largest contributor to the total output (2). Natural gas and coal both contribute to that production with coal making up around seventy-six percent of the emissions from electricity production (2).

In a world with a changing climate, impacted by rising carbon dioxide levels, it is clear that continuing to rely on fossil fuels, such as natural gas and coal, as a main form of electrical production may be an unwise course of action. Turning to renewable forms of electricity such as solar, wind, geothermal or hydroelectric generation stations must become a priority to power generation companies and regulating agencies in order to reduce future environmental impacts. While hydroelectric stations and wind farms are more efficient than solar generation, both of these are cost prohibitive and geologically restricted to very specific areas. Solar generation can be used in a variety of different ways and is a viable option anywhere that receives moderate amounts of sunshine. One area already available to many power generation companies for potential solar generation sites, are onsite coal combustion residuals (CCR) landfills. Many coal burning generation stations have these facilities to store their CCR materials. During the combustion process, the majority of the coal is turned into fly ash, which
exits the boiler and is removed in the plants smoke stack (3). Combustion also leaves larger pieces of ash and impurities from the coal that did not burn; these heavier components settle at the bottom of the boiler and are known as bottom ash (3). Finally, material from the flue gas desulfurization (FGD) scrubber stack, which combines the combustion gasses (specifically sulfur dioxide) with limestone and water, are collected via elaborate dewatering and conveyance systems (3). Some of these components, like fly ash and the synthetic gypsum produced by the FGD scrubber, can be sold and reused in commercial processes like the making of concrete and gypsum board. However, every year millions of tons of this these materials must be properly disposed of, typically at on site CCR landfills. These extensive landfills provide an ample opportunity for the installation of large solar facilities for several reasons. The landfills are massive, often reaching over one hundred acres in size and they also have strict lining and capping requirements that prohibit large vegetation growth on the landfill, which leaves immense open spaces for the installation of solar fields (4). Another key advantage is that the generation company already owns the land and because of the strict regulations surrounding the landfills, must continue to monitor the landfill for up to 30 years after it is closed (4).

Solar generation facilities located on CCR landfills may provide generation companies with, not only a secondary form of generation, but also a way to turn large empty spaces into a beneficial reuse area, while protecting and benefitting the environment at the same time. This project will study the feasibility of installing a solar generation facility on an existing and on a proposed CCR landfill. The potential production capabilities, anticipated cost and other challenges will be discussed in detail.

**Panel Selection**

One of the most critical keys in making these solar installations economically viable to the generation companies is choosing the correct form of solar panels. A general inquiry into the types of solar panels yielded an extensive list of nearly twenty-five different types of solar panels; however, most of these panels are in a purely experimental or possibly conceptual phase. This extensive list can be narrowed down into four main types of photovoltaic (PV) cells: Monocrystalline silicon, Polycrystalline silicon, Amorphous silicon, and Hybrid cells (5). As the
names dictate, the majority of current PV cells are created using cast silicon, a photovoltaic material. Currently, the main difference between the most common types of cells is not what they are made of but how they are manufactured. In the future however, the photovoltaic material may change as some newer experimental cells have begun using heavy metal compounds such as Cadmium Telluride and copper indium gallium selenide (CIGS)(5).

To narrow the scope of this research, this feasibility study will only examine Monocrystalline and polycrystalline PV cells. While hybrid cells offer distinct advantages in certain applications, like high temperature areas, the moderate efficiency combined with high cost do not mesh correctly with large scale generation projects such as this one (5). Amorphous or thin-film PV cells will also be disregarded in this study. While they have massive potential for applications in unique places such as sky scrapers and electronic devices, their main advantage of being light weight is not important in this project (5). Thin-film PV cells are also incredibly inefficient at around 6-8 percent and degrade quickly over time, making them unsuitable for sustained generation (5). Finally, developing cell technologies such as the Cadmium Telluride cells will be disregarded due to the lack of research on the technology, extreme cost and availability to general consumers.

Monocrystalline silicon and Polycrystalline silicon cells are by large the most common type of PV cells produced in the world today, constituting ninety-three percent of the world’s total PV panel sales (5). The manufacturing of all crystalline PV cells begin with the same process: the purification of silicon crystalline (6). Silicon is one of the most abundant elements on earth and is found primarily in the form of sand, though before it is used in PV cells the majority of impurities must be removed from the silicon (6). This process starts by delivering sand, a mixture of SiO₂ and carbon the production facility, and melted in a blast furnace at about 3200 degrees Fahrenheit (6). The next step of production in purified silicon is based on the potential use of the end product. If the silicon is destined to be in electronics the purification includes a multi-step and high energy refining process, which results in 99.9999999% (9N) pure silicon (6). For PV cells this purity is cost prohibitive and unnecessary. Silicon for PV cells is purified by blowing gasses through the molten element to remove impurities like boron and phosphorus,
this process is typically proprietary and dependent on the manufacturer (6). These simplified processes typically result in a silicon that is 99.999 (5N) pure (6).

Once the silicon has been purified the next step of the panel production is dependent on the type of panel. As the name implies, in a Monocrystalline panel the silicon wafers will be from a single crystal of silicon. To form this crystal a small silicon crystal seed is repeatedly dipped into and drawn out of a vat of molten polysilicon while rotating. By continuing this method, known as the Czochralski process, a large ingot that is composed of a single crystalline structure with the desired diameter can be created.
After the silicon ingot has reached the proper diameter, the Czochralski process is stopped and the ingot is sliced into thin wafers of monocrystalline silicon. These circular wafers are then cut into more suitable shapes, typically hexagons, to allow more of them to fit into a single panel (6). The scraps collected from shaping the wafers can be collected and reused in the process to create polycrystalline silicon wafers, in the process described below.

Unlike Monocrystalline panels, polycrystalline silicon panels are not made with a single crystalline structure. Instead they are made from melting the individual grains of silicon together. The same grade of silicon is used but instead of the Czochralski process being used to make an ingot, large amounts of silicon are melted and cast into a mold (6). Most often the mold is shaped as a cube to allow wafers to be cut directly from it without further shaping.

The two different methods of producing these cells results in two distinct products each with its own benefits and drawbacks. Because the monocrystalline PV cells are created from a single crystalline structure, they have a slightly higher efficiency than their polycrystalline counterparts, at around 15-20 percent and perform better in low light conditions (8). Because of this higher efficiency, the number of panels and attached infrastructure can be reduced thus...
lowering cost of a system generating the same amount of energy. Monocrystalline PV panels are also given a longer lifespan than polycrystalline panels, many with warranties of 25 years or more (5). However, there are some major drawbacks to using monocrystalline cells, the largest of which, is cost. Because the cells are created using a rather complex process the cost of each cell is higher than the cost of polycrystalline cells. As well as being expensive, the complex process surrounding monocrystalline cells also results in large amounts of wasted silicon during the cutting process (8). While polycrystalline cells are slightly cheaper and waste less material than monocrystalline cells, their major drawback is they hover around 13-16 percent efficiency, which is notably less than monocrystalline cells (8).

**Location Selection**

The ultimate goal of this research is to determine the feasibility of implementing these solar generation projects, which means selecting not only the best type of panel but also determining which brand of PV panel should be used. As earlier determined, this project will focus on only crystalline silicon PV panels. Data on the available PV panels including cost, efficiency, size and power output will be collected and compared to determine the best possible outcome. Because many landfills range dramatically in size and orientation, the calculations for generation capabilities, and eventual profit, will be based on a per acre system. In other words, the available panels selected will be arranged in a one-acre layout and the power generation from each PV installation will be calculated. CCR landfills are located all across the United States and are subjected to varying amounts of sunlight. To avoid over or underestimating the power production of a PV installation in this application by selecting one location, an average location of a network of existing CCR landfills will be used for this fictitious generation facility. Because of their publically available information and brand recognition, this study will determine an average location based on the locations of Tennessee Valley Authority (TVA) CCR landfills. The TVA power generation company was also chosen because of their previous success with implementing solar installations as a source of electrical generation. Figure 3 below shows the locations of all TVA CCR landfills. Once the addresses of all TVA CCR landfills were collected they were input into a geographic midpoint calculator. The exact calculator used was the free to use calculator available at www.geomidpoint.com (9) (10). This geo-calculator produced an average
latitude and longitude based on the latitudes and longitudes of all ten TVA sites that have a CCR disposal site. As figure 4 below shows, the average location of all TVA CCR landfills is the southeast corner of Nashville, Tennessee (10). The power generation of any of the selected PV panels will be based on this location. It will be assumed that any generation facility located north of the estimated central location (Paradise, Shawnee) will be less efficient and any facility located south of the center (Allen, Colbert) will be slightly more efficient. The six other plants are close enough in latitude to the central location that generation at these facilities is expected to be similar to that of the central location. In order for these projects to be considered feasible, electricity generated at any facility will have to be sold to recoup the investment cost. As the map shows, TVA’s existing generation facilities cover the majority of Tennessee, in fact TVA claims to provide service to all 95 counties in Tennessee and have a service area of 42,028 square miles, 99.7 percent of the area of Tennessee (11). Because of this, it will be assumed that the average price of electricity in Tennessee is the average price that TVA will be selling the electricity generated by solar facilities.

Figure 3 shows the approximate location of all Tennessee Valley Authority (TVA) coal combustion residual (CCR) landfills. Plants are located in Kentucky (Paradise, Shawnee), Tennessee (Gallatin, Cumberland, Johnsonville, Allen, Kingston, Bull Run, John Sevier), and Alabama (Colbert).
Panel Selection

Since the type of panel and general location of the generation facility have been determined the next phase of research is determining available manufacturers and their respective PV panel options and selecting the most suitable option. On January 22, 2018, United States President Donald Trump announced the implementation of a 30% tariff on all imported PV cells (12). In order to avoid this tariff and any additional complexities it may add to the calculation of cost for a new solar generation facility, only panels manufactured within the United States will be considered for this project. This stipulation also has the opportunity to reduce shipping cost of panels in comparison to panels available from China. Several companies will be considered for this research: Heliene, Itek Energy, Mission Solar, Seraphim, Solaria, SolarTech Universal, SolarWorld Americas, and Tesla/Panasonic (12). As stated these companies all produce PV panels within the United States and are known reputable companies. The top panels from each company will be selected and compared. Table 1 shows the cost, power output, size and efficiency of all of the selected panels. On all of the data sheets provided by the PV
manufacturing companies, the maximum power output of the cells under standard testing conditions (STC) are provided. However, these testing conditions do not represent real world conditions, so a more realistic power output must be calculated; this is known as the nominal operating cell temperature power output (14). All manufacturers provide the STC temperature and the NOCT, which is based on 800w/m² with 20 degrees Celsius ambient temperature and a 1 meter/second breeze, of the panel (14). For every panel selected and shown in table 1, the NOTC temperature is approximately 25 degrees higher than the ambient temperature.

Nashville, Tennessee has an average temperature of 59.55 degrees Fahrenheit or 15 degrees Celsius (13). This means that the PV panels will be operating at roughly 40 degrees Celsius on average. Each panel data sheet also provides value of efficiency decrease for every degree the temperature ranges from the given NOCT. To simplify the evaluation of the panels and based on the average temperature discussed previously, this study will assume that the panels are operating five degrees from the NOCT.

Table 1, shown below, shows the critical information of each PV cell analyzed during this study. All information, excluding cost, was extracted from product data sheets available in appendix A.

<table>
<thead>
<tr>
<th>Company</th>
<th>PV TYPE</th>
<th>Power Output (Watts)</th>
<th>Efficiency (%)</th>
<th>Size (ft²)</th>
<th>weight (lbs)</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panasonic</td>
<td>mono</td>
<td>330</td>
<td>19.7</td>
<td>18.02</td>
<td>40.81</td>
<td>$392</td>
</tr>
<tr>
<td>Solartech Uni.</td>
<td>mono</td>
<td>320</td>
<td>20.2</td>
<td>17.83</td>
<td>40</td>
<td>$340*</td>
</tr>
<tr>
<td>Solaria 350</td>
<td>mono</td>
<td>350</td>
<td>19.4</td>
<td>19.47</td>
<td>46</td>
<td>$400</td>
</tr>
<tr>
<td>Seraphim 360</td>
<td>mono</td>
<td>360</td>
<td>18.55</td>
<td>20.89</td>
<td>52.9</td>
<td>$333</td>
</tr>
<tr>
<td>Mission Solar</td>
<td>mono</td>
<td>365</td>
<td>18.46</td>
<td>21.37</td>
<td>47.6</td>
<td>$400*</td>
</tr>
<tr>
<td>ITEK 370</td>
<td>mono</td>
<td>370</td>
<td>18.55</td>
<td>21.47</td>
<td>49</td>
<td>$400*</td>
</tr>
<tr>
<td>Suniva</td>
<td>mono</td>
<td>340</td>
<td>17.43</td>
<td>21</td>
<td>50.7</td>
<td>Bankrupt</td>
</tr>
<tr>
<td>Sunmodule</td>
<td>mono</td>
<td>350</td>
<td>17.54</td>
<td>21.47</td>
<td>47.6</td>
<td>$334</td>
</tr>
<tr>
<td>Heliene</td>
<td>mono</td>
<td>490</td>
<td>18.9</td>
<td>27.59</td>
<td>83.7</td>
<td>Not In Production</td>
</tr>
</tbody>
</table>

Note: Panel price based on similar panel models. All other prices based on publically available purchase data.

In addition to a controlled temperature, during testing, it is assumed for all panels that there will be a production of 1000watts/meter squared of PV area. However, real world conditions do
not often allow for such a high production rate. To adjust for this the production of each panel is reduced to 800watts/square meter of PV area. Table 2 below shows the adjusted efficiency of each panel as well as the adjusted output of each panel with regards to temperature and radiance. It is notable that even with very high efficiency panels, there is a significant drop in production of each panel once radiance level is adjusted. Because the total production potential and cost analysis of each PV generation facility will be based on a per acre comparison, the watts/area of PV panels in square feet was determined. Based on the findings from Table 2, the panels with the best Wattage production per area, the Panasonic 330 and Solartech Universal 320, were selected as the top panels to use. The final panel selection was based on the availability of the actual panels. The Panasonic 330 was easily found at multiple locations and pricing data was easily found, the Solartech panel however was difficult to price and finding installers was also more difficult. For this reason the Panasonic 330 was selected as the proposed panel for the remainder of the feasibility study.

Table 2, below shows the actual predicted output of the selected PV panels as well as the watts/square foot each is capable of producing.

<table>
<thead>
<tr>
<th>Panel</th>
<th>Temp Reduction Factor %/°C</th>
<th>Adjusted Efficiency</th>
<th>Output</th>
<th>Watts/Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panasonic</td>
<td>-0.258</td>
<td>18.41</td>
<td>247</td>
<td>13.7</td>
</tr>
<tr>
<td>Solartech Uni.</td>
<td>-0.344</td>
<td>18.48</td>
<td>245</td>
<td>13.7</td>
</tr>
<tr>
<td>Solaria 350</td>
<td>-0.390</td>
<td>17.45</td>
<td>253</td>
<td>13.0</td>
</tr>
<tr>
<td>Seraphim 360</td>
<td>-0.400</td>
<td>16.55</td>
<td>257</td>
<td>12.3</td>
</tr>
<tr>
<td>Mission Solar</td>
<td>-0.377</td>
<td>16.58</td>
<td>263</td>
<td>12.3</td>
</tr>
<tr>
<td>ITEK 370</td>
<td>-0.390</td>
<td>16.60</td>
<td>265</td>
<td>12.3</td>
</tr>
<tr>
<td>Suniva</td>
<td>-0.335</td>
<td>15.76</td>
<td>246</td>
<td>11.7</td>
</tr>
<tr>
<td>Sunmodule</td>
<td>-0.420</td>
<td>15.44</td>
<td>246</td>
<td>11.5</td>
</tr>
<tr>
<td>Heliene</td>
<td>-0.390</td>
<td>16.95</td>
<td>348</td>
<td>12.6</td>
</tr>
</tbody>
</table>

**Facility Design**

To determine the power producing capability of the PV generation station the total output of one acre of solar panels must be determined. In order to get a realistic production value the panel area must be calculated assuming the panels are arranged properly in the field, meaning space has been left to allow for maintenance of the panels as well as necessary landfill
maintenance and operation. Because the panels will be slightly elevated and tilted to maximize the amount of direct sunlight on them, spacing between rows of panels is also important to ensure that one row of panels does not cast substantial amounts of shade onto another row.

To determine the optimum spacing of the panels, the first step was determining the angle at which the panels sit. There are three typical methods for mounting solar panels: fixed, adjustable, and tracking (15). On small installations where getting the most out of a minimal system is crucial, the most advantageous method of mounting is to use a tracking system. By turning the panels to follow the sun's path and adjusting panel angle to optimum levels these systems can increase production of the system by up to ten percent in the summer and nearly forty percent in the winter (15). However, these systems are more complicated and would add a major expense to a large solar generation facility, for this reason tracking systems will not be considered for this feasibility study. Adjustable mounting systems are slightly more complicated than fixed systems but are substantially less complex than tracking systems. Rather than relying on computer systems to constantly move the panels with the sun, adjustable systems rely on the manual adjustment of the panel angle by facility personnel. The adjustable systems are work by changing the angle of the panels to better capture the solar energy. This is typically done twice a year and can boost the production of the generation facility by roughly four percent compared to fixed panels (15). Even though four percent could become a noticeable difference in production for a large facility, adjustable panels will not be considered for this project for several reasons. The largest reason is the added cost in designing easily manipulated panel supports. Another major concern is the cost of adjusting the panels year to year as well as additional cost in the maintenance of thousands of moving components. For the remainder of the feasibility study only fixed systems will be considered due to the lower design and installation cost as well as their lower need for routine maintenance. As a general rule, in the northern hemisphere, solar generation facilities should face directly South, as this is heading will keep the panels in the direct path of the sun for the entire day. For a fixed panel system, the optimum angle of installation can be determined several different ways depending mostly on the location, more specifically the latitude, of the generation facility. For a generation facility that the latitude is less than 25 degrees, the optimum angle is .87 multiplied by the latitude
(15). For a facility located between 25 degrees and 50 degrees, the angle should be .76 multiplied by the latitude plus 3.1 degrees (15). Generation facilities where the latitude exceeds 50 degrees are not recommended due to the poor angle at which the sun will hit the panels (15). As discussed earlier, the average location of these facilities is near Nashville, Tennessee, where the latitude is approximately 36 degrees north. For the remainder of the study the panels will have an optimum angle of 27 degrees, derived from the equation shown below.

\[
\text{Optimum Angle} = (\text{Site Latitude} \times .76) + 3.1^\circ = (36^\circ \times .76) + 3.1^\circ = 30.46^\circ \approx 30^\circ 
\]  
(Eq. 1)

Using 30 degrees as the optimum angle, the spacing between the panels can now be determined. By multiplying the length of the panels by their optimum angle the height changed of the panel can be determined. For this study the panels will be arranged into rows with two panels mounted end to end on each structure. According to the product data sheet each Panasonic panel is 62.6 inches long and 41.5 inches wide, so by putting two panels end to end the final panel length is 125.2 inches. The following equation was used to determine the height change from the leading edge of the panel to the trailing edge.

\[
\text{Height Change} = \text{panel length} \times \sin(\text{optimum angle}) = 125.2 \times \sin(30) = 63 \text{ inches} 
\]  
(Eq. 2)

Once the height change is calculated it will be divided by the solar elevation angle. This angle can be determined several ways, this study will use graphical data developed by The University of Oregon, Solar Radiation Monitoring Laboratory (16). Using Nashville as the mean location, the software from The University of Oregon generated Figure 5 shown below. Using a generation time between 9 a.m and 3 P.M as well as December 21st as the worst case scenario for sun angle, a solar elevation angle of approximately 18 degrees was derived (15,16). Using the
equation shown below, the minimum spacing between the rows of panels can be determined, specifically from the trailing edge of the first row to the leading edge of the second row (15).

\[
\text{Minimum Row Spacing} = \frac{\text{Height Change}}{\tan(\text{solar elevation angle})} = \frac{63 \text{ inches}}{\tan(18)} = 194 \text{ inches}
\]

(Eq. 3)

While this spacing is adequate and will ensure that the generation facility is working properly and not casting shade on its own components, the distance between panels can be further optimized. As shown on figure 5, the Azimuth Correction Angle (ACA) can be determined by drawing a vertical line down from each end of the generation window, 9 a.m. and 3 P.M. (15). The two vertical lines fall on approximately 136 degrees East and 224 degrees west. This means that the ACA is roughly 44 degrees (15). By using the following equation, the Azimuth Correction Angle can be used to further reduce the spacing between panel rows (15).

\[
\text{Minimum Spacing}' = \text{Minimum Spacing} \times \cos(\text{ACA}) = 194 \times \cos(44) = 139.55 \approx 140 \text{ inches} \quad (\text{Eq. 4})
\]

In conclusion, based on the worst-case scenario for Solar Elevation (the winter solstice) and the size of the panels, the minimum distance required between successive rows of the Panasonic N330 panels is 140 inches. This will allow for the most direct sun on each row of panels without casting excessive shade on the subsequent rows of panels.
Figure 5, shown above, is the graph generated by The University of Oregon Solar Radiation Monitoring Laboratory based on the latitude and Longitude of Nashville, Tennessee. The Black line was used to determine the Solar Elevation angle and the two orange vertical lines were used to determine the Azimuth Correction Angle (ACA). (15, 16)

Once the spacing of the panel rows is determined, the total number of panels that can fit in one acre of land must be determined. By finding this value, a wattage production per acre can be determined and used in determining the feasibility of the generation facility. As previously stated, each Panasonic N330 panel is 62.6 inches long and 41.5 inches wide, they will be arranged in rows with two panels mounted end to end for a total length of 125.2 inches and a width of 41.5 inches and each row will be separated by a distance of 140 inches. In this configuration, ten rows of panels can be arranged, with each row containing 120 N330 Panasonic panels. A CAD generated figure of this configuration can be found in Appendix B, labeled site plan. The final step in this process is determining the total Kilowatt-Hours that one acre of the generation facility could produce. To do this the total kilowatt production of all 1200 panels, assuming the efficiency factors discussed earlier, must be multiplied by the total
amount of hours of sunlight the panels will receive in one year. To determine this value, a project by Google called Project Sunroof was used. As stated on its website, Project Sunroof uses imagery, 3D modeling and shade calculations all from Google, as well as weather data from the National Renewable Energy Laboratory to determine the yearly amount of sunlight that a specific rooftop will receive (17). Because these generation facilities will not be located on a roof and instead will be located in an empty field, a south facing roof with no obstructions and located near the mean location of the possible generation sites was chosen. Figure 6 below shows the exact location of the measurement as well as the predicted hours of sunlight, which for this case is 1,561 hours in one year.

![Google Project Sunroof](image)

Figure 6, shown above, depicts the sunlight intensity each roof is expected to receive. Also shown is the total amount of sunlight expected in one year, 1,561 hours.

After the total amount of sunlight is determined, the total output of the one acre generation facility can be determined using the following equation.

\[
Total\ Output\ (KWH) = \frac{Panel\ Output \times Number\ of\ Panels \times Number\ of\ Hours\ of\ Sunlight}{1000\ \text{watts}} \quad (Eq.\ 5)
\]

\[
Total\ Output\ (KWH) = \frac{247 \times 1200 \times 1561}{1000} = 462,680\ KWH/ACRE \quad (Eq.\ 6)
\]

In Tennessee the average commercial price of electricity is approximately 10.31 cents per kilowatt hour and the residential rates are near 10.1 cents per kilowatt hour (18). For simplicity the remainder of the study will assume that the average price that electricity can be sold for in
Tennessee is 10.2 cents per kilowatt hour. This means that every year, one acre of landfills covered in fixed solar panels that produce 462,680 Kwh can produce $47,193.36 in revenue for the electrical companies.

Cost Analysis

Now that the total revenue production per year per acre has been determined for the generation facilities erected on CCR landfills, it is necessary to determine the total cost of installing the designed facility. The cost for designing the facility will assume that the CCR landfill has not been completed and capped. This means that there will be no demolition or cutting of the liner system used to cap CCR landfills. The costs for the proposed PV generation facility will be broken down into several main categories: solar components, other materials, and labor. The first category, solar components, will become a major portion of the overall cost. The largest portion of this category will be the actual panels, at $392 per panel, filling one acre as previously described and shown in appendix B, Site Plan, it will cost approximately $470,400 dollars. Because the price of $392 is on the high side of the average prices found for the Panasonic N330 panel, and due to the high quantity of the order the shipping cost of the panels to the site will be neglected. However, another major portion of the cost will be the additional components needed to run the solar panels properly these include the necessary electrical components and inverters, together these components can add up to a substantial portion of the total cost. The graph below, provided by the National Renewable Energy Laboratory breaks down the total cost of the system.

Figure 7, shown right, breaks the total cost of a utility size PV generation facility into several main categories, listed above. (19)
For simplicity this feasibility study will base the remaining components as percentages of the total panel cost. According to figure 7, the necessary inverters would add an additional 10 percent to the final cost, labor will contribute another 15 percent, electrical BOS would add approximately 10 percent and finally soft costs listed in figure 7 would add an additional 25 percent (19, 20). However, because the CCR landfills are already owned and permitted by the generation companies and these companies have their own engineering staff who are not trying to make a profit like outside consultants, the soft costs addition to the final cost will be adjusted to 10 percent, this 10 percent will include any taxes and other unknown fees. All together these components will add an additional 45 percent to the final cost of the panel installation or approximately $625,000. This brings the total cost of the project, excluding structural mounting components, to just under 1.10 million dollars.

**Structural Design**

After the cost of the panels, necessary components, administrative or soft costs and installation costs have been determined the only cost component remaining is the structural supports holding the panels. The structural support system for this feasibility study will be a simple structure identical in each row of panels. The structure will be comprised up 4 small beams located on the ends of each individual panel running perpendicular to the length of the panel. These four beams will connect to a girder at the end of the beams which will transfer the load of the panels from the beams to two columns and into the concrete foundation. According to the Panasonic N330 data sheet, each panel weighs 40.81 pounds. This load will be carried by two separate beams, one at each end of the panel, meaning 20.42 pounds for each beam. This load will then be converted into an evenly distributed load by dividing 20.42 pounds by the width of each panel. Doing this, results in a distributed load of 5.91 lbs/linear foot of beam. For calculation purposes, this 5.91 lbs/linear ft will be considered the live load of the structure. According to ASCE and the Applied Technology Council’s hazard calculator wind loading, will be added to the design of the structure and will be approximately 16.4 psf during a 25 year storm event (20). This load will add an additional 42.7 lbs/linear foot to the structure. In addition to wind, for the proposed locations there is a 10 psf snow load, which will result in a distributed load of 26 lbs/linear foot added to the structure (20). For the final design of the structure the
LFRD method will be used. The following equation shows how the final loading of the structure was determined. Where $D$, is the dead load of the structure, $W$ is the associated wind load, $L$ is the live load and $S$ is the snow load. A dead load of 15 lbs/ft will be assumed for this section and back checked later in this report.

$$\text{Final Design Load} = 1.2D + 1.0W + 0.5L + 0.5S \quad (\text{Eq. 7})$$

$$\text{Final Design Load} = (1.2 \times 15) + (1 \times 42.7) + (0.5 \times 5.91) + (0.5 \times 26) = 76.65 \text{ lbs/ft} \quad (\text{Eq. 8})$$

The majority of the steel components will be hollow structural steel. For ease of manufacturing and delivery the beams will be twenty-one feet long. To calculate the maximum moment in each beam the following equation was used.

$$M = \frac{WL^2}{8} = \frac{76.65 \times 21^2}{8} = 4225.3 \text{ lb} - FT = 4.225 \text{ K} - ft \quad (\text{Eq. 9})$$

To determine the steel section needed to support this load the AISC steel construction manual, table 3-13 was used. It was found that a HSS 2 ½ x 2 ½ with a ¼ inch wall thickness exceeded the necessary moment capacity at 5.64 k-ft. Because the structural component is HSS, no lateral torsional buckling is to be considered.

These four beams will be bolted directly to a girder located on the end of each twenty-one foot section. The total load on the girder will be the same for each girder except the two end girders. To ensure a safe design and allow for the addition of panels to a row the end girders will be designed as if they are loaded the same way as all other girders. The beams located on the outer edges of the panels will be directly in line with the columns of the structure and will not transfer load onto the girder. The girders will all be ten feet long and will be HSS. The two beams that transfer load onto the column are located near the exact center of the girder and will be considered one point load. That total load is found using the following equations.
Total Load = 1.2(0) + 1(16.4) + .5(2.26) + .5(10) = 22.53 lb/ft² (Eq. 10)

\[ P = TA \times \text{Total Load} + \text{Dead load} = (22.53 \times 109.55) + (21 \times 2 \times 7.11)(1.2) = 2827 \text{ lbs} \]

(Eq. 11)

The moment caused by this load can then be determined using the following equation.

\[ M = \frac{PL}{4} = \frac{2827 \times 10}{4} = 7066 - ft = 7.066 \text{ kip - ft} \] (Eq. 12)

Once again the AISC steel construction manual can be used to determine the necessary section to accommodate this moment. For this load a HHS square section, 3 x 3 with \( \frac{3}{4} \) inch wall thickness capable of holding 8.55 kip-ft was selected. As before lateral torsional buckling was not considered because the section is HSS.

The next structural component for the mounting structure is the two columns located at the ends of the beams and girders. At these columns the girder holding the two center beams will tie directly into the column on the inner face. The two twenty-one foot beams on the outer edges of the panels will also tie directly into the column. The columns of the leading edge column line will be two feet tall; this will provide enough space under the leading edge of the PV panels to access components during installation and maintenance. As discussed earlier the back of the panel will be sixty-three inches higher than the front to give the panel an optimal tilt angle of thirty degrees, which means the trailing edge columns will be 7.25 feet tall. The AISC steel construction manual was used to determine an appropriate length factor, K, for each of the columns. For this structure it was assumed that the end of the column resting on the foundation would be a fixed moment connection while the top of the column was fixed in rotation but free in translation. Using table C-A-7.1 a K value of 1.2 was derived. This length factor results in a KL value of 2.4 for the leading edge columns and 8.7 for the trailing edge columns. The tributary area and resulting load for each column must then be determined using the following equations.

\[ \text{Tributary Area} = \left( \frac{10.43}{2} \right) \times (21) = 109.55 \] (Eq. 13)
Factored PSF = 1.2(0) + 1(16.4) + .5(2.26) + .5(10) = 22.53 lb/ft² (Eq. 14)

Total Load \( (P) = TA \times FPSF + \text{Factored Dead Load} \) (Eq. 15)

\[
P = (109.55 \times 22.53) + 1.2[(21 \times 2 \times 7.11) + (5 \times 8.81)] = 2879 \text{ lbs} = 2.879 \text{kips} \text{ (Eq. 16)}
\]

After the total load is determined the AISC steel construction manual is referenced to determine the appropriate HSS section. For this portion, Table 4-4 of the manual was used. Because all columns in this structure are very short, and the loads on them are minimal, any HSS square column greatly exceeds the necessary capacity. To allow for easier connections, the columns will be 3 x 3 HSS with a wall thickness of 1/8 inches. This column’s capacity, 30.3 kips, far exceeds the required strength but will allow the girders to tie into the column easier than a column with smaller dimensions, such as an HSS 2 x 2.

The final component of the structural design is the foundations to support the structural steel mounting system. This study will assume that the CCR landfill that the generation facility is being constructed on is a facility that accepts mainly bottom ash. Available geotechnical from studies in Pennsylvania show that the bearing capacity of bottom ash can reach up to 4000 psf with minimal compactive effort (23). In fact every test site examined by the study provided a bearing capacity of 4000 psf, based off of blow counts during the geotechnical investigation (23). The factored loads applied to the foundations for this feasibility study are calculated using the following equation.

\[
Pu = P + 1.2(\text{weight of columns}) \text{ (Eq. 17)}
\]

\[
Pu = 2879 \text{ lbs} + (1.2 \times (7.25 \times 4.75)) = 2920 \text{ lbs} = 2.92 \text{kips} \text{ (Eq. 18)}
\]

To remain conservative in the project cost estimation and safe design of the structure, a minimum footer size of two foot by two foot will be used. This means that the ultimate bearing on the soil will be 730.1 psf, well below the available bearing capacity of the bottom ash. Details on the sizing of the foundation can be found in Appendix B, labeled Structural Details.
**Structural Cost**

The total cost of the structural mounting system can be determined by determining the cost of each structural component and adding them together, this in addition to the necessary labor to erect the structure will result in the final cost of the structural portion of the project. Table 3 below shows the structural components used, the amount used, and the total cost for each group of members. As with earlier in the report all quantities are still based on a per acre assessment.

**Table 3**, shown above, details the structural steel sections use, the approximate quantities and the approximate cost of material.

<table>
<thead>
<tr>
<th>Structural Mounting System Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>HHS 2.25x2.25x.25</td>
</tr>
<tr>
<td>HHS 3x3x.25</td>
</tr>
<tr>
<td>HHS 3x3x.125</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
</tr>
</tbody>
</table>

To estimate the total construction cost of the structural steel members, the 2015 RSMeans Heavy Construction Cost Data, book was used. According to section 05 12 item number 3300, the cost of installing light columns between four and six inches that are not filled with concrete is 2.04 dollars per pound of steel installed. This value however takes into account the material cost. Once that is removed the installation cost is approximately 71 cents per pound. Each HSS 3x3x.125 column weighs 4.75 lbs/linear foot, in total 1018 linear feet were used for a total installed weight of 4,835.5 lbs. This results in a cost of $3,433 per acre to install columns. The rest of the structure will consist of beams and girders made from HSS. The RSMeans book does not cover structural framing made from HSS so the smallest available W shape was used to estimate the construction cost. Section 05 12 23.75, item 0100 is a W6x9 section that is shop fabricated with bolted connections. The installation cost is per linear foot and comes out to
$25.50, including material. Once Material is removed, the total installation cost is $12.40 per linear foot. This means that the total construction cost for installing the beams and girders would be approximately $116,522.

In total there will be 220 column pads per acre for this generation facility. Each column pad will be two foot by two foot and have a depth of one and a half feet. The bottom of the foundation will be at minimum one and a half feet below the bottom of the synthetic lining system. This will allow the liner to be sealed to the foundation as required by the CCR regulations. A one foot by one foot concrete column will extend from the center of the foundation to the proposed surface grade, where the steel HHS 3x3x.125 will be mounted to it. Structural details for this foundation can be found in Appendix B.

The total cost of the foundations will include the material cost as well as the labor cost for each foundation. Once again the estimate will be derived from values found in the RSMeans book. Section 03 30 53, items 0700 and 3850 will be used to estimate the cost of the foundations. Item 0700 considers square one foot by one foot columns with less than 2% reinforcing and item 3850 covers spread footings over five cubic yards. The columns for each foundation will have a total cost of $1,700 per cubic yard. The bottom portion of the foundation will cost $310 per cubic yard. The following equations are used to find the total cost. Because the liner must tie into the foundation an addition 20 percent will be added to the final cost of the foundation to account for the additional labor and specialty materials.

\[
Total \ Column \ Volumes = [1 \times 1 \times 2] \times 220 = 440 \ cubic \ feet = 16.3 \ cubic \ yards \quad (Eq. \ 20)
\]

\[
Column \ cost = (16.3 \times \$1700) = \$27,703 \quad (Eq. \ 21)
\]

\[
Total \ Spread \ Volume = [2 \times 2 \times 1.5] \times 220 = 1320 \ cubic \ feet = 48.9 \ cubic \ yards \quad (Eq. \ 22)
\]

\[
Spread \ Foundation \ Cost = (48.9 \times \$310) = \$15,155 \quad (Eq. \ 23)
\]

\[
Total \ Foundation \ Cost = (\$15,155 + \$27,703) \times 1.2 = \$51,430 \quad (Eq. \ 24)
\]
**Final Cost Comparison**

In total a PV generation station situated on a CCR landfill in central Tennessee has the opportunity to produce 462,680 kilowatt hours per year per acre at a cost of approximately 10.2 cents per kilowatt hour. This results in overall revenue of $47,193.36 per acre. To build the generation facility it will cost the generation company approximately $1,370,330 per acre. One other component that can make a substantial difference in the cost effectiveness of a solar generation facility is the federal tax credit for commercial and residential solar projects. This tax credit is thirty percent until 2020 when it drops to twenty-six percent and again to twenty-two percent in 2021 (24). If the full thirty percent is taken into account the price to build the PV generation facility drops from $1,370,330 to approximately $959,231. This means that without any changes in the price of electricity, the generation facility would pay for itself in 20.3 years. The Panasonic N330 has a warranty that guarantees ninety percent of production up to 25 years, so the facility would pay for itself before the panels hit the expected lifespan.

**Conclusion**

While the margin for profit seems narrow in this situation, the overall potential for success of these generation facilities seems positive. These generation facilities provide the generation companies with a potential for new income, a way to use existing land and finally a way to provide clean renewable energy to their clients. Advancements in solar technology that increases the efficiency of the PV panels and large cost reductions once full scale production of panels increases also offer a positive outlook to this growing industry. Since this study shows that it is at least feasible to install and operate PV generation facilities on CCR landfills any advancements or placement of facilities in climates with more sunshine will only make such a venture more profitable for generation companies.
Citations


Appendix A
Panasonic’s unique heterojunction technology uses ultra-thin amorphous silicon layers. These thin dual layers reduce losses, resulting in higher energy output than conventional panels.

Our competitive advantages

**High Efficiency at High Temperatures**
As temperature increases, HIT® continues to perform at high levels due to the industry leading temperature coefficient of -0.258% /°C. No other module even comes close to our temperature characteristics. That means more energy throughout the day.

**25 Year Product and Performance Warranty**
Industry leading 25 year product workmanship and performance warranty is backed by a century old company- Panasonic. Power output is guaranteed to 90.76% after 25 years, far greater than other companies.

**Quality and Reliability**
Panasonic’s vertical integration, 20 years of experience manufacturing HIT® and 20 internal tests beyond those mandated by current standards provides extreme quality assurance.

**Higher Efficiency 19.7%**
Enables higher power output and greater energy yields. HIT® provides maximum production for your limited roof space.

**Low Degradation**
HIT "N-type" cells result in extremely Low Light Induced Degradation (LID) and zero Potential Induced Degradation (PID) which supports reliability and longevity. This technology reduces annual degradation to 0.26% compare to 0.70% in conventional panels, guaranteeing more power for the long haul.

**Unique water drainage**
The water drainage system give rain, water and snow melt a place to go, reducing water stains and soiling on the panel. Less dirt on the panel means more sunlight getting through to generate power.
CAUTION! Please read the installation manual carefully before using the products.

Used electrical and electronic products must not be mixed with general household waste. For proper treatment, recovery and recycling of old products, please take them to applicable collection points in accordance with your national legislation.

---

**ELECTRICAL SPECIFICATIONS**

<table>
<thead>
<tr>
<th>Model</th>
<th>VBHN330SA16</th>
<th>VBHN325SA16</th>
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<tbody>
<tr>
<td>Rated Power (Pmax)</td>
<td>330W</td>
<td>325W</td>
</tr>
<tr>
<td>Maximum Power Voltage (Vpm)</td>
<td>58.0V</td>
<td>57.6V</td>
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<tr>
<td>Maximum Power Current (Im)</td>
<td>5.70A</td>
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<td>Open Circuit Voltage (Voc)</td>
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<tr>
<td>Short Circuit Current (Isc)</td>
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<td>6.03A</td>
</tr>
<tr>
<td>Temperature Coefficient (Pmax)</td>
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<td>-0.258%/°C</td>
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<tr>
<td>Temperature Coefficient (Voc)</td>
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<td>-0.16V/°C</td>
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<tr>
<td>Temperature Coefficient (Isc)</td>
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<td>3.32mA/°C</td>
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<tr>
<td>NOCT</td>
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<td>44.0°C</td>
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<td>CEC PTC Rating</td>
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<td>306.5W</td>
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<td>21.76%</td>
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<tr>
<td>Module Efficiency</td>
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<td>Watts per Ft²</td>
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<tr>
<td>Series Fuse Rating</td>
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<td>15A</td>
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<tr>
<td>Warranted Tolerance (±/+)</td>
<td>+10%/0%*</td>
<td>+10%/0%*</td>
</tr>
</tbody>
</table>

**PERFORMANCE WARRANTY**

- **97%**
- **90.76%**
- **80%**

More power over 25 years

**N330/N325**

**ELECTRICAL SPECIFICATIONS**

- **Model**: VBHN330SA16, VBHN325SA16
- **Rated Power (Pmax)**: 330W, 325W
- **Maximum Power Voltage (Vpm)**: 58.0V, 57.6V
- **Maximum Power Current (Im)**: 5.70A, 5.65A
- **Open Circuit Voltage (Voc)**: 69.7V, 69.6V
- **Short Circuit Current (Isc)**: 6.07A, 6.03A
- **Temperature Coefficient (Pmax)**: -0.258%/°C, -0.258%/°C
- **Temperature Coefficient (Voc)**: -0.16V/°C, -0.16V/°C
- **Temperature Coefficient (Isc)**: 3.34mA/°C, 3.32mA/°C
- **NOCT**: 44.9°C, 44.0°C
- **CEC PTC Rating**: 311.3W, 306.5W
- **Cell Efficiency**: 22.09%, 21.76%
- **Module Efficiency**: 19.7%, 19.4%
- **Watts per Ft²**: 18.3W, 18.0W
- **Maximum System Voltage**: 600V, 600V
- **Series Fuse Rating**: 15A, 15A
- **Warranted Tolerance (±/+)**: ±10%/0%

**MECHANICAL SPECIFICATIONS**

- **Model**: VBHN330SA16, VBHN325SA16
- **Internal Bypass Diodes**: 4 Bypass Diodes
- **Module Area**: 18.02 Ft² (1.67m²)
- **Weight**: 40.81 Lbs. (18.5kg)
- **Dimensions LxWxH**: 62.6x41.5x1.4 in. (1590x1053x35 mm)
- **Cable Length +Male/-Female**: 40.2/40.2 in. (1020/1020 mm)
- **Cable Size / Type**: No. 12 AWG / PV Cable
- **Connector Type**: Multi-Contact® Type IV (MC4™)
- **Static Wind / Snow Load**: 50 PSF (2400 Pa)
- **Pallet Dimensions LxWxH**: 63.7x42.2x65.4 in.
- **Quantity per Pallet / Pallet Weight**: 40 pcs. / 1719 Lbs. (780 kg)
- **Quantity per 40' Container**: 560 pcs.
- **Quantity per 20' Container**: 240 pcs.

**OPERATING CONDITIONS & SAFETY RATINGS**

- **Model**: VBHN330SA16, VBHN325SA16
- **Operating Temperature**: -40°F to 185°F (-40°C to 85°C)
- **Hail Safety Impact Velocity**: 1” hailstone (25mm) at 52 mph (23m/s)
- **Safety & Rating Certifications**: UL 1703, cUL, CEC
- **UL 1703 Fire Classification**: Type 2
- **Limited Warranty**: 25**Yrs Workmanship and Power Output (Linear)***

---

**NOTE:**
- Standard Test Conditions: Air mass 1.5; irradiance = 1000W/m²; cell temp. 25°C
- *Maximum power at delivery. For guarantee conditions, please check our guarantee document.
- **Installation need to be registered through our website: www.panasonicusahitwarranty.com within 60 days in order to receive twenty-five (25) year Product workmanship. Otherwise, Product Workmanship will be only fifteen (15) years.
- ***1st year 97%, after 2nd year 0.26% annual degradation to year 25.
- STC: Cell temp. 25°C, AM1.5, 1000W/m²
- Safety locking clip (PV-SSH4) is not supplied with the module.

---

**CAUTION!** Please read the installation manual carefully before using the products.

Used electrical and electronic products must not be mixed with general household waste. For proper treatment, recovery and recycling of old products, please take them to applicable collection points in accordance with your national legislation.
SUNIVA OPTIMUS® SERIES
MONOCRYSTALLINE SOLAR MODULES

OPT SERIES: OPT 72 CELL MODULES (SILVER FRAME)

Optimus® modules are known for their superior quality and long-term reliability. These high-powered modules consist of Suniva's premium ARTisun® cell technology, designed and manufactured in the U.S.A. using our pioneering manufacturing processes. Suniva’s high power-density Optimus modules provide excellent performance and value.

FEATURES

- Utilizes our premier American-made cell technology, ARTisun Select®
- Superior performance and reliability; enhanced stress tests conducted at Fraunhofer ISE
- Module families ranging from 325-340W
- Positive only power tolerance
- Marine grade aluminum frame with hard anodized coating
- Certified PID-free by PV Evolution Labs (PVEL)
- BAA and TAA compliant
- Qualifies for Ex-Im Financing
- 1000VDC UL
- 25 year linear power warranty; 10 year product warranty

QUALITY & RELIABILITY

- Suniva Optimus modules are manufactured and warranted to our specifications assuring consistent high performance and high quality.
- Rigorous in-house quality management tests beyond standard UL and IEC standards
- Performance longevity with advanced polymer backsheet
- UL1703 listed Type 2 PV module
- Passed the most stringent salt spray tests based on IEC 61701
- Passed enhanced stress tests based on IEC 61215 conducted at Fraunhofer ISE²
- PAN files are independently validated

 Engineered Excellence

- Built exclusively with Suniva’s premium ARTisun Select cells, providing one of the highest power outputs per square meter at an affordable price.
- The leading US-born, US-operated crystalline silicon cell and module manufacturer, spun out of Georgia Tech’s University Center of Excellence in Photovoltaics; one of only two such research centers in the U.S.
- Suniva’s state-of-the-art manufacturing and module lab facilities feature the most advanced equipment and technology.

Suniva Optimus modules are known for their superior quality and long-term reliability. These high-powered modules consist of Suniva’s premium ARTisun® cell technology, designed and manufactured in the U.S.A. using our pioneering manufacturing processes. Suniva’s high power-density Optimus modules provide excellent performance and value.

CERTIFICATIONS

www.suniva.com
OPTIMUM SERIES: OPT 72 CELL MODULES

ELECTRICAL DATA (NOMINAL)
The rated power may only vary by -0/+10W and all other electrical parameters by ±5%

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<th>Module Type</th>
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<th>OPT330-72-4-100</th>
<th>OPT335-72-4-100</th>
<th>OPT340-72-4-100</th>
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<tbody>
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<td>330 W</td>
<td>335 W</td>
<td>340 W</td>
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<tr>
<td>Module Efficiency (%)</td>
<td>16.66%</td>
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<td>17.18%</td>
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<td>37.8 V</td>
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<td>Current at Max. Power Point (Imp)</td>
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<tr>
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<td>Short Circuit Current (Isc)</td>
<td>9.42 A</td>
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<td>9.66 A</td>
<td>9.78 A</td>
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</tbody>
</table>

The electrical data apply to standard test conditions (STC): Irradiance of 1000 W/m² with AM 1.5 spectra at 25°C.

CHARACTERISTIC DATA

Type of Solar Cell
High-efficiency ARTsun Select cells, 3 and 5 busbar options available

Glass
Tempered (low-iron), anti-reflective coating

Solar Array
SUNIVA’s industry leading warranty

Frame
Silver anodized aluminum alloy

Junction Box
NEMA IP67 rated; 3 internal diodes

MECHANICALS

Cells / Module
72 (6 x 12)

Module Dimensions
1970 x 990 mm (77.6 x 39 in.)

Module Thickness (Depth)
38 mm (1.5 in.)

Approximate Weight
23 kg (50.7 lbs.)

TEMPERATURE COEFFICIENTS

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<th>Current</th>
<th>Power</th>
<th>NOCT Avg (+/- 2 °C)</th>
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<td></td>
<td>46.0 (+/- 2 °C)</td>
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<td>γ, Isc (%/°C)</td>
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</tr>
</tbody>
</table>

LIMITS

Max. System Voltage
1000 VDC for IEC, 1000 VDC for UL

Max Series Fuse Rating
15 Amps

Operating Module Temperature
-40°C to +85°C (-40°F to +185°F)

Storm Resistance/Static Load
Tested to IEC 61215 for 5400Pa positive and 2400Pa negative loads; hail and wind resistant

Suniva® reserves the right to change the data at any time. View manual at suniva.com.

Please read installation manual before installing or working with module.
We offer solar modules of unsurpassed quality that exceed performance expectations at an affordable price.

- Industry-leading efficient monocrystalline silicon PERC cells
- Certified PID-free above and beyond the industry standard
- Full quality check of every module along the production line
- Impact-resistant, anti-glare solar glass
- Building the highest efficiency PERC modules in the USA

Connect with us: www.itekenergy.com | info@itekenergy.com

ASSEMBLED IN U.S.A.
Itek SE 72-Cell Module
Design & Engineering Data

**GENERAL DATA**

- **Cell Type**
  - 72 high-efficiency monocrystalline p-type cells
  - 6 x 12 cell matrix
- **Solar Glass**
  - Ultra-clear anti-reflective treatment
  - Tempered, with low iron content
  - Anti-glare prismatic subsurface texture
- **Backsheet**
  - Multi-layered
  - Engineered adhesion for maximum weather protection
- **Frame**
  - High-strength corrosion-resistant anodized aluminum
  - Compatible with standard racking, accommodating both top-down clamps and bottom-flange mounting
- **Cable**
  - 90°C 12AWG PV wire
- **Junction Box**
  - 3 bypass diodes • 1000 VDC MC4 connectors • Tigo TS4
- **Grounding**
  - Certified for Wiley Electronics WEB™ grounding clips
  - Eight standard grounding locations per module for reduced ground wire length

**QUALIFICATIONS**

- **Fire Rating**
  - Type 1
- **PID Free**
  - 500+ hours
- **ARRA, BAA, and TAA Compliant**

**ELECTRICAL DATA***

<table>
<thead>
<tr>
<th></th>
<th>350 SE</th>
<th>355 SE</th>
<th>360 SE</th>
<th>365 SE</th>
<th>370 SE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Power - P_{Max} (W_p)</strong></td>
<td>350</td>
<td>355</td>
<td>360</td>
<td>365</td>
<td>370</td>
</tr>
<tr>
<td><strong>Maximum Power Voltage - V_{Max} (V)</strong></td>
<td>38.55</td>
<td>38.74</td>
<td>38.94</td>
<td>39.12</td>
<td>39.32</td>
</tr>
<tr>
<td><strong>Maximum Current - I_{Max} (A) (D,M,S,O)</strong></td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td><strong>Maximum Voltage (TS4-L only) - V_{Max} (V)</strong></td>
<td>43.57</td>
<td>43.77</td>
<td>43.99</td>
<td>44.19</td>
<td>44.40</td>
</tr>
<tr>
<td><strong>Open-Circuit Voltage - V_{OC} (D,M,S,O)</strong></td>
<td>47.43</td>
<td>47.64</td>
<td>47.87</td>
<td>48.08</td>
<td>48.31</td>
</tr>
<tr>
<td><strong>Short-Circuit Current - I_{SC} (A) (D,M,S)</strong></td>
<td>9.49</td>
<td>9.55</td>
<td>9.62</td>
<td>9.69</td>
<td>9.76</td>
</tr>
<tr>
<td><strong>Module Efficiency</strong></td>
<td>17.54%</td>
<td>17.79%</td>
<td>18.05%</td>
<td>18.30%</td>
<td>18.55%</td>
</tr>
</tbody>
</table>

**MECHANICAL DATA**

- **Dimensions**
  - 1001mm x 1993mm x 40mm
- **Weight**
  - 49 lbs/22.2kg

**MAXIMUM RATINGS**

- **Operational Temperature**
  - -40...+90°C
- **Maximum System Voltage**
  - 1000 VDC
- **Maximum Design Load (UL 1703)**
  - 113 psf/(5400pa)
- **Max Series Fuse Rating**
  - 15A
- **Max Reverse Current**
  - 15A

**TEMPERATURE RATINGS**

- **Nominal Operating Cell Temperature (NOCT)**
  - 45.01°C
- **Temperature Coefficient of P_{mp}**
  - -0.39%/°C
- **Temperature Coefficient of V_{oc} (D,M,S,O)**
  - -0.29%/°C
- **Temperature Coefficient of I_{sc}**
  - +0.04%/°C
- **Temperature Coefficient of V_{mp}**
  - -0.38%/°C

*Electrical characteristics may vary within ±2% of the indicated values at Standard Test Conditions (STC): Irradiance of 1,000W/m², AM 1.5 spectrum, cell temperature at 25°C.

Note: specifications subject to change without notice.

Choose from Safety | Safety + Optimization | Safety + Optimization + Long Strings
All of these options include Monitoring

TS4 Platform

- TS4-L
  - LONG STRINGS
- TS4-O
  - OPTIMIZATION
- TS4-S
  - SAFETY
- TS4-M
  - MONITORING
- TS4-D
  - DIODES

Tigo TS4 Junction Box

Frame Height: 40mm (1.57")

Headquarters: 3886 Hammer Drive, Bellingham, WA 98226
Sales Offices: WA: (360) 647-9531 | MN: (612) 318-6384 | CA: (360) 393-0178
info@itekenergy.com | www.itekenergy.com

V12.15.17
Superior Energy Production
Module efficiency up to 20.2% achieved by utilizing the most advanced technology in the solar industry.

Exceptional at Low-Light Conditions
The round shape of SmartWire reduces shading by 25% and introduces a light trapping effect.

SmartWire Technology (SWT)
The revolutionary process for connecting solar cells that outtrivals busbars by spreading the electric current through 18 micro-wires.

Remarkable Connection Durability
SWT acts as a protective layer for the solar cell, ensuring reliable contact points for decades of consistent performance.

Advanced HJT Technology
This cell combines the advantages of N-type crystalline silicon with the excellent absorption and passivation of amorphous silicon.

Industry Leading Warranty
HJT technology, based on n-type silicon, is immune to PID & LID effect.
Maximum Power at PTC

Temperature Characteristics

- Temperature Coefficient of Pmax: -0.3439%/°C
- Temperature Coefficient of Voc: -0.2596 %/°C
- Temperature Coefficient of Isc: +0.0447 %/°C

Electrical Characteristics STC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>STU 320 HJT</th>
<th>STU 325 HJT</th>
<th>STU 330 HJT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Power</td>
<td>320W</td>
<td>325W</td>
<td>330W</td>
</tr>
<tr>
<td>Module Efficiency (%)</td>
<td>19.6%</td>
<td>19.9%</td>
<td>20.2%</td>
</tr>
<tr>
<td>Voltage at Max power (Vmp)</td>
<td>36.7V</td>
<td>37.0V</td>
<td>37.3V</td>
</tr>
<tr>
<td>Current at Max power (Imp)</td>
<td>8.7A</td>
<td>8.8A</td>
<td>8.9A</td>
</tr>
<tr>
<td>Open Circuit Voltage (Voc)</td>
<td>44.6V</td>
<td>44.9V</td>
<td>45.3V</td>
</tr>
<tr>
<td>Short Circuit Current (Isc)</td>
<td>9.3A</td>
<td>9.3A</td>
<td>9.4A</td>
</tr>
<tr>
<td>Operating Module Temperature</td>
<td>-40°C - 85°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum System Voltage</td>
<td>1000V DC (IEC + UL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Series Fuse Rating</td>
<td>20A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Sorting</td>
<td>-0/+5W</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STC: Irradiance 1000 W/m², module temperature 25 °C, AM1.5; Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

Temperature Characteristics

- Temperature Coefficient of Pmax: -0.3439%/°C
- Temperature Coefficient of Voc: -0.2596 %/°C
- Temperature Coefficient of Isc: +0.0447 %/°C

Maximum Power at PTC: 291.5W, 296.1W, 300.6W

Warranted Power Performance

<table>
<thead>
<tr>
<th>Year</th>
<th>Power Performance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>97%</td>
</tr>
<tr>
<td>10th</td>
<td>90%</td>
</tr>
<tr>
<td>25th</td>
<td>85%</td>
</tr>
<tr>
<td>30th</td>
<td>80%</td>
</tr>
</tbody>
</table>

Industry Standard

Packing Configuration

<table>
<thead>
<tr>
<th>Equipment</th>
<th>20' GP</th>
<th>53' Trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modules per pallet</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>Pallets per unit</td>
<td>12</td>
<td>36</td>
</tr>
<tr>
<td>Modules per unit</td>
<td>240</td>
<td>828</td>
</tr>
</tbody>
</table>

1800 President Barack Obama Highway
Riviera Beach, FL 33404

Phone: (561) 440-8000
Fax: (561) 503-4141
info@solarTechuniversal.com
www.solarTechuniversal.com

IN PARTNERSHIP WITH

MEYER BURGER
USA
Achieving up to 19.4% efficiency, Solaria PowerXT solar modules are one of the highest power modules in the residential solar market. Compared to conventional modules, Solaria PowerXT modules have fewer gaps between the solar cells; this leads to higher power and superior aesthetics. Solaria PowerXT residential modules are manufactured with black backsheet and frames, giving them a striking appearance.

Developed in California, Solaria’s patented cell cutting and module assembly takes processed solar wafers and turns them into PowerXT solar modules. The process starts by creating a highly reliable PowerXT cell where busbars and ribbon interconnections are eliminated. Solaria then packages the cells into the PowerXT solar module, reducing inactive space between the cells. All of the above leads to an exceptionally efficient solar module produced in a cost effective manner.

**Higher Efficiency, Higher Power**

Solaria PowerXT modules achieve up to 19.4% efficiency; conventional modules achieve 15% – 17% efficiency. Solaria PowerXT modules are one of the highest power modules available.

**Lower System Costs**

Solaria PowerXT modules produce more power per square meter area. This reduces installation costs due to fewer balance of system components.

**Improved Shading Tolerance**

Sub-strings are interconnected in parallel, within each of the four module quadrants, which dramatically lowers the shading losses and boosts energy yield.

**Improved Aesthetics**

Compared to conventional modules, Solaria PowerXT modules have a more uniform appearance and superior aesthetics.

**Durability and Reliability**

Solder-less cell interconnections are highly reliable and designed to far exceed the industry leading 25 year warranty.

**About Solaria**

Established in 2000, The Solaria Corporation has created one of the industry’s most respected IP portfolios, with over 100 patents encompassing materials, processes, applications, products, manufacturing automation and equipment. Headquartered in Fremont, California, Solaria has developed a technology platform that unlocks the potential of solar energy allowing it to be ubiquitous and universally accessed.
Performance at STC (1000W/m², 25°C, AM 1.5)

<table>
<thead>
<tr>
<th>Solaria PowerXT®</th>
<th>340R-BD</th>
<th>345R-BD</th>
<th>345R-PD</th>
<th>350R-PD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Power (P\text{max}) [W]</td>
<td>340</td>
<td>345</td>
<td>345</td>
<td>350</td>
</tr>
<tr>
<td>Efficiency [%]</td>
<td>18.8</td>
<td>19.1</td>
<td>19.1</td>
<td>19.4</td>
</tr>
<tr>
<td>Open Circuit Voltage (V\text{oc}) [V]</td>
<td>46.9</td>
<td>47.1</td>
<td>46.9</td>
<td>47.1</td>
</tr>
<tr>
<td>Max Power Voltage (V\text{mp}) [V]</td>
<td>38.6</td>
<td>38.9</td>
<td>38.5</td>
<td>38.8</td>
</tr>
<tr>
<td>Max Power Current (I\text{mp}) [A]</td>
<td>8.79</td>
<td>8.88</td>
<td>8.93</td>
<td>9.02</td>
</tr>
<tr>
<td>Power Tolerance [%]</td>
<td>-0/+3</td>
<td>-0/+3</td>
<td>-0/+3</td>
<td>-0/+3</td>
</tr>
</tbody>
</table>

Performance at NOCT (800W/m², 20°C Amb, Wind 1 m/s, AM 1.5)

<table>
<thead>
<tr>
<th></th>
<th>[W]</th>
<th>[V]</th>
<th>[A]</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Power (P\text{max})</td>
<td>252</td>
<td>255</td>
<td>255</td>
<td>259</td>
</tr>
<tr>
<td>Open Circuit Voltage (V\text{oc})</td>
<td>44.1</td>
<td>44.3</td>
<td>44.1</td>
<td>44.3</td>
</tr>
<tr>
<td>Short Circuit Current (I\text{sc})</td>
<td>7.58</td>
<td>7.61</td>
<td>7.66</td>
<td>7.69</td>
</tr>
<tr>
<td>Max Power Voltage (V\text{mp})</td>
<td>35.5</td>
<td>35.8</td>
<td>35.4</td>
<td>35.7</td>
</tr>
<tr>
<td>Max Power Current (I\text{mp})</td>
<td>7.03</td>
<td>7.10</td>
<td>7.15</td>
<td>7.22</td>
</tr>
</tbody>
</table>

Temperature Characteristics

- NOCT: 45 +/- 2°C
- Temp. Coeff. of P\text{max}: -0.39 [% / °C]
- Temp. Coeff. of V\text{oc}: -0.29 [% / °C]
- Temp. Coeff. of I\text{sc}: 0.04 [% / °C]

Design Parameters

- Operating temperature: -40 to +85°C
- Max System Voltage: 1000 V
- Max Fuse Rating: 15 A
- Bypass Diodes: 4

IV Curves (350W Module)

Mechanical Characteristics

- Cell Type: Monocrystalline Silicon
- Dimensions (L x W x H): 1621mm x 1116mm x 40mm
- Weight: 21 kg / 46 lbs
- Glass Type / Thickness: AR Coated, Tempered / 3.2mm
- Frame Type: Anodized Aluminum
- Cable Type / Length: 12 AWG PV Wire (UL) / 1000mm
- Connector Type: Amphenol H4 (MC4 compatible)
- Junction Box: IP67 / 4 diodes
- Front Load (UL 1703): 5400 Pa / 113 psf
- Rear Load (UL 1703): 3600 Pa / 75 psf

Certifications / Warranty

- Certifications: UL 1703/IEC 61215/IEC 61730/CEC
- Fire Type (UL 1703): 1
- Power & Product Warranty: 25 years*

Packaging

- Stacking Method: Horizontal / Palletized
- Pcs / Pallet: 25
- Pallet Dims (L x W x H): 1685 x 1150 x 1230 mm
- Pallet Weight: 590 kg / 1300 lbs
- Pallets / 40-ft Container: 28
- Pcs / 40-ft Container: 700

Authorized Dealer

The Solaria Corporation 6200 Paseo Padre Parkway, Fremont, CA 94555  P: (510) 270-2500  www.solaria.com  Copyright © 2017 The Solaria Corporation

Product specifications are subject to change without notice.

Rev 1E 12-21-2017
96M
96-CELL MONOCRYSTALLINE MODULE

490 Wp
MAX POWER OUTPUT

18.9%
MAX EFFICIENCY

10 YEAR
PRODUCT WARRANTY

25 YEAR
LINEAR PERFORMANCE GUARANTEE

HELIENE INC. IS A PREMIER SOLAR MODULE MANUFACTURER, SERVICING THE GROWING SOLAR ENERGY MARKETS OF NORTH AMERICA.

COMBINING PROVEN EUROPEAN TECHNOLOGY WITH NORTH AMERICAN INGENUITY ALLOWS HELIENE TO MAKE A REAL COMMITMENT IN PROVIDING SMARTER ENERGY CHOICES FOR THE FUTURE.

HELIENE
www.heliene.com
DIMENSIONS FOR HELIENE 96M SERIES MODULES

STC - Standard Test Conditions: Irradiation 1000 W/m² - Air mass AM 1.5 - Cell temperature 25 ºC
* Calculated using maximum power based on full positive output tolerance [-0 , +4.99] Wp

MECHANICAL DATA

Dimensions (L x W x D) 1956 x 1310 x 40 mm (77 x 51.6 x 1.6 inch)
Weight 38 kg (83.7 lbs)
Output Cables > 1.3 m (51 inch) symmetrical cables with MC4 type connectors
Junction Box IP-67 rated with bypass diodes
Frame Double webbed 5 micron anodized aluminum alloy
Front Glass Low-iron content, high-transmission PV solar glass
Solar Cells 96 Monocrystalline cells (156 x 156 mm)

CERTIFICATIONS

UL Listed ULC/ORD-C1703-1 , UL1703
IEC Listed IEC 61215, IEC 61730

TEMPERATURE RATINGS

Nominal Operating Cell Temperature (NOCCT) +45°C (±2°C)
Temperature Coefficient of Peak Rated Power -0.39%/°C
Temperature Coefficient of Maximum Power Voltage -0.31%/°C
Temperature Coefficient of Maximum Power Current 0.045%/°C

MAXIMUM RATINGS

Operational Temperature -40°C - +85°C
Max System Voltage 1000V / 1500V
Max Series Fuse Rating 15 A

WARRANTY

10 Year Manufacturer’s Workmanship Warranty
25 Year Linear Power Guarantee
(Refer to product warranty page for details)

PACKAGING CONFIGURATION

Modules per box: 25 pieces
Modules per 53' trailer: 550 pieces

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.
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MSE Mono 72
High Power Mono Module

Class Leading Output:
Up to 340W power

Advanced P-Type
monocrystalline cell
technology

Certified Reliability:
3X IEC, salt mist, ammonia

5600 Pa snow load
175 mph wind rating *New!

Buy American Act

Proudly assembled in the USA
Mission Solar Energy is headquartered in San Antonio, TX with module facilities onsite. Our hardworking team calls Texas home and is devoted to producing high quality solar products and services. Our supply chain includes local and domestic vendors increasing our impact to the U.S. economy.

Assembled in the USA

Best in class quality
Mission Solar Energy production lines are fully automated and include multiple quality checks throughout the production process including 2X EL Testing, 100% Visual inspection, and positive binning.

Proven reliability and bankability
Mission Solar Energy panels have been tested by independent testing centers to meet and exceed IEC standards. Our panels are deployed in projects across North America.

25-YEAR LINEAR WARRANTY

CERTIFICATIONS
IEC 61215/ IEC 61730/ IEC 61701  UL 1703

*As there are different certification requirements in different markets, please contact your local Mission Solar Energy sales representative for the specific certificates applicable to the products in the region in which the products are to be used.
ELECTRICAL SPECIFICATIONS

Electrical parameters at Standard Test Condition (STC)

<table>
<thead>
<tr>
<th>Module Type</th>
<th>MSE330SO6J</th>
<th>MSE335SO6J</th>
<th>MSE340SO6J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Output</td>
<td>P_{max}</td>
<td>W_p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>330</td>
<td>335</td>
<td>340</td>
</tr>
<tr>
<td>Module Efficiency</td>
<td>%</td>
<td>16.63</td>
<td>16.93</td>
</tr>
<tr>
<td>Tolerance</td>
<td>-0/+3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-Circuit Current</td>
<td>I_{sc}</td>
<td>9.23</td>
<td>9.38</td>
</tr>
<tr>
<td>Open Circuit Voltage</td>
<td>V_{oc}</td>
<td>46.12</td>
<td>46.14</td>
</tr>
<tr>
<td>Rated Current</td>
<td>I_{mp}</td>
<td>8.72</td>
<td>8.87</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>V_{mp}</td>
<td>37.85</td>
<td>37.89</td>
</tr>
</tbody>
</table>

STC: Irradiance 1000 W/m^2, Cell temperature of 25°C, AM 1.5

TEMPERATURE COEFFICIENTS

Normal Operating Cell Temperature (NOCT) 44°C (±2°C)
Temperature Coefficient of P_{max} -0.419%/°C
Temperature Coefficient of V_{oc} -0.315%/°C
Temperature Coefficient of I_{sc} 0.049%/°C

OPERATING CONDITIONS

Maximum System Voltage 1,000VDC
Operating Temperature Range -40°C (-40°F) to +90°C (194°F)
Maximum Series Fuse Rating 15A
Fire Safety Classification Type 1, Class C
Front & Back Load (UL standard) 5600 Pa (117 psf) New!
Hail Safety Impact Velocity 25mm at 23 m/s

MECHANICAL DATA

Solar Cells P-type Mono-crystalline Silicon (156.75mm)
Cell orientation 72 cells (6x12), 4 busbar
Module dimension 1987mm x 999mm x 40mm (78.23 in. x 39.33 in. x 1.57 in.)
Weight 21.6 kg (47.6 lb)
Front Glass 3.2mm (0.126 in.) tempered, Low-iron, Anti-reflective coating
Frame Anodized aluminum alloy
Encapsulant Ethylene vinyl acetate (EVA)
J-Box Protection class IP67 with 3 bypass-diodes
Cables PV wire, 1.2m (47.24 in.), 4mm^2 /12 AWG
Connector MC4 or compatible

Mission Solar Energy reserves the right to make specification changes without notice.
Rev. 2.02
Our Watts+ guarantees our panels will produce at least the minimum advertised nameplate power

PowAR-TECH™ Glass features the industry’s best anti-reflective coating, capturing more light and increasing your panels’ power

Our patented INFINITEE™ Corners and Frame Technology are press-fit for superior strength and aesthetics and enhanced drainage

By capturing more light, OPTIGRID™ Cell Layout increases lifetime performance while also greatly increasing durability

Perma-Sil™ J-Box sealing encloses critical electrical connections, protecting them against moisture intrusion

With CoAST Salt Resistance, installations on islands or near coastal areas are certified against salt corrosion

For over four decades SolarWorld Americas has been creating the highest quality solar cells and panels. Driven by uncompromising standards of quality and reliability, every solar panel we produce demonstrates our commitment to American innovation, manufacturing and sustainability.

www.solarworld-usa.com
PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

<table>
<thead>
<tr>
<th></th>
<th>SWA 340</th>
<th>SWA 345</th>
<th>SWA 350</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power</td>
<td>P\text{max}</td>
<td>340 Wp</td>
<td>345 Wp</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>V\text{oc}</td>
<td>47.0 V</td>
<td>47.2 V</td>
</tr>
<tr>
<td>Maximum power point voltage</td>
<td>V\text{mpp}</td>
<td>37.1 V</td>
<td>37.5 V</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>I\text{sc}</td>
<td>9.81 A</td>
<td>9.82 A</td>
</tr>
<tr>
<td>Maximum power point current</td>
<td>I\text{mpp}</td>
<td>9.26 A</td>
<td>9.28 A</td>
</tr>
<tr>
<td>Module efficiency</td>
<td>η\text{m}</td>
<td>17.04 %</td>
<td>17.29 %</td>
</tr>
</tbody>
</table>

Measuring tolerance (Pmax) traceable to TUV Rheinland: +/- 2%

*STC: 1000W/m², 25°C, AM 1.5

PERFORMANCE AT 800 W/m², NOCT, AM 1.5

<table>
<thead>
<tr>
<th></th>
<th>SWA 340</th>
<th>SWA 345</th>
<th>SWA 350</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power</td>
<td>P\text{max}</td>
<td>257.3 Wp</td>
<td>260.4 Wp</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>V\text{oc}</td>
<td>43.6 V</td>
<td>43.6 V</td>
</tr>
<tr>
<td>Maximum power point voltage</td>
<td>V\text{mpp}</td>
<td>34.4 V</td>
<td>34.7 V</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>I\text{sc}</td>
<td>7.97 A</td>
<td>7.98 A</td>
</tr>
<tr>
<td>Maximum power point current</td>
<td>I\text{mpp}</td>
<td>7.49 A</td>
<td>7.50 A</td>
</tr>
</tbody>
</table>

Minor reduction in efficiency under partial load conditions at 25°C: at 200 W/m², 97% (+/-3%) of the STC efficiency (1000 W/m²) is achieved.

PARAMETERS FOR OPTIMAL SYSTEM INTEGRATION

<table>
<thead>
<tr>
<th></th>
<th>SWA 340</th>
<th>SWA 345</th>
<th>SWA 350</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power sorting</td>
<td>-0 Wp / +5 Wp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum system voltage</td>
<td>SC II / NEC</td>
<td>1000 / 1500 V</td>
<td></td>
</tr>
<tr>
<td>Maximum reverse current</td>
<td>25 A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of bypass diodes</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-40 to +85 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum design loads (Two rail system)*</td>
<td>113 psf downward, 64 psf upward</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Please refer to the Sunmodule installation instructions for the details associated with these load cases.

COMPONENT MATERIALS

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Cells per module</td>
<td>72</td>
</tr>
<tr>
<td>Cell type</td>
<td>Monocrystalline PERC</td>
</tr>
<tr>
<td>Cell dimensions</td>
<td>6 in x 6 in (156 mm x 156 mm)</td>
</tr>
<tr>
<td>Front</td>
<td>Tempered safety glass with ARC (EN 12150)</td>
</tr>
<tr>
<td>Back</td>
<td>Multi-layer polymer backsheet, white</td>
</tr>
<tr>
<td>Frame</td>
<td>Clear anodized aluminum</td>
</tr>
<tr>
<td>J-Box</td>
<td>IP65</td>
</tr>
<tr>
<td>Connector</td>
<td>PV wire (UL 4703) with Amphenol UTX connectors</td>
</tr>
<tr>
<td>Module fire performance</td>
<td>(UL 1703) Type 1</td>
</tr>
</tbody>
</table>

DIMENSIONS / WEIGHT

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Length</td>
<td>78.46 in (1993 mm)</td>
</tr>
<tr>
<td>Width</td>
<td>39.40 in (1001 mm)</td>
</tr>
<tr>
<td>Height</td>
<td>1.30 in (33 mm)</td>
</tr>
<tr>
<td>Weight</td>
<td>47.6 lb (21.6 kg)</td>
</tr>
</tbody>
</table>

ORDERING INFORMATION

<table>
<thead>
<tr>
<th>Order number</th>
<th>Description</th>
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<tbody>
<tr>
<td>82000664</td>
<td>Sunmodule SWA 340 XL mono</td>
</tr>
<tr>
<td>82000561</td>
<td>Sunmodule SWA 345 XL mono</td>
</tr>
<tr>
<td>82000563</td>
<td>Sunmodule SWA 350 XL mono</td>
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CERTIFICATES AND WARRANTIES

<table>
<thead>
<tr>
<th></th>
<th>IEC 61730</th>
<th>IEC 61215</th>
<th>UL 1703</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certificates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warranties*</td>
<td></td>
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</tr>
</tbody>
</table>


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SRP-6MA | SERIES | 6 INCH 72 CELLS

340-360W

AMERICAN RECOVERY AND REINVESTMENT ACT

Modules manufactured at our Jackson, MS facility qualify for projects that are required to meet the “Buy American” clause of the American Recovery and Reinvestment Act (ARRA)

MANAGEMENT SYSTEM

ISO 9001: Quality management system
ISO 14001: Standard for environmental management system
OHSAS 18001: International standard for occupational health and safety assessment system

PRODUCT CERTIFICATES

WARRANTY

Guarantee on product material and workmanship
Linear power output warranty

Safety

Safety for salt mist corrosion (IEC61701, tested in TÜV SÜD)
Safety for ammonia corrosion (IEC62716, tested in TÜV SÜD)
Fire Rating: Class C
Module Fire Performance: Type 1

Reliability

PID free products, passing TÜV SÜD system voltage durability test
World 1st company to pass “Thresher Test” and “On-site Power Measurement Validation” certificate
Bankable products

Performance

Advanced
100% In-line Electroluminescence (EL) tests minimize breakage rate
Top rank in Photon yield measurement

SERAPHIM SOLAR USA MANUFACTURING, INC.
Web : www.seraphimusa.com
Email : info@seraphimusa.com

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SRP-6MA    SERIES    6 INCH 72 CELLS

**SRP-6MA**

**Electrical Characteristics (STC)**

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Power STC - Pmp (W)</td>
<td>340</td>
<td>345</td>
<td>350</td>
<td>355</td>
<td>360</td>
<td></td>
</tr>
<tr>
<td>Open Circuit Voltage - Voc (V)</td>
<td>46.60</td>
<td>46.80</td>
<td>47.00</td>
<td>47.20</td>
<td>47.40</td>
<td></td>
</tr>
<tr>
<td>Short Circuit Current - Isc (A)</td>
<td>9.32</td>
<td>9.43</td>
<td>9.51</td>
<td>9.61</td>
<td>9.70</td>
<td></td>
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<tr>
<td>Maximum Power Voltage - Vmp (V)</td>
<td>37.70</td>
<td>37.90</td>
<td>38.10</td>
<td>38.30</td>
<td>38.50</td>
<td></td>
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<tr>
<td>Maximum Power Current - Imp (A)</td>
<td>9.02</td>
<td>9.11</td>
<td>9.19</td>
<td>9.27</td>
<td>9.35</td>
<td></td>
</tr>
<tr>
<td>Module Efficiency STC - ηm (%)</td>
<td>17.52</td>
<td>17.78</td>
<td>18.04</td>
<td>18.30</td>
<td>18.55</td>
<td></td>
</tr>
</tbody>
</table>

STC: Irradiance 1000 W/m² module temperature 25°C AM=1.5;
Power measurement tolerance: +/-3%

**Electrical Characteristics (NOCT)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Power NOCT - Pmp (W)</td>
<td>252</td>
<td>256</td>
<td>260</td>
<td>263</td>
<td>267</td>
<td></td>
</tr>
<tr>
<td>Open Circuit Voltage - Voc (V)</td>
<td>43.00</td>
<td>43.20</td>
<td>43.40</td>
<td>43.60</td>
<td>43.80</td>
<td></td>
</tr>
<tr>
<td>Short Circuit Current - Isc (A)</td>
<td>7.59</td>
<td>7.68</td>
<td>7.68</td>
<td>7.75</td>
<td>7.84</td>
<td></td>
</tr>
<tr>
<td>Maximum Power Voltage - Vmp (V)</td>
<td>35.50</td>
<td>35.60</td>
<td>35.80</td>
<td>35.90</td>
<td>36.10</td>
<td></td>
</tr>
<tr>
<td>Maximum Power Current - Imp (A)</td>
<td>7.10</td>
<td>7.19</td>
<td>7.27</td>
<td>7.33</td>
<td>7.40</td>
<td></td>
</tr>
</tbody>
</table>

NOCT: Irradiance 800 W/m² ambient temperature 20°C wind speed: 1m/s;
Power measurement tolerance: +/-3%

<table>
<thead>
<tr>
<th>Power Tolerance (W)</th>
<th>(0, +4.99)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum System Voltage (V)</td>
<td>1000 (TÜV), 1000 (UL)</td>
</tr>
<tr>
<td>Maximum Series Fuse Rating (A)</td>
<td>20</td>
</tr>
</tbody>
</table>

**Temperature Characteristics**

- Pmp Temperature Coefficient: -0.40 %/°C
- Voc Temperature Coefficient: -0.32 %/°C
- Isc Temperature Coefficient: +0.05 %/°C
- Operating Temperature: -40~+85°C
- Nominal Operating Cell Temperature (NOCT): 45±2°C

**Mechanical Specifications**

<table>
<thead>
<tr>
<th>External Dimensions</th>
<th>1956 x 992 x 50 mm</th>
<th>1956 x 992 x 40 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>24.0 kg</td>
<td>23.0 kg</td>
</tr>
<tr>
<td>Solar Cells</td>
<td>Monocrystalline 156 x 156 mm (72pcs)</td>
<td>Monocrystalline 156 x 156 mm (72pcs)</td>
</tr>
<tr>
<td>Front Glass</td>
<td>3.2 mm tempered, low iron, AR coating</td>
<td>3.2 mm tempered, low iron, AR coating</td>
</tr>
<tr>
<td>Frame</td>
<td>Anodized aluminum alloy</td>
<td>Anodized aluminum alloy</td>
</tr>
<tr>
<td>Junction Box</td>
<td>IP67</td>
<td>IP67</td>
</tr>
<tr>
<td>Output Cables</td>
<td>4.0 mm², cable length: 1300 mm</td>
<td>4.0 mm², cable length: 1300 mm</td>
</tr>
<tr>
<td>Connector</td>
<td>MC4 Compatible</td>
<td>MC4 Compatible</td>
</tr>
<tr>
<td>Mechanical Load</td>
<td>5400 Pa</td>
<td>5400 Pa</td>
</tr>
</tbody>
</table>

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Appendix B
1. TOTAL AREA OCCUPIED IS APPROXIMATELY 1 ACRE

2. TOTAL NUMBER OF PANELS 1000 ARRANGED INTO 10 ROWS OF 100 PANELS EACH.

NOTES:

NOTES:

NOTES:

NOTES:

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NOTES:

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NOTES:

NOTES:

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NOTES:

1. TOTAL AREA OCCUPIED IS APPROXIMATELY 1 ACRE