# Solar Racking Installation for an Automated Public Transportation System

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## Abstract

The Sustainable Mobility System for Silicon Valley (SMSSV), also known as the Spartan Superway, is a project to develop a grid-tied solar powered Automated Transit Network (ATN) system. The ATN system will be elevated allowing for traffic and infrastructure below. The ATN system is designed for the vehicles or pods to be hanging from the track, giving the system opportunities for a solar module system on the top of the ATN.

Recent work has focused on analyzing the power requirements and designing the solar power system for a potential implementation of ATN in the city of San José. The System Advisor Model (SAM) software from the National Renewable Laboratory (NREL) estimates the POA (plane-of-array) energy available for the ATN network and how much can be used for other applications. Results show to power 88 vehicles over a 14km guideway 24 hours a day requires 19,600 monocrystalline solar panels with an area of 38,000m2. 24/7 and be zero net-metered (on average) over a calendar year.

Extensive research determining the boundary condition required for our solar racking system is underway. A design for a racking system utilizing bolts was analyzed showing more

difficult maintenance & installation, however cheaper infrastructure. Another design for a semi-automated design was analyzed essentially showing cheaper maintenance & installation, however more expensive infrastructure. Four different designs for semi-automated locking mechanism were created. Two different blind-connecting maximizers were designed to be implemented with the semi-automated racking system. Cost-analysis of the solar installation shows that an automated cleaning system is necessary for the large scale installation. Solutions for Building Integrated Photovoltaic tiles and modules were also analyzed. However, do to the unrefined design of the ATN system, no racking system can be solidified yet.

Different options of monocrystalline, polycrystalline, and thin film solar modules were examined. The First Solar thin-film module utilize cadmium-telluride (CdTe) cells obtained an efficiency of 17% and was determined to be a the best cost per watt in the thin-film category; some installation have be seen to be as low as 25cents per watt (Christ Martin 2016). The 15.5% Miasole thin-film (CIS/CIGS) again was a cheap option at 28 cents per watt yet still reasonably efficient (Eric Wesoff 2015). The Q-Cells

*Keywords: Automated Transit Networks (ATN), Personal Rapid Transit (PRT), sustainable energy, photovoltaic cells, System Advisor Model (SAM)*

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## Introduction

San José State University started the Sustainable Mobility System for Silicon Valley (SMSSV), also known as Spartan Superway, in 2012. It addresses sustainable mobility through the use of a solar-powered automated transit network (ATN), sometimes referred to as personal rapid transit (PRT) or pod cars. The Spartan Superway solves the problems of traffic congestion, accidents, high vehicle costs, environmental degradation, clean & sustainable energy, loss of productivity due to transportation, and dependence on fossil fuels for transportation.

The United States Energy Information Agency (EIA) estimated in 2015 that energy sources used for transportation in the US were 92% petroleum, 3% natural gases, and 3% natural gas - in other words 92% of our energy for transportation came from hydrocarbons with harmful emissions (EIA, 2015). The objective of the authors' research is to power the Spartan Superway ATN completely using solar energy, drastically reducing the amount of toxic material, i.e., batteries, fossil fuel, coal, etc., that are used by other modes of transit. The integration of solar power into the Superway encompasses solar panel mechanical design, solar panel orientations and material, relevant energy consumption and production calculations, the electrical system design, and most recently the racking design.

The summer work has made progress in: determining the general power consumption for the Spartan Superway, solar panel array designs, general power production of PV panels, electrical system and electrical rail traction (wayside pick-up). This fall progress has been made in: determine specific module for installations, designing locking mechanisms, determining possible racking companies, cost analysis of installation and maintenance as well as gathering concepts for a custom racking system. A full-scale test track is being designed so that the complete system can be validated and refined. The rest of this paper will summarize results of research to date.

**Description of Solar Team Objectives**

The Solar Team had one main objective during the fall internship; define the boundary conditions for a the Spartan Superway's racking system. The boundary condition encompassed: pre-use fabrication methods, materials for modules (all solar specs), manufacturers, durability, cost, ease of assembly and installation, maintenance, connecting mechanisms, solar panel aesthetics, and analysis of frame and frameless system. The Solar Team wanted to understand the thousands of solar racking companies designs and utilize those that were most effective in the Spartan Superway. Categorizing the most effecting system required analyzing installations, & maintenance methods, mechanical components and durability. Another objective was determining the most efficient and cost effective thin-film, polycrystalline, and monocrystalline module that can be implemented in our designs. When designing the frames and racks, the solar team needed to consider, aesthetics, limiting material, transporting material, automated connections, and a system that can be implemented in different locations and tracks. To satisfy these designing goals the solar team needed to develop a blind connecting maximizer, a curved (implementable) module frame, flat module frame, and an automated/mechanical connecting racking system.

Previously regarding the Simulation and Design; the Solar Team wanted to develop a power consumption simulation tool able to work in different guideway layouts. Also, the solar team wanted to simulate optimal power productions and orientations of modules, specifically in the San

Jose area. The solar team made a basic simulation of the entire electrical system; consisting of all components from solar arrays to the grid. To satisfy others team's simulations goals, power consumption equations were developed, System Advisor Model was used to determine power production, and a basic electrical block diagram of the Spartan Superway was created. When designing the solar team needed to consider, aesthetics, limiting material, automated connections, and a system that can be implemented in different locations and tracks. To satisfy these designing goals the solar team needed to develop a blind connecting maximizer, a curved (implementable) module frame, flat module frame, and an automated connecting racking system.

### 03. Design Requirements and Specifications for the Sub-Team's Work Products

The design will fulfill the requirements and specifications listed below

- Frames need to fit a curved module
- Frames need to fit a flat module
- Frames must be able to be implemented on track area and structure
- Frames need to semi-automatically be installed
- Frames need to manually be installed
- Full/semi-Automated cleaning
- Rack needs to be easily installed
- Rack and frames must be socially aesthetic
- Motor is DC making its optimal to use a DC wayside
- Needs to power at least 88 vehicles all 1900kg
- Structurally sturdy

## 04. State –of-the-Art/Literature Review for the Solar Teams Sphere of Work.

Currently, we have three main solar panels that are widely used throughout the world. There are monocrystalline silicon solar panels, polycrystalline silicon solar panels, and thin-film solar cells. Each solar panel has its advantages and disadvantages depending on the application for which it is used for. Specifically, for the Spartan Superway, the intermediate solar team decided to select the types of solar panels based on “cost, efficiency, lifespan, and simplicity of manufacturing, and the amount of space allowed to installed the solar panel” (Spartan Superway, 2014). Almost 90% of the World’s photovoltaics today are based on some variation of silicon. In 2011, about 95% of all shipments by U.S. manufacturers to the residential sector were crystalline silicon solar panels. The silicon used in PV takes many forms. The main difference is the purity of the silicon. The more perfectly aligned the silicon molecules are, the better the solar cell will be at converting solar energy (sunlight) into electricity (the photoelectric effect) (Mathias Maehlum 2015). The efficiency of solar panels goes hand in hand with purity, but the processes used to enhance the purity of silicon are expensive. Efficiency should not be the Spartan Superway’s primary concern. As cost-and space-efficiency are a significant determining factors for our commercial application.

Monocrystalline silicon solar panels are made with high purity silicon as shown in Figure 01. High purity means that the solar cells are packed and aligned extremely well. As a result, the precise alignments will help convert solar energy to electricity better. “Monocrystalline silicon solar panels has an efficiency of 15-20%, it has the highest efficiency of the different types of solar panels, a long life span, and produces the most efficient result under low light conditions” (Spartan Superway, 2014). Unfortunately, it is the most expensive amongst the three types of solar panel due to the amount of work to produce precise alignments.

**Figure 01: Monocrystalline Silicon Solar Panel example.**

Polycrystalline silicon solar panels utilizes raw silicon, they are manufactured by pouring raw silicon into a square mold. As a result, polycrystalline silicon solar panels are easier to manufacture and cost less compared to monocrystalline silicon solar panels. Polycrystalline silicon solar panels has an efficiency of 13-16%, in this case, there needs to be more polycrystalline silicon solar panels in order to produce the same amount of power output compared to a monocrystalline silicon solar panel. A polycrystalline silicon solar panel is shown in Figure 02.

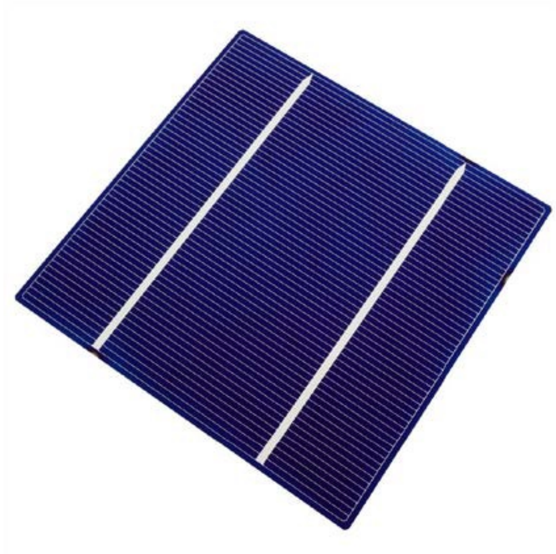


**Figure 02: Polycrystalline Silicon Solar Panel Example.**

They require more space in order to produce the same amount of power output. Thin-film solar cells are easier to mass produce and they are aesthetically appealing due to the ability to bend. Unfortunately, thin-film solar cells degrade faster compared to polycrystalline and monocrystalline solar panels. A picture of a thin-film solar cell is shown in Figure 03. Polycrystalline thin-film are made out of two main materials Cadmium Telluride (CdTe) and Copper Indium Gallium Diselenide (CIGS). CdTe is the most widely used in commercial applications. Recent research has matched the efficiency of multicrystaline silicon while maintaining cost leadership (NREL 2016). However this is lots of potential for CIGS which has shown the highest-efficiency alternative for large scale, commercial thin-film solar cells. CIGS has set records of small-area single-junction efficiency at 22%.

**Figure 03: Thin Film Solar Panel Example.**

When determining racking systems, it was necessary to understand the varies regulations and standards that would constrain our racking system. The 2016 "California Solar Permitting Guidebook" (CSPG) developed by the Solar Permitting Task Force, The Governor's Office of Planning and Research, and the Office of Governor Edmund G. Brown Jr., explains some of the regulations we need to obey. California's state and local governments put in place rigorous objectives to expand renewable energy which may encourages the implementation of the Spartan Superway. In 2011, California adopted a Renewable Portfolio Standard (RPS) which needs a minimum of one-third of the state's electricity to come from clean energy sources by 2020. Many local governments established their own goals for renewable energy which will be explained later. Furthermore, Governor Edmund G. Brown Jr. has set a specific goal of developing 12,000 megawatts of small-scale, localized renewable electrical power in California by 2020.

California's state building codes provide rigid requirements for buildings throughout the state. These requirements are established in the Title 24 of the California Code of Regulations (CCR). The CCR is separated contains 28 separate titles based on topic or state agency authority. Title 24 reserved for state regulations that govern the design and constructions of buildings, associated facilities and equipment. These regulations are also known as the state's "building standards" (CSPG 2016, p. 8). Title 24 applies to all building occupancies, related building features, and equipment throughout the state. The codes contain requirements for a building's structural, mechanical, electrical and plumbing systems, in addition to measures for energy conservation, sustainable construction, maintenance, fire and life safety and accessibility.

A common misunderstanding is that Title 24 specifically related to energy conservation or accessibility requirements. However, it covers a much broader variety of requirements for buildings. Only Specific areas within Title 24 identify a limited amount of requirements for solar PV installations such as the California Electrical Code, California Building Code, California Plumbing Code, California Mechanical Code and California Residential Code (which applies to residential buildings of one or two units).

State regulations should not be confused with state laws enacted through the legislative process. State regulations are adopted by state agencies where necessary to implement, clarify and specify requirements of state law. The California Building Standards Commission and the other state adopting agencies review the codes and update Title 24 as appropriate. Title 24 is updated every 18 months with a model code update every three years. Several portions of Title 24 govern installation of a solar energy system. (CSPG 2015, p.8). Title 24 covers 5 main categories of codes, Building Code, Electrical Code, Residential Code, Energy Code, and Fire Code. Below are some of the relevant regulations the Spartan Superway will be constrained to in each category.

**Codes:**

The California Building Code (Sections 1.1.8 and 1.1.8.1) outlines the specific findings that a city or county must make for each amendment, addition or deletion to the state building codes.

General Codes:

1. Module manufacturer, make, model and number of modules match the approved plans. (CBC 107.4)

2. DC PV modules are listed to UL 1703. Ac modules are listed to UL 1703 and UL 1741. (CEC 110.3, 690.4 & CBC 1509.7.4 & CRC R908.1.5)

3. Modules are attached to the mounting structure according to the manufacturer's instructions and the approved plans. (CEC 110.3[B], CBC 107.4 & CRC R908.1.4)

4. Roof penetrations/attachments are properly flashed. (CBC Chapter 15 & 2012 CRC Chapter 9)

5. Rooftop systems are designed in accordance with the CBC. (CBC 1509.7 & CRC R908.1)

6. Roof access points, paths and clearances need to comply with the CFC. (CFC 605.11.3.1 - 605.11.3.3.3, CRC R331.4.1 through R331.4.2.4)

7. PV installation shall comply with requirements of the standard plan.

8. PV system operating at 80 volts or greater shall be protected by a listed DC arc fault protection. (CEC 690.11)

9. All work done in a neat and workmanlike manner. (CEC 110.12)

**Fire Safety Requirements**

1. Rooftop-mounted PV panels and modules have the proper fire classification rating. (CBC 1509.7.2 & CRC R908.1.2)

2. Conduit, wiring systems and raceways for photovoltaic circuits are located as close as possible to the ridge, hip or valley (figure 4.) and closest to an outside wall in order to reduce trip hazards and maximize ventilation opportunities. (CFC 605.11.2 & CRC R331.3)

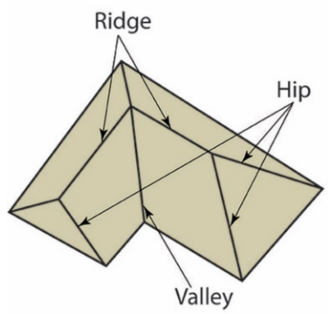



**Figure 04: Ridge, Hip, and Valley of a roof.**

3. Conduit runs between sub arrays and to DC combiner boxes are installed in a manner that minimizes total amount of conduit on the roof by taking the shortest path from the array to the DC combiner box. (CFC 605.11.2 & CRC R331.3)

4. DC Combiner Boxes are located so that conduit runs are minimized in the pathways between arrays. (CFC 605.11.2 & CRC 331.3)

5. DC wiring in enclosed spaces in buildings is installed in metallic conduit or raceways. Conduit runs along the bottom of load bearing members. (CFC 605.11.2 & CEC 690.4[F] & CRC R331.3)

6. All roofs have an access point that does not place ground ladders over openings such as windows or doors, are located at strong points of building construction, and in locations where the access point does not conflict with overhead obstructions such as tree limbs, wires, or signs. (CFC 605.11.3.1 & CRC R331.3)

7. Roofs with slopes greater than 2:12 have solar panel layouts with access pathways that comply with approved roof plan that meet the following criteria:

A. Hip Roofs: Panels/modules are located so that there is a 3-foot wide clear access pathway from the eave to the ridge on each roof slope where panels/modules are located. ( CFC 605.11.3.2.1 & CRC R331.4.2.1)

B. Hips and Valleys: If panels/modules are placed on both sides of a hip or valley they are located no closer than 18 inches to a hip or valley. If the panels are located on only one side of a hip or valley that is of equal length, then the panels can be placed directly adjacent to the hip or valley. (CFC 605.11.3.2.3 & CRC R 331.4.2.3)

C. Single Ridges: Panels/modules are located so that there are two 3-foot wide access pathways from the eave to the ridge on each roof slope where there are panels/modules installed. (CFC 605.11.3.2.2 & CRC R331.4.2.2)

D. Ridges: Panels/modules are located no higher than 3 feet from the top of the ridge in order to allow for fire department smoke ventilation operations. (CFC605.11.3.2.4 & CRC R331.4.2.4)

E. Access pathways are located at a structurally sound location capable of supporting the load of fire fighters accessing the roof. (CFC 605.11.3.2.1 & CRC R331.4.2.1)

Electrical Requirements

1. DC modules are properly marked and labeled. (CEC 110.3, 690.4[D] & 690.51)

2. AC modules are properly marked and labeled as shown in figure 5. (CEC 110.3, 690.4[D] & 690.52)

Job Address: ______________________________ Permit #: ________________

Contractor/ Engineer Name: ______________________ License # and Class: __________

Signature: ____________________ Date: _______ Phone Number: ____________

Total # of Inverters installed: _______ (If more than one inverter, complete and attach the "Supplemental Calculation Sheets" and the "Load Center Calculations" if a new load center is to be used.)

Inverter 1 AC Output Power Rating: _______________ Watts

Inverter 2 AC Output Power Rating (if applicable): ________ Watts

Combined Inverter Output Power Rating: _____________ ≤ 10,000 Watts

Location Ambient Temperatures (Check box next to which lowest expected temperature is used):

| |
|---|
| 1) ☐ Lowest expected ambient temperature for the location ($T_L$) = **Between -1 to -5 °C** |
| ☐ Lowest expected ambient temperature for the location ($T_L$) = **Between -6 to -10 °C** |
| Average ambient high temperature ($T_H$) = 47 °C |
| Note: For a lower $T_L$ or a higher $T_H$, use the Comprehensive Standard Plan |

DC Information:

| | |
|---|---|
| Module Manufacturer: __________________ | Model: ______________________ |
| 2) Module $V_{oc}$ (from module nameplate): _____ Volts | 3) Module $I_{sc}$ (from module nameplate): _____ Amps |
| 4) Module DC output power under standard test conditions (STC) = _______ Watts (STC) | |

**Figure 05: CEC 110.3 document for listing or labeling equipment.**

3. PV modules are in good condition (i.e., no broken glass or cells, no discoloration, frames not damaged, etc.). (CEC 110.12[B])

## PV Source/output Circuit Conductor Management

1. Cables are secured by staples, cable ties, straps, hangers or similar fittings at intervals that do not exceed 4.5 feet. (CEC 334.30 & 338.12[A][3])

2. Cables are secured within 12 inches of each box, cabinet, conduit body or other termination. (CEC 334.30 & 338.12[A][3])

3. Cable closely follows the surface of the building finish or of the running boards. (CEC 690.4[F] & CFC 605.11.2 & CRC R331.3) NOTE: see Section 12 below for additional requirements on routing of conductors for fire fighter safety concerns.

4. Exposed single conductors, where subject to physical damage, are protected. (CEC 230.50[B] & 300.5[D])

5. Exposed single conductors used for ungrounded systems are listed and identified as "PV wire." (CEC 690.35[D][3]) For other conductor requirements for ungrounded systems, see CEC 690.35(D).

**Description of Designs**

Throughout the process of determining effective designs there was never a solidified design for our ATN track. Because there was no track design to reference multiple variations of tracks must be accounted for. There were multiple constrains to take into account: support beams are 24 meters apart, most commercial aluminum or galvanized steel beams are limited at 40 feet, the design must have aesthetic capabilities, and efficiently installed and maintained. Hundreds of different racking systems were analyzed, examining unique components, durability, installation, maintenance and cost. Three main racking categories were analyzed, system for pitched roofs, flat roofs, and ground mounts. Also another option of solar panels known as Building Integrated Photovoltaics were analyzed. Below are the designs that were determined to fit best in our system and their corresponding description.

**Canopies**

One of the Canopies that contained the aesthetics the Spartan Superway desired was the Burke Solar Pavilion in Cincinnati, Ohio shown below. The solar canopy only produced 368.73 kW with 1,505 panels. The panels were 245 W poly Sunmodule Solar panels. One 260 kW inverter and one 100 kW inverter were used. The system features a gently curved design to match the existing aesthetics present on Burke's LEED Gold seven-acre campus in downtown Cincinnati. The solar installation generate approximately 30% of Burke's electrical generation requirements. Burke employees use the solar pavilion for break times, lunches, company gatherings, and team meetings. The distance in between supports was roughly 10 meters, however the current design concepts for the track only allow require a length of 24meters.

**Figure 06: The Burke Solar Pavilion in Cincinnati, Ohio**

The other canopy that utilized the curved aesthetics was the Solar carport installation on Plantronics shown in figure 6. The installation at Plantronics was done by our own Ron Swenson which allows us access to the crucial CAD files. The installation produced 608 kW with 2,482 solar panels utilized 245 W mono Sunmodule panels and 5 PV powered inverters. The distance in between supports was roughly 10 meters, however the current design concepts for the track require a length of 24meters. If the supports could be replaced by the roof of the track, it would allow the us to have small incremented supports as well as additional supports at 24 meters. To utilize the 24 meter support however would require a custom length beam.

**Fig 07: Solar canopy installation for the Plantronics headquarters.**

The modules were designed to have a 5 degrees' increment to achieve the aesthetic curve. However, in this design the modules are welded to the curved beam which may not be ideal in the Spartan Superway's circumstances as seen below. Most of the fabrication is done directly on the canopy.

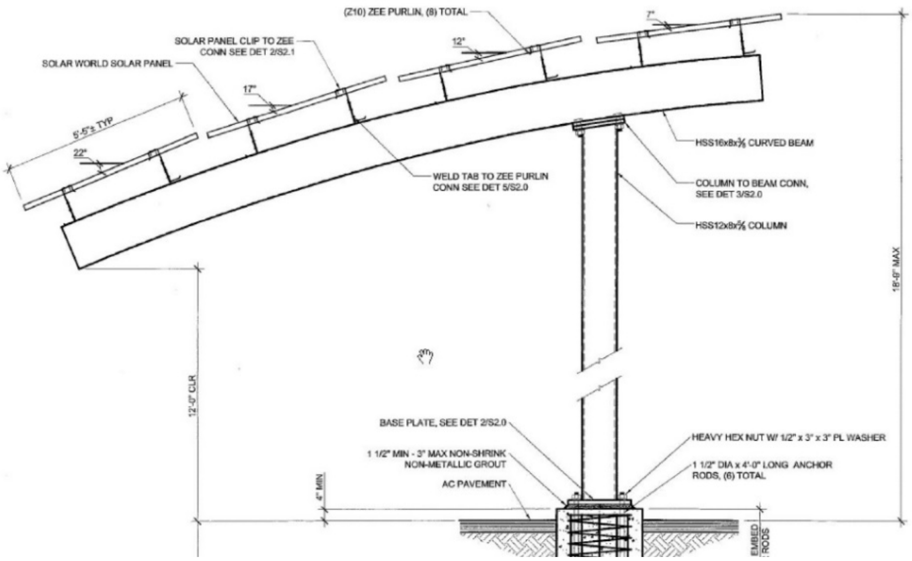



**Figure 08: Design for Plantronics curved solar installation.**

Also, removing the existing modules is more difficult than desired for the Spartan Superway. To remove a corrupted module a company will need to remove the bird screens below the section of the corrupted module. Then worker will come from above on a cherry picker or possibly below with a scissor left shown in the figure below. In the figure you can see a worker bringing up the modules on a scissor lift and another worker drilling in modules on a cherry picker. Also to cover the seams in between the inclined modules there were metal sheet put over the seams, which has led to leakage issues. Another concern is that the maximum distance in between supports is designed for 8 meters, however these designs could be altered to support a 24-meter system utilizing custom length beams.

**Figure 09: Module uninstalling/Installing process in the Plantronics Solar Canopy.**

**Sloped Roofs**

Standard Solar created unique curved design for one of their installations, however after contacting the company, they are very hesitant to release any information such as pictures. The curved design is an aesthetic the Spartan Superway would like to achieve, and very few companies have managed to design working version. Standard Solar designed and installed the solar power equipment at the University of Denmark. UD wanted to construct a significant electricity-generating solar PV system, but was limited by the capital outlay of such a large installation. A significant challenge to this project was one of the initial sites chosen, the UD Field House, that features a half barrel-shaped roof. Although the shape of the roof is nearly ideal for solar, the installation of flat solar modules on a rounded roof presented the team with quite a challenge.

This installation required re-engineering some of the mounting hardware and special safety equipment for the crew, among other things which are proprietary. Their system resulted in 1,035 megawatt-hours (MWh) of energy annually, enough electricity to offset 906 tons of carbon dioxide annually. The decline in emission would equate to the use of 93,363 gallons of gasoline each year.

**Fig 10: Standard Solar's curved solar roof installation.**

A benefit of Standard Solar is that they pride themselves on their strong connections with leading vendors and utility companies. Standard Solar is NABCEP-certified PV Installation and partner with Vigilant Energy Management to offer operation and maintenance solutions. Although Standard Solar does not give information regarding their mechanical components, it seems they use the standard bolt and screw mechanism that most companies utilize. Standard Solar claims they were selected because they offered a turnkey solution including finance, design, construction, operations and maintenance at a cost that was lower than UD's current electricity rate. Standard Solar designed, installed and will own and maintain the system hosted by UD.

Another option is using a thin-film canopy. Konarka installed a thin-film canopy in a parking lot as shown in figure 11.

**Figure 11: Konarka solar canopy**

The Konarko solar canopy uses 8.4% efficient cells however these can be replaced by more efficient thin-films. Also thin-films can usually be printed at any custom size, so it will be able to span the 24 meter distance of our support beams.

## Flat Roofs

The SnapnRack system features snap-in installation and integrated bonding hardware that leads to an overall reduction in material costs and dramatic reduction in labor. It is also UL 2703 certified and Class A fire rated for Type 1 and Type 2 modules ensuring installers provide the best-in-class installations in quality, safety and efficiency. The standard rails used in the SnapNRack system is compatible with all components, allowing installers to manually snap in clamps, base attachments, etc. The company has multiple clamps; Module clamp has two bonding pins, making sure the module is not just only bonded to the rail but to the entire clamp. The Universal End Clamp (UEC ) is a unique one-size-fits-all time saver that slips inside the module frame – completely out of sight. SnapnRack also has a screen that can be installed below the SnapnRack, preventing rodents and other animals from destroying the racking system and modules. All components have been through a load and torque analysis and has compliance certifications and a UL module certification.

**Fig 12: SnapnRack solar racking system.**

**Building Integrated Photovoltaics (BIPV)**

**Figure 13: Solar glazed Building Integrated Photovoltaics.**

Building integrated photovoltaics (BIPV) have three significant advantages. BIPVs can be an aesthetical, economical and technical solution for integrating solar cells within the climate envelopes of buildings. Photovoltaic (PV) cells are conventionally mounted on above or directly on the existing roofing structure. BIPV systems replace the outer building envelope (separator between the conditional and unconditional environment of a building) skin allowing BIPVs to be utilized simultaneously as both a climate screen and a power source. Because the modules can be utilized for multiple uses, BIPVs may provide savings in materials and labor, in addition to reducing the electricity costs.

In addition to specific requirements put on the BIPV technology, it is crucial to abide by satisfactory or strict requirements of water resistance and durability when implementing BIPV products. Issues like heat and moisture transport in the building envelope also have to be considered and accounted for possible physical problems. The work done by professor Bjorn Petter Jelle, from both a technical and scientific point perspective, summarizes the generalities of the current state-of-the-art for BIPV systems, including both BIPV foil, tiles, modules and solar cell glazing products.

**Figure 14: Examples of a BIPV tiles (a) and BIPV modules (b) (Applies Solar, DuPont)**


(a) (b)

**Figure 15: Example of a BIPV as solar glazing products for facades (a) and roof (b) (ASI Glass photovoltaic module, Schott Solar AG).**

**Thin Film:**

**Table 01: Literature data for one of the building integrated photovoltaics (BIPV) foil products.**

| Manufacturer | Product * | η (%) | $U_{oc}$ (V) | $I_{sc}$ (A) | $P_{max}$ (W) | FF | Area (mm × mm) | $P_{max}$/Area (W/m$^2$) |
|---|---|---|---|---|---|---|---|---|
| Alwitra GmbH & Co. | Evalon V Solar 408 | | 138.6 | 5.1 | 408/module | 0.58 | 1550 × 6000 | 42.9 |
| | Evalon V Solar 136 | | 46.2 | 5.1 | 136/module | 0.58 | 1050 × 3360 | 38.5 |

* Several models are available from the producer in the Evalon V Solar series.

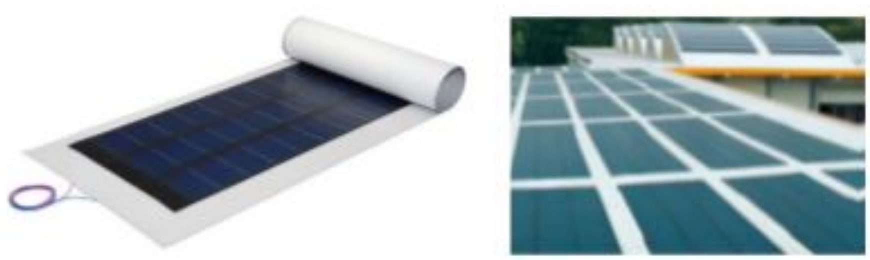


**Figure 16: Example of a BIPV foil product from Alwitra GmbH & Co. using amorphous silicon cells from Uni-Solar.**

BIPV Foil Products BIPV foil products are lightweight and flexible, which promotes easy installation, aesthetics designs, and reducing weight on the system. The PV cells are most commonly derived from thin film cells to maintain the flexibility in the foil and the efficiency during high temperatures for on non-ventilated roof solutions. Unfortunately, Jelle claims there are few manufacturers on the market that provide weather tight solutions. Table 1 and Figure 3 present an example of one BIPV foil products.*(Jelle p.2, 2016)*

PV foil products have a low fill factor due to both the low efficiency and the large solar cell electrical resistances of thin film cells. However, due to their flexibility and relatively low weight, these solar cell foil products may easily be applied to a lot of different building surfaces.

** The **Fill Factor** (FF) is essentially a measure of quality of the **solar** cell. It is calculated by comparing the maximum power to the theoretical power ($P_T$) that would be output at both the open circuit voltage and short circuit current together

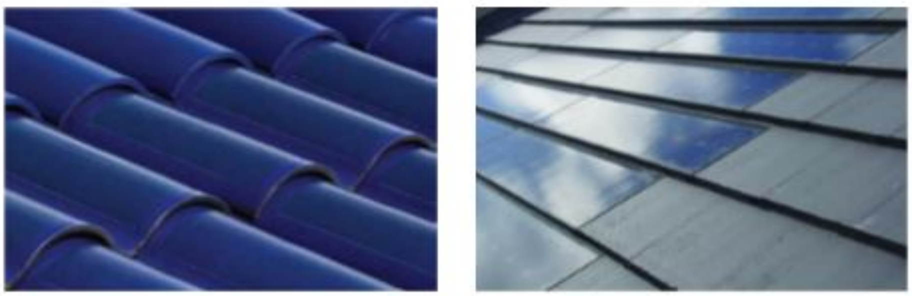
**Mono/Poly-Crystaline:**

BIPV Tile Products: BIPV tile products can be utilized to cover the entire Spartan Superway Transit or sections of the transit. Mono/Poly-Crystalline BIPVS are usually arranged in modules with the appearance and properties of standard roof tiles and substitute a certain number of traditional roof tiles, allowing convenient retrofitting of roofs. The cell efficiency and tile shape varies. Some tile products may resemble curved ceramic tiles  that are commonly seen on roofs and will not be as area effective due to the curved surface. However, curved tiles, or other geometric shapes may be more aesthetically pleasing. Some examples of BIPV tile

**Table 02: Literature data for some of the BIPV tile products**

| Manufacturer | Product * | η (%) | $U_{oc}$ (V) | $I_{sc}$ (A) | $P_{max}$ (W) | FF | Area (mm × mm) | $P_{max}$/Area (W/m$^2$) |
|---|---|---|---|---|---|---|---|---|
| Solardachstein | STEPdesign | | 23.15 | 2.40 | 1.36/cell | 0.76 | 8 units 100 × 100 | 136 |
| SRS Energy | Solé Powertile | | 6.3 | 4.6 | 15.75/module | 0.54 | 868 × 457.2 | 39.7 |
| Lumeta | Solar Flat Tile | | 7.4 | 5.2 | 28/module | 0.73 | 432 × 905 | 71.6 |
| Solar Century | C21e Tile | 20/cell | 12.0 | 5.55 | 52/module | 0.78 | 1220 × 420 | 101.5 |

* Lumeta has also a Solar S Tile available.



(a) (b)

**Figure 17: Example of a BIPV tile products from SRS Energy (a) and Solar Century (b).**

products on the market today are given in Table 2, with two of them depicted in Figure 7.

Solardachstein, Lumeta and Solar Century (Table 2) provide the highest FFs in BIPV Tile products, indicating high effeciencies. Solar Century claims to have an efficiency of 20% per cell for their C21e Tile. The design concept of the STEPdesign and the Solé Powertile are solutions that appear replace standard roof tiles. The module has an integrated panel of poly- or monocrystalline cells. i.e., parts of the module are not covered with PV cells, thus the total area efficiency will not be as high as indicated. The STEPdesign solution from Solardachstein can be mounted on several different tile products. The C21e Tile from Solar Century has a larger area exposed to the sun than the previous products; since The C21 monocrystalline silicon cells scree the entire module area, and is suitable for a series of named tiles and slates. Solé Powertile from SRS Energy has a design much like standard roof tiles and the amorphous silicon cell cover from Uni-Solar acts as the skin of the tiles.

**BIPV Module Products**

The BIPV module products are slightly similar to conventional Solar panels, however The difference is that the BIPV modules are made with weather skin solutions. Some BIPV solutions will substitute various catagories of roofing, or they are compatible with a specific roof solution produced by its manufacturer. These mounting systems increase the ease of installation. Several products are on the market and some of them are promoted as BIPV products without in fact functioning as weather skins, whereas other products are not very specific on how they are actually mounted which leads to uncertainty whether they are BIPV or BAPV. Some of the BIPV module products are premade modules with thermal insulation or other components included in

**Table 03: Literature data for some of the BIIPV products.**

| Manufacturer | Product * | η (%) | $U_{oc}$ (V) | $I_{sc}$ (A) | $P_{max}$ (W) | FF | Area (mm × mm) | $P_{max}$/Area (W/m$^2$) |
|---|---|---|---|---|---|---|---|---|
| Creaton AG | Creaton Solesia | | 13.86 | 8.46 | 90/module | 0.77 | 1778 × 355 | 142.6 |
| Rheinzink | PV Quickstep | | 17.10 | 5.12 | 68/module | 0.78 | 2000 × 365 | 93.2 |
| Abakus Solar AG | Peak On P220-60 | 13.2 | 36.77 | 8.22 | 220 | 0.73 | 1667 × 1000 | 132.0 |
| | Peak On P235-60 | 14.6 | 37.21 | 8.48 | 235 | 0.74 | 1630 × 1000 | 144.2 |
| | ANT P6-60-230 | 14.07 | 36.77 | 8.42 | 230 | 0.74 | 1658 × 986 | 140.7 |
| DuPont | Gevity | 17.7, 17.7 | 24.20, 24.43 | 8.77, 8.87 | 160, 165 | 0.75, 0.76 | 1332.5 × 929, 1332.5 × 929 | 129.36, 133.4 |
| Suntech | MSZ-190J-D | | 45.2 | 5.62 | 190/module | 0.75 | 1641 × 834.5 | 139 |
| | MSZ-90J-CH | | 22.4 | 5.29 | 90/module | 0.76 | 879 × 843.5 | 125 |
| Schott Solar | InDax 214 | 12.5 | 36.3 | 8.04 | | | 1769 × 999 | |
| | InDax 225 | 13.1 | 33.5 | 6.60 | | | 1769 × 999 | |
| Solar Century | C21e Slate | 20/cell | 12.0 | 5.55 | 52 | 0.78 | 1174 × 318 | 139.3 |

* Several models are available from various producers.

(a) (b)

**Figure 18: Example of a BIPV module products from Creaton Ag (a) and Rheinzink (b).**

the structure of the module. Some examples of BIPV module products are given in Table 3, with two of them depicted in Figure 5

The given FF values for the BIPV module products in Table 3 are approximately the same. The efficiencies for Abakus Solar AG products in Table 3 are between 13.2% and 14.6%, DuPont provides an efficiency of 17.7%, while the Schott Solar modules are stated with efficiencies 12.5% and 13.1%. Solar Century gives an efficiency of 20% per cell for their C21e Slate.

## Solar Glazing

BIPV as solar cell glazing: products provide a great variety of options for windows, glassed or tiled facades and roofs. Different colors and transparencies can make many different aesthetically pleasing results possible. Solar PV Glass design consists of Solar PV Cells that are built into transparent double and triple glazing units. Solar PV Glass can easily be integrated into roofs and building facade systems. It is generally available as a comprehensive package, complete with all the necessary electrical components and equipment. Transparent Solar PV is so called to differentiate it from the commonly available crystalline Solar PV Panels which are opaque. The word transparent refers to the background material e.g. glass and not the Solar PV Cells themselves, which are opaque.Some solar cell glazing product examples are given in Figure 19.

**Table 03. Literature data for some solar cell glazing products**

| Manufacturer | Product * | η (%) | $U_{oc}$ (V) | $I_{sc}$ (A) | $P_{max}$ (W) | FF | Area (mm × mm) | $P_{max}$/Area (W/m²) |
|---|---|---|---|---|---|---|---|---|
| Abakus Solar AG | Peak In P210-60 | | 36.50 | 7.70 | | | 2000 × 1066 | |
| Vidursolar | FV VS16 C36 P120 | | 21.6 | 7.63 | | | 1600 × 720 | |
| Glaswerke Arnold GmbH & Co KG | Voltarlux-ASI-T-Mono 4-fach | | 93 | 1.97 | 100/module | 0.55 | 2358 × 1027 | 41.3 |
| Schott Solar | ASI THRU-1-L | 6 | 111 | 0.55 | 48 | 0.79 | 1122 × 690 | 62.0 |
| | ASI THRU-4-IO | 6 | 111 | 2.22 | 190 | 0.77 | 1122 × 2619 | 64.7 |
| Sapa Building System | Amorphous silicon thin film | 5/cell | | | 32/cell | | 576 × 976/cell | 50 |
| | Poly-crystalline | 16/cell | | | 1.46–3.85/cell | | 156 × 156/cell | 120 |
| | Mono-crystalline high efficient | 22/cell | | | 2.90–3.11/cell | | 125 × 125/cell | 155 |

* Several models are available from various producers.

**Figure 19: Example of solar cell glazing products from Sapa Building System use either amorphous, polycrystalline or monocrystalline cells with different distance between the cells.**

The solar cell glazing modules will similarly serve as weather protection as well as a power source. The distance between solar cells will depend on the desired transparency and the amount of energy needs to be produced. Normally the distance is on average around 3 to 50 mm in between solar cells. Surprisingly, the high efficient mono-crystalline glazed modules of 155W per m$^2$ will have an almost identical power per area as a regular mono-crystalline module shown in table 3 at 139W per m$^2$. Solar glazing also usually offers customized products for specific projects, regarding shape, cell material, color transparency etc. giving the Spartan Superway many different options to choose from.

Work is also underway to define concepts for mounting the array and improving the assembly process of the solar panels on the guideway. An important consideration for the whole solar design is to make maintenance be relatively easy. A goal of ours is to design a racking system for the solar panels to have an automated connection. To do this we also had to design "blind connection" maximizer, figure 05, so each array can essentially clip into each other.

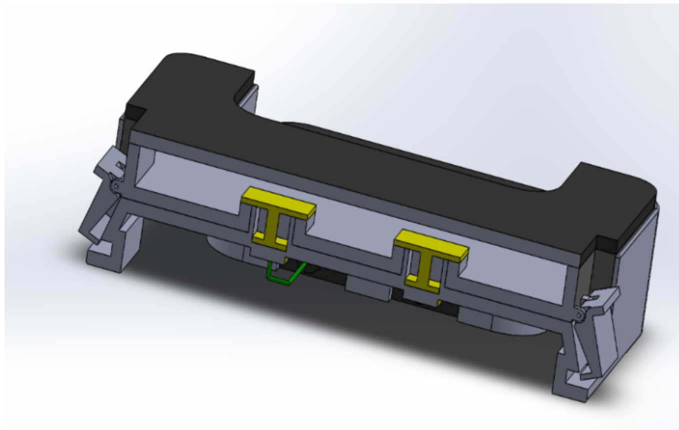


**Figure 20: Concept of the Clip Connection Maximizer.**

The racking system is designed to reduce material by allowing all electrical connection to be snapped into a side electrical rail that will in turn connect to the third rail. All of the mounting and racking designs were assumed to be implemented on Spartan Superway's old test track as shown below in figure 06.

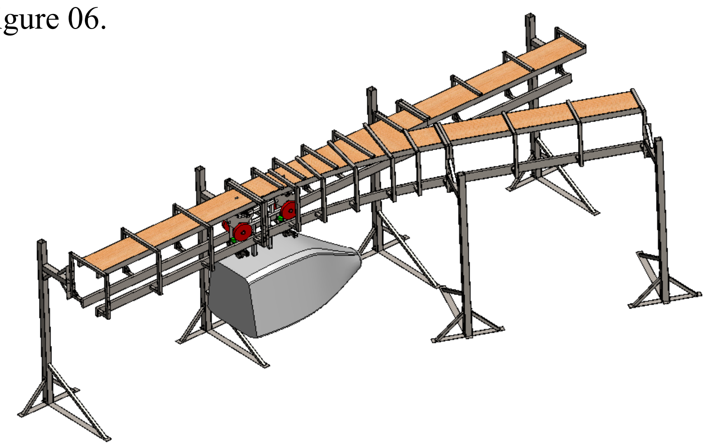


**Figure 21: Spartan Superway's old Test Track.**

There are two tracks for the solar panels rack, figure 07, one of the tracks will be on the far right or far left of the rail, and the other track will be connected to the support beams that hold up the rails. One track to utilize the ribs on top of the railing as support, and the other one to utilize the support beams.

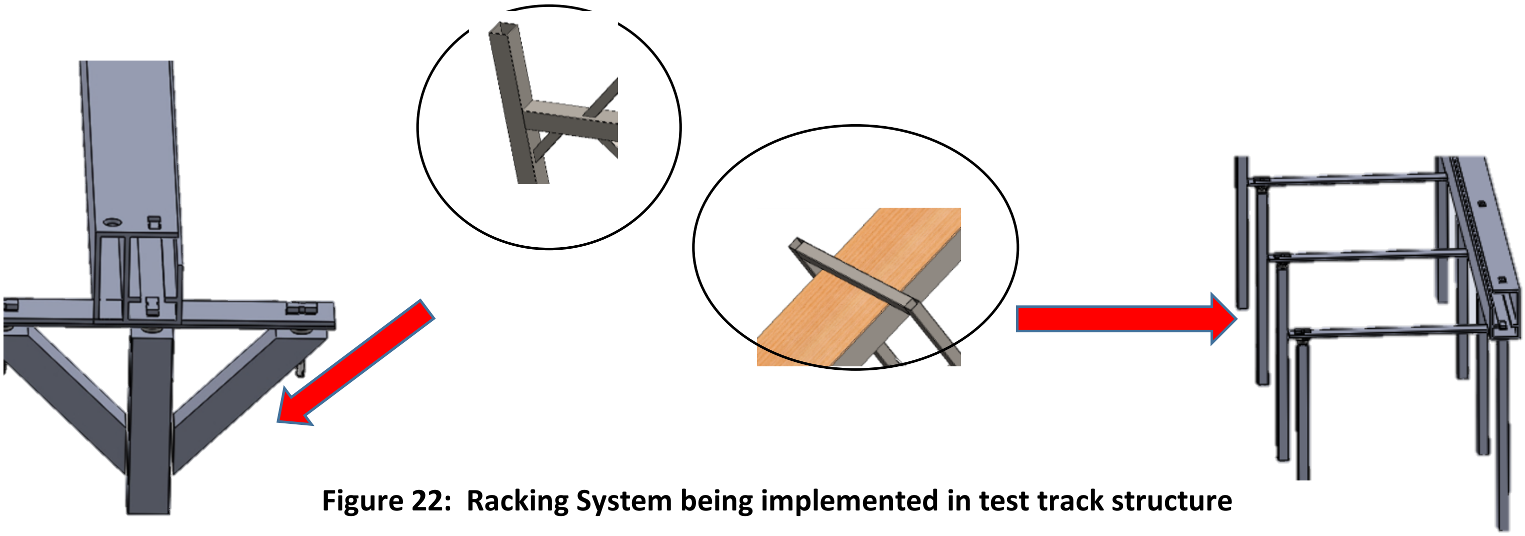
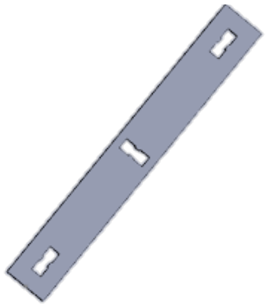


**Figure 22: Racking System being implemented in test track structure**

Each track will use the same “CAM LOCK” mechanism that is essentially a 90-degree lock and opening mechanism as Shown Below. On the rack connecting the support beams; there will be three of this Cam Lock that connects to a support plate on each of the support beam. The rack on the support ribs of the track will on use two Cam Lock mechanisms.



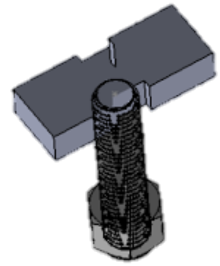
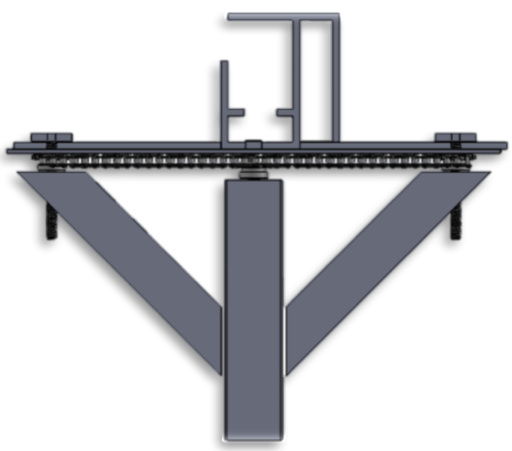


**Figure 23: On the left is an extruded plate to fit the head of the CAM Lock located on the right.**

For the support best track, there will be a connecting mechanism that slides inside of each support beams, and becomes drilled into the support beam. The connecting mechanism allows the cam lock to tighten the support beam plate as shown below. With the sprocket and chain it gives a basic example of all cam locks tightening by turning one. It very important to note that the racking system will only be slightly altered dependent on the solar panel frame design, and track design, and manufactures; all of which are still in progress.



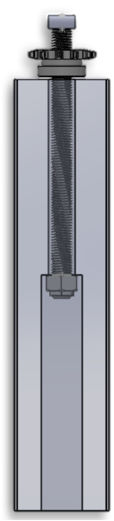


**Figure 24: On the left is a sprocket system for locking, and on the right is the CAM lock connecting inside the track supports.**

The first concept design is a module composed of 12 PV panels arranged in an arch and fixed in orientation. The second initial concept design supports a module composed of three thin-film photovoltaic cells bent into an arched shape. This concept integrates a tracking system that changes the tilt of the modules to guarantee an optimal tilt angle for each season of the year.

The panels have a tilt angle of at least 10° to reduce losses due soiling (Cano, 2011).

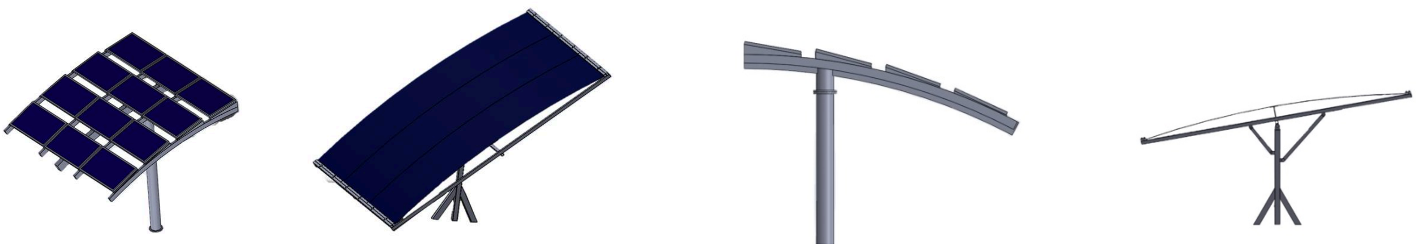


**Figure 25: Initial concepts design of the mounting array for the solar panel modules.**

The optimal tilt angle is a function of the latitude and the season of the year. Landau, 2015, proposed a group of equations to determinate the optimal tilt angle based on how many times during the year the tilt angle is changed. It is also essential that the frame of the mounting array to mechanically snap into the racking system as described previously. To do this the maximizer will snap modules into array. The support pieces that connect the mounting array to the racking system will have a central electrical component that will act as the last maximizer connecting to the electrical connections that is implemented into the side of the rack.

Other options for semi-automated locking mechanism were analyzed. One was a simple tubular lock that is commonly seen on door knobs. Most doors specifically have bores that are custom design for tubular locks shown in figure 26.

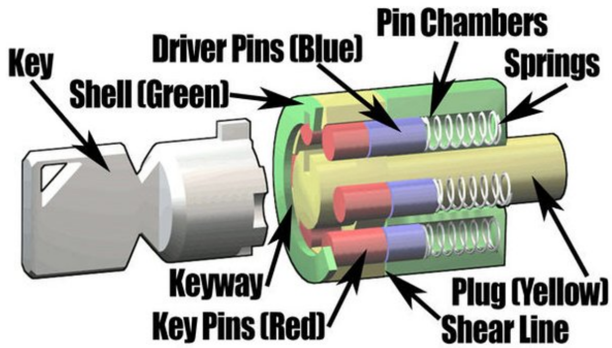



**Figure 26: Diagram of tubular lock, (red) key and (blue) driver pins.**

Each complete pin stack is pushed (with help from the designated spring) towards the front of the lock. This binds the shear line and prevents the plug from turning (colored yellow in the diagrams.) The difference with a tubular key and a standard key is that instead of the cuts of a key, a tubular key has half-cylinder indentations with map to the height of the pin stack. It also means that duplicating a tubular key requires different machinery making it difficult for people in the public to remove.

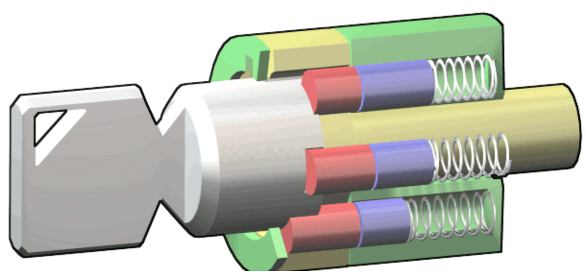


**Figure 27: key fitting into tubular lock, (red) key and (blue) driver pins**

The top center of the interior of a tubular key features a raised protrusion that aligns the key in it's proper configuration to map to each pin-tumbler stack. When the key is inserted, those mapped heights align, causing the shear line to separate and allow the plug to turn from the outer shell (green in the diagram below.)

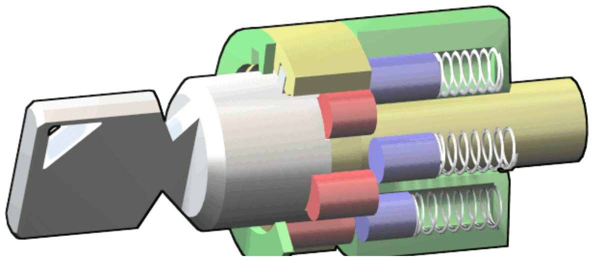


**Figure 28: key twisting in tubular lock, (red) key and (blue) driver pins**

The Yellow plug will attach to a cam lock mechanism and will be able to lock in a groove shown in figure 29.

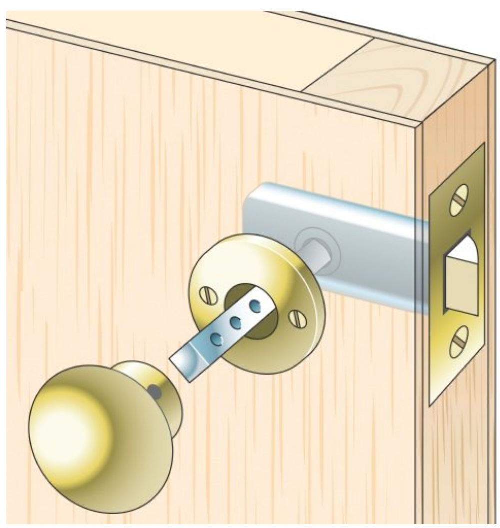


**Figure 29: Cam lock mechanism connecting to tubular lock's plug axle.**

## Cleaning

*DOs:*

- Choose a cool or cloudy day; preferably during the morning or early afternoon.
- Dust off debris first before pouring down the water.
- Lukewarm water and mild soaps are the best.
- Isopropyl alcohol can be good for clearing out oil stains.
- An air hose can be used when water is scarce.
- Avoid hard water for final wash.
- Dry off any extra water with soft towel or cloth.
- Solar panels cleaning kits are also very useful.

*DON'Ts:*

- Never rinse with cold water while in a hot sun. Sudden temperature change can create cracks in the glass coating on the panels.
- Never use abrasives.
- Better not to use aggressive detergents, scrubbers or acidic soaps; smooth, soft cloths are best for rubbing off the extra water. (It is not recommended by solar panel manufacturers to use chemicals to clean your panels. Tap water and rain water will not clean solar panels sufficiently to keep them running at maximum efficiency. Using detergents to clean solar panels leaves a sticky microscopic film on the solar panel which actually attracts dirt and grime. Again, this will lead to your solar panels not running efficiently)
- Never scratch the glass, not even to remove hardened bird droppings! No metal can be rubbed against the glass.
- No need to clean the underneath wiring.

Researchers from the University of San Diego found that for a 145 days during a summer drought in California, modules lost around 7.4 percent efficiency due to pollution. On average modules lost little less than .05 percent of overall efficiency per day. However, considering the Spartan Superway's 19,600 module system with approximately 360W panels, the efficiency loss of 7.4% in the first 12 months would drastically effect the 10.4MW system. A study was done at the Toyota Solar Farm that suggested this 7.4% efficiency loss would rise to %10 percent after 23 months. The 10% loss of efficiency would result in 1960kWh of the Spartan Superway to be loss every day, which calculated for a whole extra year to recoup the initial outlay. After examining the theorized maintenance cost for the Spartan Superway, and the efficiency benefits, a semi-automated cleaning mechanism was decided to be implemented in the solar racking system. (University of San Deigo, 2013). Multiple companies were contacted, however many cleaning companies do not have or follow the proper regulations in California. Below are some of the possible options that can be implemented in the Spartan Superway's racking system.

The self-cleaning technology was developed by Boston University professor Malay K. Mazumder and his colleagues, in association with the National Aeronautics and Space Association. The robot utilizes something known as deposition of a transparent, electrically sensitive material on glass or on a transparent plastic sheet that cover modules. Sensors are integrated to monitor dust concentrations on the top layer of the modules and energizes the material when dust concentration reaches a critical level. The electric charge repels dust in wave sover the surface of the material, lifting away the dust and transporting it off of the screen's edges. The company claims that their electric deposition method removes about 90 percent of dust on a solar panel within two minutes. The electric deposition reportedly requires only a small amount of the electric current generated by the panel for it to work. On top of that, the robots are capable of cleaning 10MW of solar panels in one eight-hour shift with a three-person team operating six robots (pvsolarreport 2013).

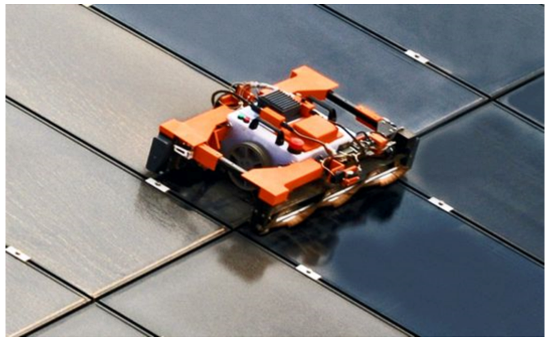


**Figure 30: Maraikikai's Wall Walker: a water-free automated module cleaning robot**

Another solution is the Heliotex system shown in figure 30. Once the Heliotex is installed and programmed to the Spartan Superway's needs, it will only require attention such as the occasional refilling of the soap concentrate and replacement of the deionized water filters. The system can be programmed to wash and rinse as regularly as desired. Heliotex places customized spray nozzles at the corners of each panel. The spray nozzles connect to the existing water supply shown in figure 30. To run the controller for the system a 110V power supply is required. The specially formulated soap concentrate is mixed into the line for the wash cycle to clean the panels and rinsed twice. Heliotex recommends that the panels are washed

**Figure 31: Heliotex automated water-powered solar cleaning.**

around every 1 to 2 weeks and rinsed every 2 to 3 days to keep dirt build up and debris at a minimum. Heliotex say that for a regular 50 solar panel residential system the soap and filters will need to be replaced approximately once every 6 months, assuming the system is washed every two weeks. Heliotex claims that the system can be adapted to any panel array configuration, whether 20 or 20,000 panels. However Heliotex does not have experience with curved configurations. Heliotex offer a 10 year warranty on all parts in the system and can also provide a security fastener for securing the solar panel *system.* There were very little information on the amount of water used for rinses, however this may play a significant role in the cost of the system.

The E4 water-free, robotic solution from Ecoppia cleans panels every day with a soft microfiber and gentle air flow. Floating over a frame that travels alongside each row of panels, Ecoppia claims the E4 removes 99% of dust during its daily cleanings. Each E4 robot has its own solar panel, so no power is taken from the solar row it's cleaning. Headquartered in Israel, Ecoppia has cleaned more than 5.1 million panels since forming in 2013, mostly in the dusty, desert regions of the Middle East. However, after contacting them they said they would not be able to sell the robot in the United States. However, this is such a brilliant idea that I feel the

Spartan Superway can design a robot to do this. Meller, a 300-megawatt solar plant spends more than $5 million annually on cleaning and lose approximately $3.6 million in energy production from lost to dust. Eccopia costs around $11 million for this large of an installations, which can be recovered in 18 months, and also translates in 110 million gallons of saved water over 10 years (TheGreatEnergyChallenge 2014).

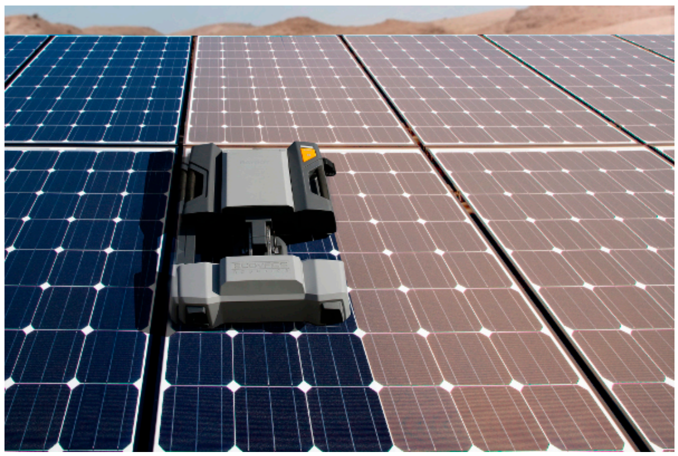


**Figure 32: Ecoppia automated cleaning robot.**

**Solution: Manual Cleaning Services**

When looking at manual cleaning solutions the effectiveness and price all depend on three main factors. Accessibility, essentially is the effort required to clean the specific modules. Conventionally the more challenging it is to clean to clean the Spartan Superway, the more we will be charged. Frequency, is essentially how often do the modules need to be cleaned. The price for a one-off clean will be much more than a normal 6-monthl clean. Dirt Accumulation, is simply how dirty have the modules become since installation. A cleaning schedule will be determend depending on the duration of the installation and the number of times the system has been cleaned. For most installs this will be 6 monthly, but it may be as often as every 3 months. The article "Impact of Soiling and Pollution on PV Generation Performance"" by Jessie Denver explains that the most lost from soiling we will see in the city of San Jose is approximately %6.0 annual loss from dust. The impact of semi-permanent energy loss due to unusual pollution sources was analyzed as well. A PV array located 50 m from a rail line was examined. Results showed Strips of pollution that stayed even throughout seasonal rains. Modules contained high levels of iron dust from the railway lines. The strips of pollution also contained pollen and growth of intrusive plants. After the efficiency loss of 8-10 percent over four years, the modules were cleaned and most of the power loss due to pollution was reversed.

Sunflare Maintenance explains the general process for cleaning services:

1. Inspect site prior to work being performed. Note any hazardous conditions.
2. Cover all electrical equipment, i.e. inverters and combiner boxes, beneath area to be cleaned with tarps prior to cleaning.
3. Use of aerial man lift where required to reach surface of solar modules to be cleaned.
4. No chemicals or abrasive cleaning are applied to solar modules during the cleaning process.
5. Surface of solar modules to be visually inspected prior to cleaning. All accumulated debris to be removed from array surface.
6. Spray down all solar modules with water at minimal pressure. (No high pressure washers are to be used.)
7. Water to be conditioned through water softener prior to application. This is done to minimize mineral deposit.

8. In heavy soil situations a soft bristle automotive style brush to be used to break free accumulated soil on surface of solar modules. Brushes are designed to avoid causing micro fractures or scratches on surface of solar modules.

For a 10MW system an effective manual cleaning would take easily 24 hours, requiring the entire Spartan Superway to shut down every cleaning (PVsolarreport 2013). Homewyse estimated for panels to be cleaned by a franchise cleaning company is approximately $173 for 5 panels considering a “light cleaning”. This estimate was verified by Clean Solar Solutions who say $35 is the average price for a credible cleaning. That approximately equates to $680,000 a year to clean 19,600 panels on the Spartan Superway. However, another estimate from PV Cleaner’s executive summary states that professional cleaning services charge approximately $6.25 per panel for cleaning residential PV solar panels, representing $150 for a single cleaning of a typical 24 panels el, 5.5kW residential solar panel installation. This would be approximately $100,000 to clean the Spartan Superway., which is more reasonable for a commercial cleaning.

A Local company, Solar Maid, are highly reviewed and provide great deals, currently they will wash 40 panels for $99, which is essentially $2.475 per panel for residents (Solarmaid 2016)! At the resident’s price per panel it would cost $48,000 to clean the Spartan superway. The commercial price for the Spartan Superway is still being discussed by the company, however a quote given by Jay Welsh estimates for the Spartan Superway’s 19,600 modules it will cost approximately $13,550 to service the modules for 7w to 9 days.. Manual cleaning would estimate total of %3-%6 efficiency increase compared to an automated cleaning system improving the efficiency by approximately %10. The Ecoppia, robot for example, would cost approximately $366,600 for our 10MW system, and would save $857,032 in energy considering the San Jose electricity rate of 14.08 center per kWh and a 10 percent efficiency reduction at the start of the year. The manual cleaning would cost on average $150,000 and would save around $255,000 in energy. These results show that A robotic cleaning saves about two times more dollars in the initial cleaning and would be essentially be free (despite maintenance) for future cleanings.

**Financing**

Last summer in the paper “Case Study of a Solar Power Installation for an Automated Transit Network in San José” the financial aspects of the proposed module system was analyzed. The SunEdison SE-R360EzC-4y modules were considered with a nominal power of approximately 360.192 Wdc with an nominal efficiency of 18.42%. The system requires an array size of 7045 kWdc essentially requiring 19,548 with 12 modules per string and 1,629 strings in parallel. The price was of the SunEdison module was estimated around .63 cents per watt and the Advanced Energy Industries AE 500NX-HE was around .21 cents per watt. The module installation is estimated to cost around $4,435,851.50 and the inverter installation around $1,478,617 (System Advisor Model, 2017). However, these costs do not account for the price of hardware, installation labor, and other soft costs. Many companies and solar customers keep the financial aspects of project hidden making it very difficult to get an accurate estimate of the Spartan Superway. The National Laboratory of Renewable Energy published the article “U.S. Photovoltaic prices and

Costs Breakdowns" which give a general estimate of the components the System Advisor Model neglects. In figure 33 the cost for commercial systems similar to the Spartan Superway would be approximately $2.15 per watt. The residential and commercial benchmarks represent rooftop systems, with residential systems modeled as pitched-roof installations and commercial systems modeled as ballasted flat-roof installations. The utility benchmarks represent ground-mounted,

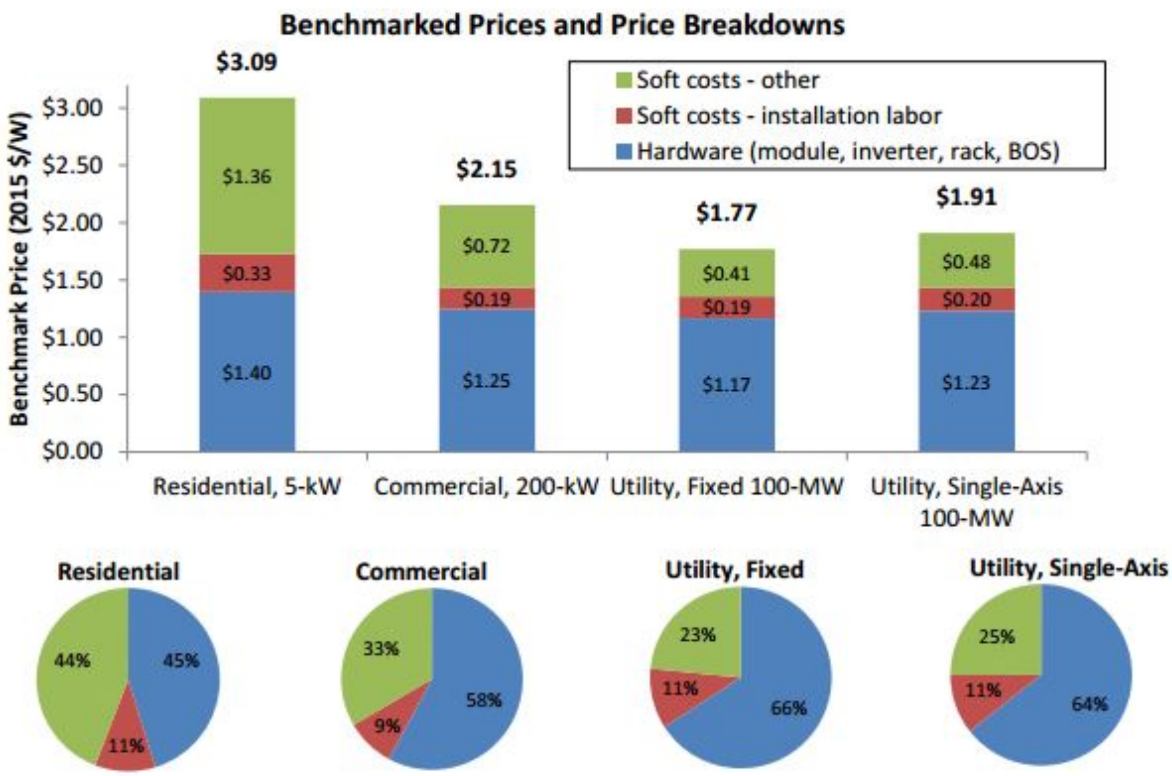



**Figure 33: Solar Benchmark Prices and Breakdowns.**

fixed-tilt and single-axis tracking systems. The hardware category includes modules, inverters, racking, and all balance-of-system (BOS) hardware required for a complete system. The soft costs-other category includes all non-hardware and non-installation-labor costs, primarily overhead and customer acquisition in the residential model and EPC (engineering, procurement, and construction) overhead/profit and development costs in the commercial- and utility-scale models (NREL 2015). Modules were estimated to range from $0.64-$0.74 per watt, inverters were approximately $0.23-$0.34 per watt, Racking $0.09-$0.14 per watt, and BOS material $0.20 per watt and $.72 per watt for overhead costs. Utilizing the NREL data in the Spartan Superway's solar installation we can see that with a 7,045 kw array size it would cost around $15,076,300 considering all soft costs, installation labor, and hardware. Below are compared prices of TrinaSolar, Hanwha, Canadian Solar, REC, and Solarworld's solar racking systems for a flat roof, sloped roofs, commercial building.

| System | 50 KW | 75 KW | 100 KW | 250 KW | 500 KW | 1,000 KW | PV Module Origin |
|---|---|---|---|---|---|---|---|
| Trina, Hanwha or Canadian Solar | $67,275<br>3,526 sq. ft. | $99,157<br>5,288 sq. ft. | $131,040<br>7,051 sq. ft. | $327,600<br>17,628 sq. ft. | $638,400<br>35,256 sq. ft. | $1,220,800<br>70,513 sq. ft. | China |
| REC | $67,275<br>3,274 sq. ft. | $99,157<br>4,911 sq. ft. | $131,040<br>6,548 sq. ft. | $327,600<br>16,369 sq. ft. | $638,400<br>32,738 sq. ft. | $1,254,400<br>65,476 sq. ft. | Singapore |
| SolarWorld | $75,900<br>3,342 sq. ft. | $111,870<br>5,013 sq. ft. | $147,840<br>6,684 sq. ft. | $369,600<br>16,710 sq. ft. | $694,400<br>33,420 sq. ft. | $1,332,800<br>66,840 sq. ft. | USA, Germany |

**Table 04: Compared pricing of solar racking companies on flat roofs with regards to kw array size and area.**

| System | 50 KW | 75 KW | 100 KW | 250 KW | 500 KW | 1,000 KW | PV Module Origin |
|---|---|---|---|---|---|---|---|
| Trina, Hanwha or Canadian Solar | $56,350<br>3,526 sq. ft. | $83,055<br>5,288 sq. ft. | $109,760<br>7,051 sq. ft. | $271,600<br>17,628 sq. ft. | $526,400<br>35,256 sq. ft. | $996,800<br>70,513 sq. ft. | China |
| REC | $56,350<br>3,274 sq. ft. | $83,055<br>4,911 sq. ft. | $109,760<br>6,548 sq. ft. | $271,600<br>16,369 sq. ft. | $526,400<br>32,738 sq. ft. | $1,030,400<br>65,476 sq. ft. | Singapore |
| SolarWorld | $64,975<br>3,342 sq. ft. | $95,767<br>5,013 sq. ft. | $126,560<br>6,684 sq. ft. | $313,600<br>16,710 sq. ft. | $582,400<br>33,420 sq. ft. | $1,108,800<br>66,840 sq. ft. | USA, Germany |

**Table 05: Compared pricing of solar racking companies on sloped roofs with regards to kw array size and area.**

| System | 50 KW | 75 KW | 100 KW | 250 KW | 500 KW | 1,000 KW | PV Module Origin |
|---|---|---|---|---|---|---|---|
| Trina, Hanwha or Canadian Solar | $52,900 3,526 sq. ft. | $77,970 5,288 sq. ft. | $103,040 7,051 sq. ft. | $249,200 17,628 sq. ft. | $481,600 35,256 sq. ft. | $907,200 70,513 sq. ft. | China |
| REC | $52,900 3,274 sq. ft. | $77,970 4,911 sq. ft. | $103,040 6,548 sq. ft. | $249,200 16,369 sq. ft. | $481,600 32,738 sq. ft. | $940,800 65,476 sq. ft. | Singapore |
| SolarWorld | $61,525 3,342 sq. ft. | $90,682 5,013 sq. ft. | $119,840 6,684 sq. ft. | $291,200 16,710 sq. ft. | $537,600 33,420 sq. ft. | $1,019,200 66,840 sq. ft. | USA, Germany |

**Table 06: Compared pricing of solar racking companies on carports with regards to kw array size and area.**

The data above shows that the average price considering only the hardware: for a flat roof system is 1.04 center per watt: for a slope roof system .98 centers per watt: for a canopy system is around 1.26 cents per watt. Comparing the average of these with the value from NREL gives around a 12.67% difference, showing these values are accurate. Utilizing this information for the SunEdison Module as described before, it will cost approximately $0.63 per watt for the module, $0.21 per watt for the inverter, $0.19 per watt for the installation labor, $.72 for overhead costs and approximately $0.14 per watt for the racking system, a full installation would cost around $13.5 million.

The global market for BIPV is expected to grow from $1.8*10^9 in 2009, to $8.7*10^9 in 2016, according to consulting firm NanoMarkets, however the BIPV technology is still rather expensive at around $1-$2 per watt (Jelle, 2016). Furthermore, it is important to note that the building sector is rather price-sensitive when implementing no projects. Due to the fact that BIPV is still far from being a thoroughly developed technology, uncertainty about BIPV and their implementation is another crucial aspect to be considered. This uncertainty includes many factors, such as installation, electrical aspects, safety issues, integration aspects, building physical aspects, protection versus climate exposure, durability, maintenance, demolition, life cycle assessment, possible to sell surplus electricity to the grid or not, architectural aspects and others. Naturally, all these factors may also lead to increased costs. Today, a maximum payback time for PV modules of ten years is generally expected in Europe. However, such a short payback time is normally not achieved without subsidies. Countries developed for electricity grid connected PV systems give a higher price into the grid than exerting from the grid (Jelle, 2016).

**Conclusion**

In conclusion there are four general types of racking systems we can utilize in the Spartan Superway. The first is a canopy system which allow us to have a curved aesthetic while utilizing the efficient of a mono-crystalline module. One of the systems that has an aesthetic curve is the Solar Canopy installed at the Plantronics Headquarters by Ron Swenson. This design allows for 5 degree increments, and a overhanging feature. To utilize a solar canopy, the top of the track of the transit system must be designated for primary support do to the fact that support beams are at a distance of 24meter and most commercial aluminum or galvanize beams are limited at 13.3meters. Another solution being flat racking systems which are more commonly designed, allowing for more options, easier integration, and cheaper installation. SnapnRack was one of the most effective flat racking system that could be utilized by the Spartan Superway. SnapnRack is UL 2703 certified and Class A fire rated for Type 1 and Type 2 modules ensuring installers provide the best-in-class installations in quality, safety and efficiency. The standard rails used in the SnapNRack system is compatible with all components, allowing installers to manually snap in clamps, base attachments and many more. A sloped racking system was another solution. Standard Solar was one of the top candidates as they are able to custom railings, frames, etc. for the customer. Standard Solar created unique curved design for one of their installations, however after contacting the company, they are very hesitant to release any information. The curved design is an aesthetic the Spartan Superway would like to achieve, and very few companies have managed to design working version. Building Integrated Photovoltaics are a new, up-in-coming technology that can have the same efficiency as standard mono-crystalline modules.  The solar cell glazing modules will similarly serve as weather protection as well as a power source. The distance between solar cells will depend on the desired transparency and the amount of energy needs to be produced. Normally the distance is on average around 3 to 50 mm in between solar cells. However, these may be the most expensive option at approximately $1-$2 per watt. Comparing the start-up price, and the annual saving from energy, a semi-automated robotic cleaning would be more effective for the Spartan Superway's designs. Cleaning will cost approximately $366,000 onetime to save an estimated $857,032 of energy per year. Lastly there is further work need to analyze and develop other semi-automated connecting mechanisms, however a solidified design for the Spartan Superway is needed to determine designs and tests.

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