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Daniel Morgan
Honors College Research Project, dm139@zips.uakron.edu

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Abstract

This project examines the feasibility of installing a solar panel array to the top deck of the Exchange Parking deck via canopy structure. Installation of solar panels would provide potential environmental and financial benefits to The University of Akron. Available solar panels analyzed were limited to two types, monocrystalline and polycrystalline, based on the properties of each panel. The pool of available panels was then narrowed to the 10 most promising panels based on power generated and cost. The most cost efficient panel was then chosen based on projected cost savings over a 25-year period, based on guaranteed performance warranty given for each panel. A canopy system was then designed to support the weight of the panels. The cost savings over the 25-year lifespan of best available panel was found to be $1,163,000, but the cost of the canopy support structure and solar panel material was found to be $2,673,000. This leads to a cost deficiency of $1,510,000 over the 25-year performance warranty period for the panels and a payback period of 60 years. Given the risks associated with a payback period 45 years beyond the warranty period, it is therefore recommended that a solar panel array is not constructed on the Exchange Parking Deck at this time. Once newer technologies with better power conversion efficiencies are available for purchase, a new study should be done to determine feasibility of installation.

Introduction

Fossil fuels are an unrenewable and unsustainable source of energy. Estimates based on current fossil fuel consumption state that crude oil will run out in 2052, natural gas in 2060, and coal in 2088; all of which could feasibly occur during the current college student’s lifetime (1). It would take plant matter 422 years to naturally decompose into the amount of fossil fuel the world uses in one year. (2). As the world consumes fossil fuels at an unsustainable rate, a premium price will be put on the diminishing available resources. Additionally, the continued use of fossil fuels creates massive amounts of greenhouse gases. Since 1970, CO2 emissions have risen 90% globally, with the United States the second largest culprit by country, tallying 16% of this total (3). To combat the rising amounts of carbon dioxide emitted into the atmosphere, future carbon taxes may be implemented in the United States. As well as making a long term economically responsible decision to lower its dependence on fossil fuels, The University of Akron has a duty to reduce its carbon footprint, as it prides itself being "the region's most influential public research university" (4).

One option to reduce The University of Akron's reliance on fossil fuel use, use cleaner energy, and make a sound long term investment, is to install solar panels. Solar panels turn the sun's energy into usable electricity by offsetting the electricity that would have been supplied by fossil fuels and therefore lowering the amount of greenhouse gasses produced. Solar panels are a sustainable option that also make a good choice as a business decision, as a federal tax credit can be claimed. Additionally, the university would have access to a set electricity rate, independent of the market price fluctuations. Solar panels would provide a return in investment as opposed to paying for utility bills which provide no long-term payout (5).

This project will focus on the feasibility of installing a solar panel canopy over the top level of the Exchange parking deck. This location was chosen because of the large, open area uninterrupted by large structures that would block sunlight to the panels. When choosing a solar panel, the user's specific needs must be taken into consideration. The material of the panel, expected power output, cost effectiveness, and ability of the structure in question to support the weight of the panel are examined in this feasibility study.

Types of Solar Panels

The primary types of solar panels available today are thin-film silicon, monocrystalline silicon, and polycrystalline silicon. Thin-film silicon panels are a newer technology and not as developed as the polycrystalline and monocrystalline panels (6). Manufactured by depositing a photovoltaic substance on glass, these panels are easier and cheaper to mass produce (6,7). Thin-film panels generally have an efficiency range (which denotes the rate at which sunlight energy is converted to usable electrical energy) between 7-13%, but higher temperatures and shade coverage generally have less of an impact on the efficiency (7). The major drawback lies in the amount of space needed to install the thin-film panels. Four times the amount of thin-film panel would be needed to supply the same amount of electricity as crystalline panels. The last drawback worth mentioning is that thin-film panels deteriorate faster than other panels, and therefore come with a shorter warranty. While this is a newer and developing technology, “vast improvements in this technology are expected in the next 10 years” (7). Because of the numerous drawbacks of this type of panel, thin-film panels were not considered during this study.

The other two panel types closely examined in this study are monocrystalline and polycrystalline silicon panels. The primary difference in these panels lies in the way in which they are made (8). Monocrystalline panels are made from a single, pure crystal of silicon (9). The raw quartz product is placed in a furnace and burned at a high temperature, creating molten silicon and carbon dioxide byproduct. This creates a silicon containing 1% impurities, and while this may be useful in other manufacturing applications, purer silicon is needed. To further purify the silicon, a rod of impure silicon is dragged through the silicon in one direction, pulling impurities with it. Once the silicon has been deemed pure enough, the end with the impurities is removed. From here, the Czochralski process is used (commonly used in silicon manufacturing). During this process, a rod mounted seed crystal is dipped in the molten silicon and then extracted while rotating (10). This is repeated until the desired diameter is obtained. From here, wafers for the solar panel are cut from the cylinder. Polycrystalline cells are made by a much simpler process in which the molten silicon is poured into a cast opposed to being made into a single crystal (8). A crystal seed is used to cool the molten silicon into a desired shape. During this process, the crystal surrounding the seed is not uniform, branching into many smaller crystals, hence the name “polycrystalline” (11).

Monocrystalline silicon provides several advantages, the first of which being the highest efficiency (7). Made from the highest-grade silicon, these panels generally have efficiency of 15-20%. Because of this superior efficiency, this type of panel is space efficient, requiring less space for the same amount of power output as other panels. For this reason, monocrystalline panels have been recommended for installation where space is limited and the maximum power output is desired, such as an urban rooftop (10). Additionally, monocrystalline panels also tend to have the longest life, as panels installed in the 1970's are still producing power today. Each panel specification sheet designates a calculated drop in efficiency per degree risen. Monocrystalline panels experience the lowest drop in efficiency as temperature rises.

Monocrystalline panels have a few drawbacks, the first of which is cost. Being made from the highest-grade silicon provides better efficiency but this generally leads to a higher cost (7). The second drawback is that the panels themselves are fragile (9). A tree limb or high-wind driven projectile could damage the panel. Given the location of the proposed structure, falling tree limbs should not be a factor in this decision. The last disadvantage of monocrystalline panels is in how they are produced. Made using the Czochralski method, the initial product is in the shape of a large cylindrical ingot (6). The four corners are cut out of the ingot to make a cylindrical wafer, leaving a large waste product. This shape distinguishes monocrystalline from polycrystalline panels.

Polycrystalline panels provide a distinct advantage in that they are generally less expensive. Previously deemed inferior to the monocrystalline panels, developments in technology have increased efficiency to be more comparable with the monocrystalline panels at a lower cost. Polycrystalline panels are comparable in durability and longevity to monocrystalline panels (8). Manufacturer warranties provided on each type of panel typically have a 25-year performance warranty, which will be discussed later. One drawback to polycrystalline panels is being less space efficient relative to monocrystalline panels given their relative lower efficiencies (7). Additionally, as stated above, polycrystalline panels are similar to monocrystalline panels because they are susceptible to damage if contacted by a large force.

Other Considerations

Another type of panel that is used (albeit in a small market share of approximately 5%), is bifacial panels (12). This type of panel is able to collect energy from both the top of panel through direct sunlight and also collect ambient energy through the back of the panel from the reflection off the surface below the panel. This type of panel will not be examined in this report because of the structural support system used does not allow collection of light from the back side of the panel.

One thing not considered in this study is the implementation of a battery system to store excess power generated by the panels. With today's current technology, energy generated must be used immediately or the energy is lost. This can be combatted by installing a battery storage system to collect unused power. This power could be used at nights or on cloudy days when the sun is not shining as brightly. A battery system will not be explored in this study. Instead, it is proposed that any excess power generated be sent back into the electricity grid for credits on the next electric bill (13). This common practice is known as net metering.

The federal solar tax credit, also known as the investment tax credit (ITC), allows residential and commercial establishments to deduct a portion of the cost of installing a solar panel system from federal taxes (14). The deduction is a percentage of total cost without a cap on maximum value. Initially put in place by the Energy Policy of 2005, the ITC was set to expire in 2015, but a Congressional bill extended the tax credit through 2021, albeit with diminishing credit percentages. According to the U.S. Department of Energy's website, a 30% tax credit can be claimed in years 2017-19, 26% in 2020, 22% in 2021, and 10% from 2022 onward (15). Additionally, in past years, owners could not claim the tax credit until the panel system was operational 925). Now, legislation allows the owners to claim tax credit as soon as construction begins as long as the system is operational by December 31, 2023 (14). Therefore, it will be more beneficial to install the solar panel system sooner rather than later. The caveat is that only the owner may file for this tax credit. If the university signs a lease from a third-party installer, for example, the university may not file for the solar tax credit.

Panel Selection

In order to properly assess the feasibility of installing a solar panel array on the roof of the Exchange parking deck, the proper panel must be selected. After initial research was done to determine what types of panels should be examined (monocrystalline and polycrystalline), recommended manufacturers and suppliers were found. For each available panel identified, the wattage, dimensions, weight, efficiency, and cost data was collected, as shown in Table 1 in Appendix A. Each panel has two different wattages given on the specification sheet. The first is a maximum wattage under Standard Test Conditions (STC). These conditions are designated as iridescence of 1000 W/m^2 (equivalent to a strong sun) and a solar panel temperature of 20^{o}C. (16). These are essentially “perfect” test conditions and do not resemble expected field conditions. Generally, the ambient temperature is 20^{o}C cooler than the panel temperature, meaning the test condition temperature depicts an outdoor temperature of 5^{o}C (41^{o}F) at all times. To gain a better picture of expected power output, another power output wattage is used. This wattage is based off of the Nominal Operating Cell Temperature (NOCT). The NOCT is given on the manufacturer’s specifications sheet and depicts the panel temperature given 800 W/m^2 iridescence, 25^{o}C ambient temperature (note that this is ambient temperature, not panel temperature as given in the STC), and 1 m/s wind speed. Each panel specification sheet also has a given temperature coefficient of maximum power, which represents the decrease in efficiency per degree Celsius. Using the information supplied, a more accurate power output for field conditions can be found and will be used in any further power output computations in this study.

The ultimate goal was to determine which panel would have the greatest amount of net positive profit over the warrantied lifespan of the panel. To calculate this, first the maximum number of panels that could fit on the proposed canopy structure was found by comparing the length and width of each panel to the length and width of each of the 7 proposed canopy sizes. (These widths ranged from 30 to 45 feet, and each length was a consistent 240 feet.) The maximum power generated from each layout was then calculated by multiplying the power per panel at NOCT by the number of panel for each potential layout. The cost of each was also found by multiplying the material cost plus $50.50 installation cost per panel by the number of panels for each respective setup (17). This data can be seen in Table 2 in Appendix A.

For each array, an expected kilowatt hour supplied figure was found using Google's Project Sunroof. As shown in Figure 1 in Appendix B, Google has integrated expected yearly sunlight exposure for selected rooftop structures into Google Earth. In short, Project Sunroof incorporates preexisting Google imagery and 3D modeling combined with weather data from the National Renewable Energy Laboratory to perform exposure calculations for each specific location. For the Exchange Parking Deck, this was found to be 1357 hours of sunlight per year. These sunlight hours were multiplied by power output per array to find power generated per year (18). To find out how much cost this would offset for the University of Akron, we multiplied this by electricity cost of 5.17 cents per kilowatt hour, a figure supplied by Stephen Myers, the Chief Planning & Facilities Officer for The University of Akron's Capital Planning and Facilities Management Office. These calculations are shown in Table 3 in Appendix A.

To determine the validity of this potential savings, the warranty information for each panel was determined. Each panel studied supplied a 25-year power output warranty that offered various guarantees for performance over a 25-year period. The warranties gave a guaranteed percentage of output for the 1st year and a guaranteed maximum efficiency loss for each subsequent year until year 25. These guaranteed efficiencies were used when determining a corrected 25-year factor for each panel, which is seen in Table 4 in Appendix A. It is to be noted that a manufacturer's workmanship warranty is also provided, which guarantees the product free of defects in materials given proper installation, use, and service conditions for a set amount of time. The length of warranty varies for each panel manufacturer and will be taken into consideration in final panel selection. The corrected total power output and associated cost savings expected over the same 25-year period were calculated. To reach the final cost number by which the panel was selected, the total array cost was subtracted from each panel's respective expected 25-year cost savings, shown in Table 5 in Appendix A.

While research suggested that polycrystalline panels would be readily available and at a lower cost compared to monocrystalline panels, this was not the case. Suppliers generally carried monocrystalline panels, and panels of the polycrystalline variety were hard to find.

Additionally, with a vast number of panels available, the panel selection was limited to reputable manufacturers and large suppliers. We only examined monocrystalline and polycrystalline panels based on our findings on types of panels. The prices represented in this paper for solar panels are from suppliers during research of this paper in March 2017. Suppliers may change prices or discontinue availability of panels if examined at a later date.

Canopy Structure

After the panel is selected, the canopy structure was considered. A canopy system is needed to support the solar panels above the top floor of the Exchange parking deck to allow vehicles to pass underneath and provide a support to mount the panels. Due to the varying distances of the support columns, seven canopy structures were designed. Each is designed at an optimal angle such that the panels will be exposed to the maximum amount of sunlight. Sun positioning data for Ohio dictates that the panels be angled towards the south, at an angle such that the north end of each canopy be 21 feet tall and the southern end 10 feet tall to provide optimal sun exposure year-round. A 10-foot clearance allows cars to pass underneath and is consistent with the clearances throughout Exchange parking deck.

The canopy system proposed is to be constructed from steel beams and support columns and metal sheeting. Steel beams are proposed to run north-south with girders running east-west supporting the metal sheeting. The support columns will be integrated into the existing structure's support columns, with calculations performed to ensure the structural capability of the columns handling the load of the canopy system and solar panels. Metal sheeting was chosen because of its structural properties, cost effectiveness, and the ability to easily attach solar panels. The canopy structure was also designed to handle the appropriate dead load for the panels (conservatively 3 pounds per square foot), and the wind load and snow load according the ASCE Specification Manual.

Using the Steel Construction Manual, it was determined that W12x53 beams, W14x90 girders, W10x39 exterior columns, W12x40 interior columns will be used. W "AxB" refers to properties of steel beams where “W” is the shape, “A” is the nominal-depth in inches, and “B” is the unit weight in pounds per foot (19). The quantity of each type of steel beam required for this canopy structure and associated costs (including labor) are shown in Table 6 in Appendix A. This canopy structure has an estimated installed cost of $1,365,844.58.

Project Cost Analysis

The results were not as hoped for. As shown in Table 5 in Appendix A, after taking into consideration each panel’s material and installation costs only one panel out of ten has a projected cost savings over 25 years. The other nine panels are projected to have not yet paid back the startup cost of the materials and installations. This does not yet include the cost of the canopy structure, which will further extend the payback period. This is analyzed in Table 7 in Appendix A, where the first 25-year savings are calculated as before, with each additional year after 25 having the assumed panel efficiency of the 25th year and the associated cost savings with this efficiency. After review of the payback periods, it is recommended that the solar panel canopy structure on the Exchange Parking Deck not be installed. The smallest payback period for any canopy layout examined is 60 years, which is much longer than the warranty period. It is therefore recommended that The University of Akron wait until future technologies are available to make installing solar panels a more financially sound option.

Biomimicry

One example of future technological development is implementation of biomimicry-inspired products. Biomimicry ideas is one example of a developing tactic that has been implemented into solar panel design. In general, “[b]iomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature’s time-tested patterns and strategies” (20). Biomimicry provides a mother nature-engineered solution to many of humans’ problems. One of the most widely known examples of biomimicry is Velcro (21). In 1941, Swiss engineer George de Mestral noticed burrs were stuck to his dog and took a closer look at how this worked. The hooks at the end of the burr needles led him to invent what is known as Velcro, shown in Figure 2 in Appendix B. Researchers have applied principles from plant leaves, moth eyes, and butterfly wings into solar panels.

One area of exploration is the development of polymer solar panels as an alternative to the traditional silicon panels. Polymer solar panels have generally been inferior to silicon panels in power conversion but have a key advantage in that they can be manufactured from solution (22). This means they can be printed or coated, which is much cheaper than the process to create silicon solar panels. Polymer solar panels are also flexible, allowing for the potential to roll out panels onto a roof or other surface during installation would also save on costs (23). In 2001, scientists at the University of Groningen in Northern Netherlands published research claiming to "have fabricated a [solar panel] with a power conversion efficiency of 2.5%" which was "nearly threefold enhancement over previously reported values for such a device" at the time of publication (24). In 2007, Alan Heeger at the University of California, Santa Barbara developed a process to create a then record 6.5% efficiency for photovoltaics that use plastics to capture solar energy (25). In 2012, researchers at Princeton University were able to apply principles of biomimicry to elevate this efficiency even further (26). Using the wrinkles and folds of leaves as inspiration, they created a solar cell that showed a 47% increase in current compared to solar cells constructed on a flat surface. This method had a notable impact on the near-infrared end of the light spectrum. Usually, cells of this type would collect virtually no energy from this end of the light spectrum, but with the folds incorporated into the cell design, an increase of over 600% at wavelengths over 650 nm compared to solar cells constructed on flat surfaces. To achieve the wrinkled surface, researchers first applied a compressive stress to an adhesive film supported by glass to produce wrinkles from 1.2 to 1.5 µm in depth. Exposing these wrinkles to an electric field and differing the duration of contact, different depths of wrinkles and folds were created, which are shown in Figure 3 in Appendix B. A bonus of incorporating wrinkles is increased structural stability. Conventional flat surface solar cells lost 70% efficiency after mechanical bending but the solar cells developed by the Princeton researchers experience no efficiency loss.

Researchers at University of California, Los Angeles (UCLA) have developed a new technology that allows solar cells to store energy for up to several weeks, opposed to the microseconds that most solar panels can store energy (27). This technology was also inspired the photosynthetic process by which plant leaves convert sun energy. Plant leaves are extremely efficient at converting solar energy because “carefully organized nanoscale structures within their cells . . . rapidly separate charges — pulling electrons away from the positively charged molecule that is left behind, and keeping positive and negative charges separated” (27). Current plastic solar cells lack efficiency compared to silicon panels in large part because of the inability to keep positive charges separate from negative cells. To generate electricity, a polymer donor absorbs sunlight and passes electrons to an acceptor. Current orientation of these components at the nanoscale level are largely random, which inhibits current flow because as electron attempt to flow from the donor to the acceptor, the electrons are sometimes intercepted by a polymer donor again in which case the charge is lost (28). However, researchers at UCLA have developed a system that allows the donors and acceptors to become more organized, and therefore more efficient. The acceptors are manipulated such that some sit on the inside of the donors while others are located on the outside. The acceptors on the inside of the donors are able to send electrons to the acceptors on the outside of the polymer acceptor, effectively keeping the electron away from the polymer. This allows fewer electrons to be lost, creating a more efficient process. A visual representation of this process can be seen in Figure 4 in Appendix B. This technology is in the developmental stages and researchers are working on how to incorporate this technology into functioning solar panels.

Nature has also been the influence for researchers at the U.S. Department of Energy’s Brookhaven National Laboratory in the development for a process that cuts reflectivity of the panels, emulating moth eyes (29). The patent pending process involves “etching a nanoscale texture onto the silicon material itself create[ing] an antireflective surface that works as well as state-of-the-art thin-film multilayer coatings” (29). This etching helps control the abrupt change refractive index that occurs when two materials with very different refractive indexes meet (in this case, silicon and air). Panels constructed with coatings are required to have multiple layers, because each individual layered coating is optimized for a specific color of light spectrum and specific direction of light. This process eliminates the need for these layers. The process also cuts reflected light "down to less than 1% across entire visible and near infrared spectrum, and across a wide range of incident light angles" compared to 30% reflectivity of traditional silicon solar panels (30, 31). An image of the reflective property of this material is shown in Figure 5 in Appendix B. Other uses for this approach may include reducing window glare and providing radar camouflage for military equipment (29).

The last nature influenced technology examined is a low cost, reflection mitigating coating that can be applied to solar panels developed by a team at the Massachusetts Institute of Technology (MIT) (31). This coating is influenced by the glasswinged butterfly, as the wings of the butterfly are coated with nanostructures resembling tapered pillars, which acts as an anti-reflective coating, reflecting only 2-5% of light. To accomplish this coating, the team deposits an oxide on a glass film, and applies a mask layer made from silver. Then, different gasses are used to remove layers from the surface, except what is covered by the mask. The different gasses allow the nanostructure geometry to be tweaked to resemble the tapered pillar of the glasswinged butterfly. Additionally, this process is low cost at the price of $14 per square meter of coating.

Conclusion

This study considered the feasibility of installing a solar panel canopy system on the top floor of the Exchange Parking Deck in order to be responsible stewards of the environment and make a sound financial decision for future years. While it was found that purchasing the currently-available products would not make financial sense, future installation of solar panels should not be discounted. As solar panel technology develops, products will be cheaper and more efficient. While the panels influenced by biomimicry are not readily available, it is recommended that The University of Akron explore options inspired by biomimicry when those products become publicly available.

Appendix A

Table 1: General Panel Information

Panel	Power Generated (W)	Dimensions W x L (ft.)	Weight (lb)	Efficiency (%)	Cost per Panel
Sharp 300 watt ND-F4Q300	218	3.25 x 6.47	50	15.3	$329.16
Sunmodule SW 340 - 350 Mono	259.3	3.28 x 6.54	47.6	17.04	$385.00
Sunmodule SW285-300 Mono	220.5	3.15 x 5.50	39.7	17.59	$320.00
Sunmodule Plus SW 280-290 Mono	211.1	3.15 x 5.51	39.7	17	$335.00
LG 315N1C Black Mono	230	3.28 x 5.38	37.48	19.2	$392.00
LG 305N1K-G4	225	3.28 x 5.39	37.48	18.6	$384.00
LG 280S1C Mono	205	3.28 x 5.40	37.48	17.1	$300.00
Mitsubishi PV-UD185MF5	179.5	2.73 x 5.44	37	13.4	$350.00
Astronergy VIOLIN CHSM6610P-260	195	3.25 x 5.41	40.57	15.9	$225.00
Panasonic HIT Power N325SA16	245	3.46 x 5.22	40.81	19.4	$373.75

Table 2: Solar Panel Cost

Panel	# Panels wide	# Panels long	Total # panels per layout	Total Power Generated (KW)	Panel Cost per Layout
Sharp 300 watt ND-F4Q300	71	37	2,627	572	$997,362.56
Sunmodule SW 340 - 350 Mono	70	36	2,520	653	$1,097,460.00
Sunmodule SW285-300 Mono	73	43	3,139	692	$1,162,999.50
Sunmodule Plus SW 280-290 Mono	73	43	3,139	663	$1,210,084.50
LG 315N1C Black Mono	70	44	3,080	708	$1,362,900.00
LG 305N1K-G4	70	44	3,080	693	$1,338,260.00
LG 280S1C Mono	70	44	3,080	631	$1,079,540.00
Mitsubishi PV-UD185MF5	83	44	3,652	656	$1,462,626.00
Astronergy VIOLIN CHSM6610P-260	71	44	3,124	609	$860,662.00
Panasonic HIT Power N325SA16	67	46	3,082	755	$1,307,538.50

Table 3: Yearly Savings

Panel	Power Generated (KW)	KWh per year	Potential Savings per year at 5.17 cents per KW
Sharp 300 watt ND-F4Q300	572	776,065	$40,122.58
Sunmodule SW 340 - 350 Mono	653	886,713	$45,843.04
Sunmodule SW285-300 Mono	692	939,247	$48,559.06
Sunmodule Plus SW 280-290 Mono	663	899,206	$46,488.97
LG 315N1C Black Mono	708	961,299	$49,699.15
LG 305N1K-G4	693	940,401	$48,618.73
LG 280S1C Mono	631	856,810	$44,297.07
Mitsubishi PV-UD185MF5	656	889,560	$45,990.23
Astronergy VIOLIN CHSM6610P-260	609	826,657	$42,738.18
Panasonic HIT Power N325SA16	755	1,024,657	$52,974.77

Table 4: 25-year Correction

Panel	First year efficiency	Subsequent year efficiency loss	25th year efficiency	Workmanship warranty (years)	25-year degradation correction
Sharp 300 watt ND-F4Q300	90% first 10 years	80% years 11-25	80.0%	10	21
Sunmodule SW 340 - 350 Mono	97%	-0.7%	80.2%	10	22.15
Sunmodule SW285-300 Mono	97%	-0.7%	80.2%	20	22.15
Sunmodule Plus SW 280-290 Mono	97%	-0.7%	80.2%	10	22.15
LG 315N1C Black Mono	98%	-0.6%	83.6%	12	22.7
LG 305N1K-G4	98%	-0.6%	83.6%	12	22.7
LG 280S1C Mono	98%	-0.6%	83.6%	12	22.7
Mitsubishi PV-UD185MF5	97%	-0.7%	80.0%	10	22.15
Astronergy VIOLIN CHSM6610P-260	97%	-0.7%	80.2%	10	22.15
Panasonic HIT Power N325SA16	95%	-0.6%	80.6%	15	21.95

Table 5: Cost Savings Over 25 Years

Panel	Cost Savings per year at 5.17 cents per KW	Cost savings over 25 years	Degradation correction	25-year corrected savings	Panel Cost per Layout	Savings after 25 years
Sharp 300 watt ND-F4Q300	$40,122.58	$1,003,064.59	21	$842,574.26	$997,362.56	$(154,788)
Sunmodule SW 340 - 350 Mono	$45,843.04	$1,146,076.10	22.15	$1,015,423.43	$1,097,460.00	$(82,037)
Sunmodule SW285-300 Mono	$48,559.06	$1,213,976.58	22.15	$1,075,583.25	$1,162,999.50	$(87,416)
Sunmodule Plus SW 280-290 Mono	$46,488.97	$1,162,224.29	22.15	$1,029,730.72	$1,210,084.50	$(180,354)
LG 315N1C Black Mono	$49,699.15	$1,242,478.70	22.7	$1,128,170.66	$1,362,900.00	$(234,729)
LG 305N1K-G4	$48,618.73	$1,215,468.29	22.7	$1,103,645.21	$1,338,260.00	$(234,615)
LG 280S1C Mono	$44,297.07	$1,107,426.67	22.7	$1,005,543.41	$1,079,540.00	$(73,997)
Mitsubishi PV-UD185MF5	$45,990.23	$1,149,755.83	22.15	$1,018,683.67	$1,462,626.00	$(443,942)
Astronergy VIOLIN CHSM6610P-260	$42,738.18	$1,068,454.51	22.15	$946,650.69	$860,662.00	$85,989
Panasonic HIT Power N325SA16	$52,974.77	$1,324,369.34	21.95	$1,162,796.28	$1,307,538.50	$(144,742)

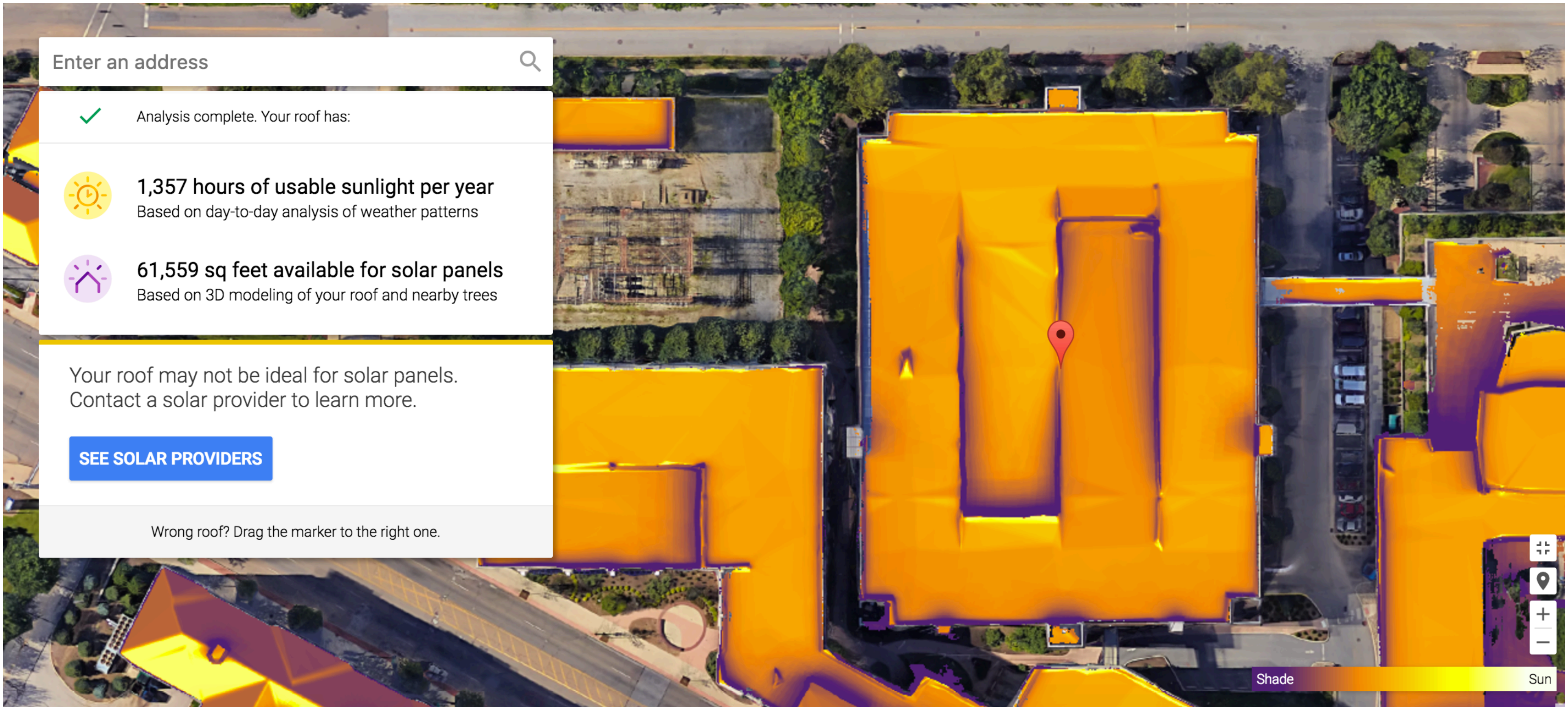
Table 6: Canopy Structure

Material	Linear Footage	Cost per Linear Foot	Total Cost
W10x39	434	$65.19	$28,292.46
W12x40	434	$72.34	$31,395.56
W12x53	6970	$66.70	$464,869.93
W14x109	5040	$133.87	$674,685.08
Sheeting	66908	$2.49	$166,601.55
		Total	**$1,365,844.58**

Table 7: Project Payback Time

Panel	Total cost per layout (panels, canopy, installation)	25-year corrected savings	Cost Savings per year at 5.17 cents per KW	25th year panel efficiency	26+ year assumed savings	Total payback time (years)
Sharp 300 watt ND-F4Q300	$2,363,207.14	$842,574.26	$40,122.58	80.0%	$32,098.07	72
Sunmodule SW 340 - 350 Mono	$2,463,304.58	$1,015,423.43	$45,843.04	80.2%	$36,766.12	64
Sunmodule SW285-300 Mono	$2,528,844.08	$1,075,583.25	$48,559.06	80.2%	$38,944.37	62
Sunmodule Plus SW 280-290 Mono Black	$2,575,929.08	$1,029,730.72	$46,488.97	80.2%	$37,284.16	66
LG 315N1C Black Mono	$2,728,744.58	$1,128,170.66	$49,699.15	83.6%	$41,548.49	64
LG 305N1K-G4	$2,704,104.58	$1,103,645.21	$48,618.73	83.6%	$40,645.26	64
LG 280S1C Mono	$2,445,384.58	$1,005,543.41	$44,297.07	83.6%	$37,032.35	64
Mitsubishi PV-UD185MF5	$2,828,470.58	$1,018,683.67	$45,990.23	80.0%	$36,792.19	74
Astronergy VIOLIN CHSM6610P-260	$2,226,506.58	$946,650.69	$42,738.18	80.2%	$34,276.02	62
Panasonic HIT Power N325SA16	$2,673,383.08	$1,162,796.28	$52,974.77	80.6%	$42,697.67	60

Appendix B



Analysis complete. Your roof has:

1,357 hours of usable sunlight per year
Based on day-to-day analysis of weather patterns

61,559 sq feet available for solar panels
Based on 3D modeling of your roof and nearby trees

Your roof may not be ideal for solar panels. Contact a solar provider to learn more.

Wrong roof? Drag the marker to the right one.

Figure 1. Screenshot of Google's Project Sunroof. Using this sunlight exposure data, estimations of power output was calculated.
Source: Project Sunroof

Figure 2. Early example of biomimicry. Velcro inspired by burrs.
Source: Mother Nature Network

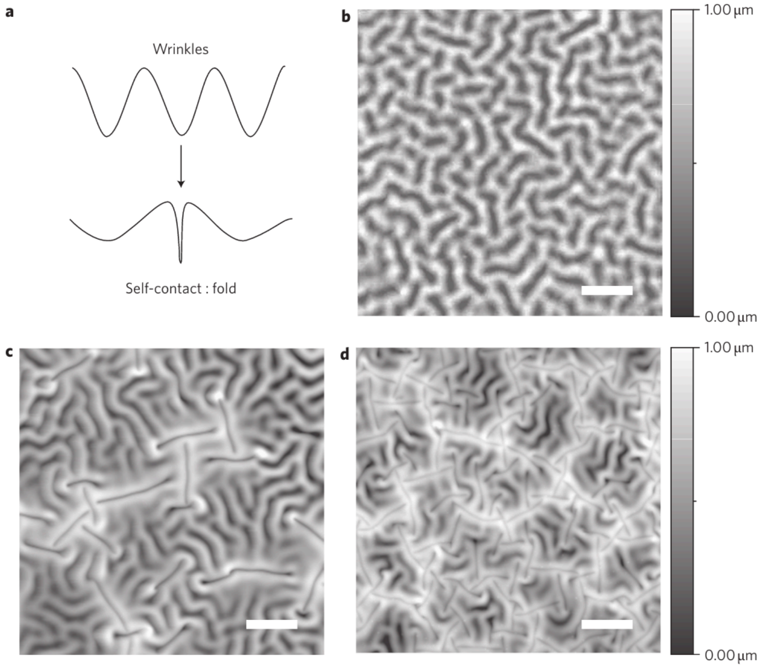
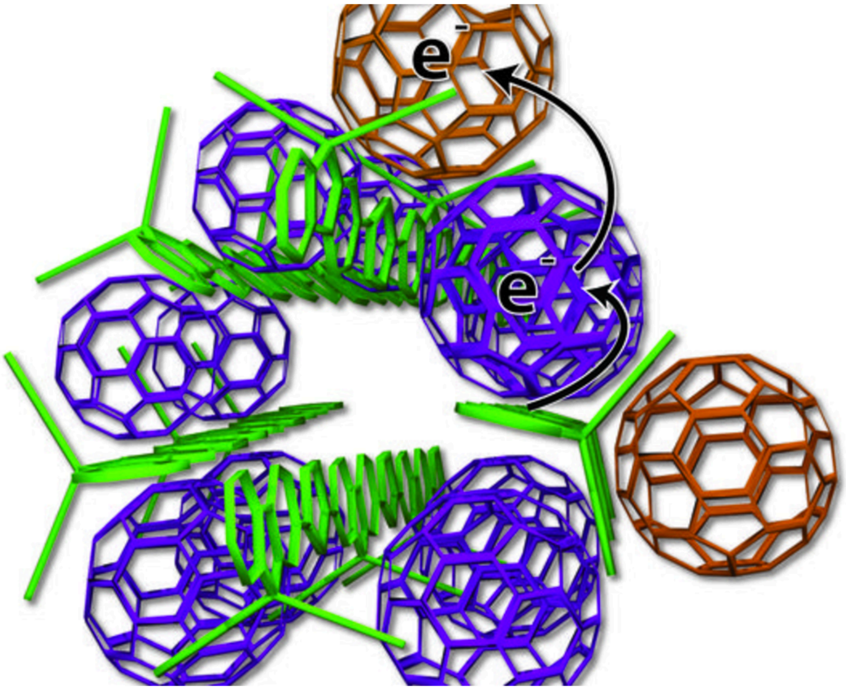


Figure 1 | Morphological evolution of wrinkles to folds. a, Schematic of the wrinkle-to-fold transition. **b–d**, Morphological evolution of the surface with increasing compressive stress. When wrinkles are subjected to excessive compressive stress, self-contact of neighbouring wrinkles generates folds. The fractional area of the folds (R_{fold}) increases in proportion to the magnitude of the compressive stress. The wrinkle wavelength (λ_w) in **b** is 1.8 μm and the peak-to-valley height is 180 nm. We maintained a constant $\lambda_w = 1.8$ μm in **c** and **d** while increasing R_{fold} from 0.037 to 0.174, respectively. Scale bar, 5 μm.

Figure 3. Source: Nature Photonics



UCLA Chemistry

The scientists devised a new arrangement of solar cell ingredients, with bundles of polymer donors (green rods) and neatly organized fullerene acceptors (purple, tan).

Figure 4. Source: UCLA Newsroom

Figure 5. The reflective property of a Nano textured square of silicon influenced by moth eyes compared to a normal silicon wafer.
Source: Brookhaven National Laboratory

Figure 6. A photo of a Glass winged Butterfly.
Source: Christine Lepisto

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