Effect of Environmental and Ultraviolet Degradation on the Albedo of Polyethylene Sheet Materials for Improved Energy Harvesting by Bifacial Photovoltaic Power Plants

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Bachelor of Science in Materials Engineering

by

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Abstract

Solar energy farms typically utilize monofacial photovoltaic (mPV) cells in their arrays to capture direct sunlight to produce renewable energy. However, the efficiency of these farms can be increased by 2 – 6% through the implementation of bifacial photovoltaic cells (bPV). These bPV cells function by capturing incident ultraviolet (UV) light energy that is reflected off the surface to increase its overall energy production. The amount of UV energy that is reflected is dependent on the albedo value of surface, which is a measure of energy reflectance. In this study, samples of unreinforced polyethylene (PE), scrim-reinforced polyethylene (SR-PE), and woven polyethylene (W-PE) sheeting materials were tested to determine which had the highest albedo value as well as the most resistance to environmental degradation. Samples subjected to outdoor conditions were visited on a biweekly basis to measure their albedo values using an albedometer and to record any physical changes observed in the material. Samples were also placed in an accelerated weathering chamber in a laboratory which exposed the materials to continuous UV light in intervals of 20 hours. The results from testing determined that woven PE produced a 23% higher average albedo in comparison to the other candidate PE materials. Woven PE also demonstrated lower quantitative and qualitative environmental degradation. Based on these results, woven PE was concluded to be empirically superior as a ground albedo material among the materials tested in this study.

1. Introduction

Solar energy accounted for 3.4% of the energy produced in the United States in 2022 and is predicted to increase to approximately 20% by 2050.[1] The primary contributor to this increase will come from commercial solar facilities that have a minimum capacity of 1 megawatt.[1] These commercial solar facilities require sizable plots of land that can range between 500 to 3,000 acres, and are generally located in low population areas that experience a high degree of annual sun exposure. The primary solar modules utilized are mono-facial photovoltaics (mPV), which are solar panels containing solar cells on a single face. These mPV panels account for a majority current of panels used in commercial applications and have historically been the standard in the solar energy industry. However, in 2009 a new type of solar panel was introduced with the potential to significantly increase solar energy production without requiring greater land allocations than is currently used at existing mPV facilities. These new solar modules, known as bifacial photovoltaics (bPV), differentiate themselves from conventional mPV by replacing the typical opaque backing layer with a transparent layer that will allow the rear of the cells to be exposed to sunlight.[1] The purpose of this design is to increase the amount of solar energy produced by capturing direct sunlight incident light that is reflected off the ground beneath the solar panel. By capturing incident light, bPV modules can increase their solar energy output by a margin of 2 – 6% in comparison to conventional mPV.[1,2] The factor that determines the degree to which energy output increases with a bPV panel is the albedo value of the ground material under the module.

The focus of this project is to determine what high albedo material can be used to cover the ground to maximize the energy output from the reverse face of a bPV panel. To further align this project with the needs of the solar industry, all candidate albedo materials will be low-cost, commercially available products that can be easily installed at an existing bPV solar facility. In addition, the candidate materials will be subjected to prolonged exposure to varying degrees of solar radiation, humidity, and temperature to test their ability to withstand environmental degradation. Further testing will be done to determine the changes in mechanical strength of the candidate materials with varying degrees of UV exposure. Final analysis will determine which candidate material would quantitatively provide the best performance when applied in a commercial setting for a bPV facility.

2. Background

2.1 Defining Albedo

Albedo is a unitless material property that is defined as the ratio of reflected radiation to the ambient incident radiation at a material's surface.[3] The values for albedo range on a scale from 0 – 1 with a value of 1 indicating that a material perfectly reflects incident solar radiation while a value of 0 indicates that the material does not reflect at all and instead completely absorbs incident solar radiation. Both extremes of this range are impossible albedo values to obtain in naturally occurring materials and are only obtainable with heavily processed synthetic materials.[4] The albedo value of most materials lies within the range of 0 – 1, but albedo is not a permanent property value. Environmental factors such as varying solar altitude, UV index, and humidity will change a material's albedo value on an hourly basis. This change is known as diurnal variation, and when plotted generates a U-shaped curve that illustrates how environmental conditions can cause fluctuations in albedo value (Figure 1).

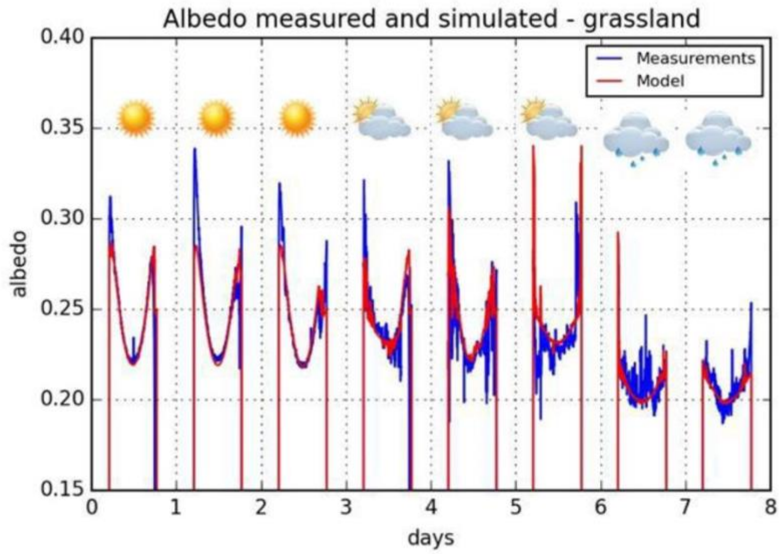


Figure 1 – Comparison between model and albedo measurements for a characteristic set of days. The three first days are clear days, the next three are overcast, and the last two are rainy days. [4]

The U-shape illustrated by the diurnal curve indicates an inverse relationship between solar altitude and albedo. This inverse proportionality is a result of the testing methodology used which has an albedometer directly above the albedo material and as a result there is less opportunity for solar reflection into the albedometer at noon. The average albedo is typically extracted from these daily U-shaped albedo curves for use in material property data sheets, but they should not be viewed as definitive values. No material is exempt from experiencing fluctuations in albedo value. However, some materials are better suited at minimizing these diurnal variations due to their composition and surface roughness. An example of this can be seen by comparing the diurnal albedo variations of grass and concrete. Given the same environmental conditions, concrete can exhibit an albedo variation of approximately 25% while grass can have up to a 60% change.[4] This discrepancy in albedo variation is a result of the surface roughness of grass which irregularly scatters photons to a greater degree in comparison to a flat surface. A rougher surface does not, however, always equate to a decrease in albedo value as reflectance is also predicated on other physical characteristics such as the material's color or moisture content. Both color and moisture content can either increase or decrease a material's albedo based on the inherent reflectance or absorptivity properties associated with both factors. For instance, a material with a surface color closer in hue to white will most likely exhibit a higher albedo while soil can exhibit a lower albedo when moistened.

2.2 Standardized Solar Spectrum Albedo Data

In addition to environmental conditions, material albedo data is also affected by the wavelength (λ) of radiation. In the specific application of a ground albedo covering for a bPV array, the wavelength range of radiation that is to be reflected consists of light within the ultraviolet (UV), visible, and infrared spectrum.[5] These three types of light radiation span across the λ range of 290 – 1200 nm, and all contribute towards the production of energy for any solar cell (bPV or mPV).[6,7] However, as the surface roughness can cause the albedo of a material to fluctuate, so can the λ of incident light (Figure 2). The albedo value associated with a specific wavelength is known as the spectral albedo (A_s) and it serves as an important reference point to determine the reflective efficiency of a material within the solar range. A_s does not consider potential albedo values that result from interactions with λ outside of the solar range of 290 – 1200 nm. However, this is inconsequential as bPVs are not reliant on λ outside of the solar range for energy production. Many studies have tested and measured the albedo values for numerous materials across a wavelength range from 300 - 2500 nm as seen in Figure 2. This provides reference data from which informed inferences can be made on which materials could theoretically produce the highest albedo values across a significant portion of the solar wavelength range. The only caveat is that these studies generally do not identify the exact specification of material used for collecting their albedo data. Instead, these materials are typically referred to by their material classification (sand, snow, grass, etc.).

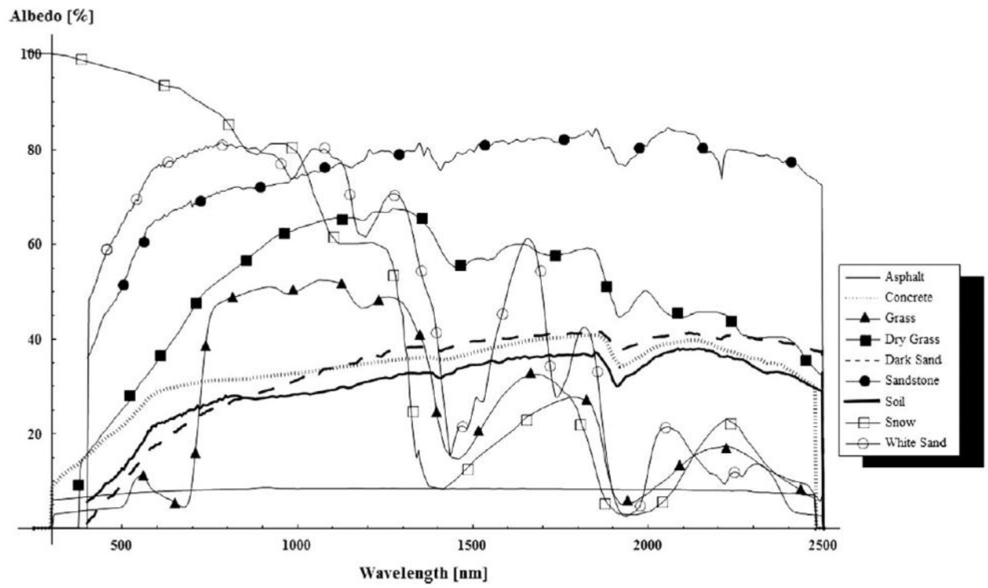


Figure 2 – The albedo range for selected materials for industrial (solar farm) PV applications.[1]

Since albedo is highly dependent on the geographic location and weather conditions, there is no standardized method for testing albedo value in a natural environment which makes comparisons of literature albedo values difficult. For the purposes of this study, the literature values for potential albedo materials were derived from the ECOSTRESS Spectral Library (ESL). ESL is a data library collated by NASA's Jet Propulsion Laboratory, and it provides the albedo values for 3,447 different materials in relation to the radiation spectrum. In this project, the ESL will serve as the primary reference point for albedo values to ensure uniformity when comparing albedo values gathered from project data. This is an extremely useful resource as it provides reference albedo data for a wide range of materials (synthetic and natural) across the entire solar spectral range that are used with bPV panels.[8]

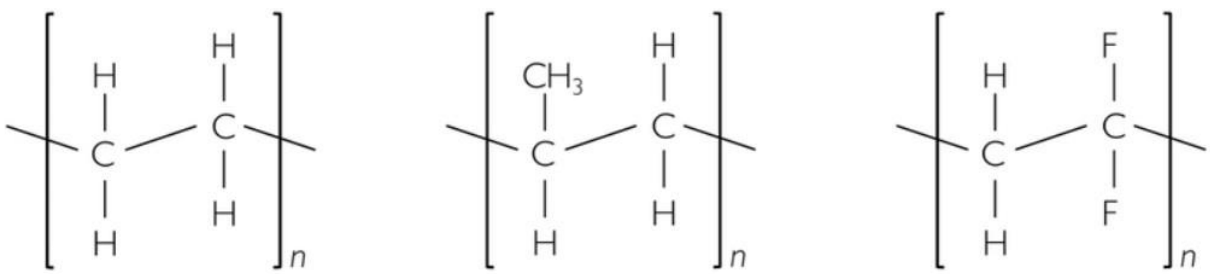
2.3 Commercially Viable Candidate Ground Albedo Materials

The primary material families that were considered for ground albedo treatments at bPV solar facilities include aggregate, polymer sheeting, and spray-on coatings. Based solely on albedo values from ESL, polymer sheets generally have higher albedo values versus aggregates and some spray-on coatings.[9] However, the viability of any ground albedo material is not based entirely on its albedo as other factors such as cost, maintenance, and resistance to degradation are also important points of consideration. Factors such as cost and maintenance are desired to be quantitatively low, but their level of importance is subject to the requirements of the customer as degradation-resistant materials are usually more expensive. Resistance to degradation is always desired to be maximized as this equates to reduced maintenance cost and greater energy output over the lifetime of the material. Given the importance of resistance to degradation, the effects of degradation on the albedo of the candidate materials will be examined in this project.

For this project, materials that were considered for testing included polymer-based sheets, white rock aggregate, and road paint. These materials were considered based on research of existing literature which indicated that these materials could serve as a high albedo ground covering in a bPV application. However, after discussions with the project sponsor, and logistical issues concerning procurement of necessary materials, the rock aggregate and road paint were dropped as potential material candidates. The rock aggregate material did move forward to the testing phase, but its excessive mass and cost made its application in a multi-acre bPV solar facility non-viable. The road paint was discarded from testing due to issues in procurement, which would have put its testing well beyond the scheduled testing timeframe intended for this project. This left the polymer sheet materials, which consisted of three candidate materials: unreinforced polyethylene (PE), scrim-reinforced polyethylene (SR-PE), and woven polyethylene sheets. Each candidate material has a different density, surface roughness, and construction, which will affect both their albedo and mechanical performance during testing. In addition, besides evaluating these material specific characteristics, other factors such as cost, ease of installation, and observed maintenance needs will also be taken into consideration in the final recommendation of this report.

2.3.1 Polymer Classifications and Compositions

The material family of polymers consists of three principal classifications: thermoplastics, thermosets, and elastomers. Among these polymer types, the classification most used for outdoor applications are thermoplastics in the form of large sheets. Thermoplastics are polymers that can have either a crystalline or amorphous structure and are made up of long linear chains of molecular bonds primarily held together by van der Waals forces. They exhibit little to no cross-linking, and as a result exhibit a relatively low glass transition temperature (T_g) that allows them to be manufactured into a variety of complex geometries. In addition, thermoplastics can be softened and reshaped through heating and cooling, which allows them to be more easily recycled and therefore a more environmentally friendly choice as an albedo materials.[10,11] Among the variety of thermoplastics used for commercial outdoor applications, the most common include polyethylene (PE), polypropylene (PP), and polyvinylidene fluoride (PVF). The chemical compositions of these thermoplastics can be seen in Figure 3.[12]



(a) (b) (c)

Figure 3 – Mer structures of (a) polyethylene (b) polypropylene (c) and polyvinylidene fluoride.[12]

Among these thermoplastics the most common for outdoor applications is PE due to its higher resistance to photodegradation and greater mechanical properties in comparison to PP and PF. These superior properties of PE and their benefits are further explained in sections 2.3.2 – 2.3.5.

2.3.2 Selection of Polyethylene

Thermoplastics like PE, PP, and PVF are best utilized below their melting temperature (T_m). As a result, identifying the operational temperature range at which the candidate materials will be subjected is critical to ensure they will not degrade prematurely. For the thermoplastics examined in this study, the lowest T_m is seen in PE (specifically low-density polyethylene) which has a T_m of 130˚C.[13] Given that the highest recorded surface temperature at the intended application site is 80˚C, all three candidate materials will be able to safely operate under the T_m

by a margin of approximately 50˚C.[14] Therefore the mechanical properties of the high albedo materials, such as elastic modulus and tensile strength, are not expected to significantly compromise the physical integrity of the polymer sheeting.

However, when examined under the scope of use in a commercial solar farm application, the most viable thermoplastic from among PE, PP, and PVF is PE. PE is superior to PP due to its higher chemical and UV resistance as well as its greater density, which assists in making it mechanically stronger. PVF is superior to PE in terms of chemical and UV resistance, but its higher cost and lack of availability as large sheets with thicknesses up to 1 mm make it commercially unviable for a large-scale application on a solar farm. Hence, PE was chosen as the polymer sheeting material for testing in this project.

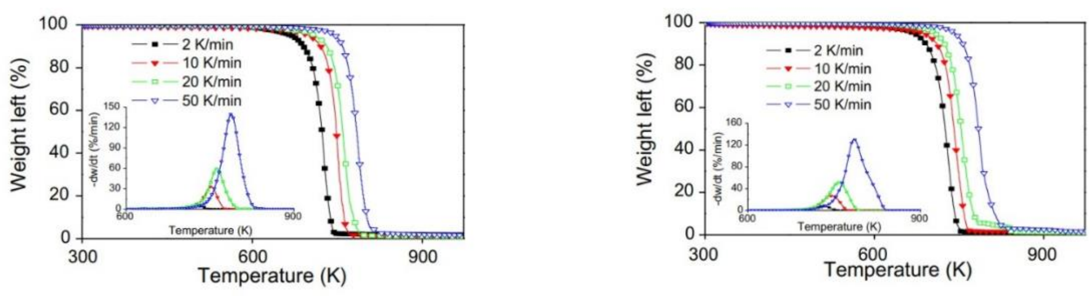
To improve the capabilities and mechanical properties of PE, its density can be increased to create more closely packed molecular chains that require greater physical stress to induce failure. Additionally, PE can be structurally reinforced using a scrim string lattice or by integrating a woven pattern into the material. The inclusion of a reinforcing scrim or a woven pattern create a physical cross-linking network within the PE material that significantly increases its elastic modulus and tensile strength, which in turn can extend the operational lives of the sheeting samples. Chemical additives such as nonylphenols (e.g., barium and calcium salts) can also be used to strengthen a polymer's resistance to environmental conditions such as UV exposure.[14]

2.3.3 Degradation Effects on Albedo Values

When examining the average albedo values of various materials over an extended time interval such as on an annual basis, a steady decline in effective albedo will always be present. This decline in albedo can be attributed to external physical factors that alter the effective reflectivity of the material such as from dirt or debris covering its surface. However, even with regular maintenance to minimize the effect that external physical factors have on the albedo performance of the material a continual decline will still occur due to abiotic degradation. Abiotic degradation refers to changes in the chemical and physical properties that occur in a polymer due to exposure to environmental factors such as temperature, UV exposure, and hydrolysis.[10] Degradation caused by these factors will subsequently lead to changes in the material's color, roughness, and surface composition which can reduce its albedo. Therefore, energy solar facilities that employ a bPV system not only seek a ground covering that has a high albedo, but also a high resistance to abiotic degradation. The mitigation of environmental deterioration is vital for any candidate material, as any extension in service life saves money for the customer in resurfacing and maintenance costs. Understanding the effects that temperature, UV exposure, and hydrolysis can have on the degradation of our candidate materials, we selected commercially available PE sheeting materials that can effectively operate for an extended period in climate conditions that are typical for southern California.

2.3.4 Thermal Effects

Thermal degradation is induced when the physical or chemical structure of a material is significantly altered due to exposure to elevated temperature. Based feedback from the sponsor of this project, it was determined that highest air temperature the candidate materials would be exposed to would be 45˚C. Given that ground surface temperatures can be up to 50% higher than that of ambient air, the highest surface temperature that the candidate material would need to be to withstand is approximately 68˚C.[14] Polymers are sensitive to elevated temperature environments as studied by Aboulkas *et al.*, who experimentally determined the temperature ranges in which polymers like high density polyethylene (HDPE) and low-density polyethylene (LDPE) will thermally degrade. The onset temperature for the physical degradation of HDPE and LDPE were found to be 687.2 K and 657.5 K, respectively (Figure 4).[15]



(a) (b)

Figure 4 – Thermal degradation behavior of (a) HDPE, and (b) LDPE measured as remaining sample mass versus temperature.[15]

Based on the results shown in Figure 4, the least thermally resistant polymer is LDPE with a minimum temperature to induce physical degradation of 657.5 K (385˚C). This temperature is well beyond the temperature range that will be experienced in the expected application site in southern California. Therefore, the prospect of a polymer-based ground albedo material physically degrading at an accelerated rate is not likely. Even at a lower temperature of 200˚C where exothermic oxidation is likely to occur within most plastics that contain hydrogen (i.e. thermoplastics), this temperature is still well above the expected application site environmental temperature.[11] However, this does not rule out the possibility of the polymer sheeting experiencing discoloration when exposed to the outdoor environment over an extended period.

2.3.5 UV Exposure Effects

Degradation induced by exposure to UV light is called photodegradation, and is one of the most important factors that initiate polymer degradation. The primary component of UV light that contributes to the degradation of materials is the UVA spectrum, which has a λ range of 315 – 400 nm.[16] When polymers are exposed to UV radiation, they can experience yellowing that is attributed to the formation of conjugated polyenes from the reaction between the solar radiation and the carbon polymer chains (Figure 5). Yellowing of the polymer can decrease its average albedo value by up to 60%.[17]

Figure 5 – Gradual discoloration of a PE film when exposed to UV radiation at various time intervals. Samples are arranged from upper left to lower right with the former having an exposure time of one week and the latter having an exposure time of one year.[17]

Among the candidate polymer materials considered, PE is the most resistant to photodegradation due to its lack of chromophores. Chromophores are regions within a molecule that serve as the catalyst sites for the formation of conjugated polyenes. A chemical reaction between the UV radiation and chromophores form the conjugated polyenes which gives a polymer its yellowish hue. Despite a lack of chromophores PE is not impervious to photodegradation, as impurities in its composition from the manufacturing process can act as chromophore stand-ins to initiate the degradation process and subsequent yellowing. Extended UV exposure will also induce a loss in mechanical integrity as the polymer's molecular chains undergo scissions that oxidize the material. This form of UV-induced oxidation is known as a photooxidative reaction and is the most common form of degradation experienced by agricultural films and plastic pipes. The impacts of the photooxidative reaction can be mitigated using light stabilizing additives such as hindered amine light stabilizers (HALS), which have been found to successfully extend the lifetime of many outdoor polymers.[17] However, the added cost of polymers dosed with HALS can be a point of contention for customers who may find it more cost-effective to simply replace the polymer sheeting.

Though not studied in this project, UV degradation also affects aggregate materials but instead of discoloring them like polymers, UV radiation decreases their "gloss". Gloss is a similar measurement to albedo but used specifically in the field of geology to measure the reflectance of stones or aggregate materials. A study by Careddu *et al*. found that prolonged exposure to UV at temperatures between 20º – 60˚C can lead to gloss losses of 0.89 – 13.43% for granite-based aggregates.[18] Though not an equivalent comparison, this loss in gloss can be approximated to a loss of 0.025 – 0.0375 in albedo, which when compounded over the course of years can build up and decrease the potential energy output of a bPV panel. However, this 3 – 6% loss in albedo is small when compared to a potential loss of up to 60% in albedo as seen in polymer materials due to degradation. As a result, UV degradation in aggregate materials is not as critical a concern as it is with polymer sheets.

2.3.6 Hydrolysis Effects

Degradation of polymers based on exposure to water depends on the breaking of bonds in the polymer chain. If a particular polymer's molecules are susceptible to bonding with water molecules, then that polymer will be more likely to exhibit physical degradation when exposed to water.[19] The pH of the water also plays a factor in the rate at which a polymer may degrade, but since most commercial polymer sheets do not easily react to form ester bonds with water molecules, the effect of pH is somewhat mitigated.

Hydrolysis for stone aggregate or sand has little to no effect in terms of inducing any significant degradation within a predicted maximum life span of 50 years. In fact, exposure to water can serve as a benefit for albedo as the water increases the gloss of the aggregate materials for the short duration when water coats the material. The more concerning issue in relation to the interaction between water and these materials is how it can potentially change the topography of its surface. In large enough quantities, if rainwater were able to displace the material in a manner where it would no longer have an even surface, then this change in geometry could have the same effect as the uneven surface of grass by scattering solar radiation instead of more evenly reflecting it towards the bPV. However, when examining weather records of the application location, this potential issue is likely of little concern as the location does not receive enough rainwater to make this type of displacement occur.[11] On the days the intended application site receives rain, the days following the downpour will more than likely result in higher albedo values and greater energy output from the bPV panels.

3. Methods and Materials

3.1 Project Plan

Based on suggestions from the project sponsor, the testing methodologies used to quantitatively measure the albedo performance of the candidate materials were split into two categories: field testing and laboratory testing. The purpose of employing two different testing environments is to broaden the scope of the material data being collected throughout the testing period. Data collected from samples exposed to a natural environment during field testing will provide a close approximation to actual performance if deployed at a commercial solar facility. However, given the 4-week time frame of testing, the data collected is not completely representative of the material's potential sustained performance over a possible multi-year life span. Ancillary testing in a laboratory environment provides additional data on a material's projected performance using highly accelerated life testing (HALT) equipment and methodologies. Analyzing and comparing the data from both field and laboratory testing of samples will produce a more complete description of the performance of all candidate materials.

Analysis of this data will quantitatively determine which of the candidate materials is best suited for the application of a ground albedo material for a bPV solar array.

3.2 Research Question

How do the albedo and mechanical properties of candidate polyethylene sheet materials for a ground albedo treatment change depending on material structure, UV light exposure, environmental degradation, solar altitude angle, and accelerated cyclic exposure to changes in heat and UV light?

3.3 Description of Candidate Materials

Table 1 gives descriptions of the three candidate materials that were studied in this project: unreinforced polyethylene (PE), scrim-reinforced polyethylene (SR-PE), and woven polyethylene (W-PE), These materials were tested in sheet format.

Table 1 – List and description of candidate polyethylene materials used in testing.

Material	Vendor	Model	Thickness (mm)	Density (g/cm^3)	HALS Additives Included	Additional Notes
PE	Farm Plastic Supply	Silage Tarp Black/White	0.15	0.72	Yes	Black backing
SR-PE	Farm Plastic Supply	Dura Skrim White	0.15	0.65	Yes	Scrim reinforcement is prominent on one side only
W-PE	The Tarps Wholesaler	Heavy Duty White	0.30	0.91	Yes	N/A

3.4 Design and Description of Testing Factors

Based on the goals of this project, the primary factors that can impact the performance of the candidate materials are albedo, structure, and physical resistance to environmental degradation. The way these factors are defined and tested (both in the field and under laboratory conditions) are shown in Table 2.

Table 2 – 3^3 factorial design of experiment (DOE) with accompanying levels and testing criteria.

Factor	Description	Testing Criteria
Albedo	Measure the ratio of reflected radiation to incident radiation. This measures the material's efficiency in reflecting light on a scale of 0 – 1 with 1 representing 100% reflectance.	Testing will take place in both field and lab environments. In the field site, albedo will be measured on a biweekly basis over the course of 4 weeks according to the appropriate safety protocol when the solar altitude angle is 20˚, 25˚, 30˚, 35˚, and 40˚. Laboratory tested samples will not have their albedo measured as their physical dimensions do not meet the requirements necessary for accurate albedo measurements.
Structure	Testing the effect sheet structure has on its ability to withstand environmental conditions (heat, humidity, UV exposure) while maintaining acceptable mechanical and albedo properties.	Plastic sheeting materials consisting of unreinforced polyethylene (PE), scrim reinforced polyethylene (SR-PE), and woven polyethylene (W-PE) will be subjected to the same testing conditions (exposure to UV, temperature change, humidity, etc.). After exposure in natural and accelerated UV conditions for a duration of 4 weeks the samples will undergo tensile testing. Subsequent tensile tests can then be used to compare the change in tensile strength of the different PE sheets being tested to draw conclusions about their ability to resist environmental degradation.
Environmental / UV Degradation	Testing the impact of UV/environmental exposure on albedo to generate a quantitative correlation between these factors.	UV/environmental degradation of the testing materials in the field site will be visually inspected at the same time when albedo measurements are taken. Any discoloration or physical damage that the testing materials take on while exposed to the elements will be documented and used in drawing conclusions on the material's effectiveness as an albedo material. A correlation between observed environmental degradation, recorded temperatures, humidity, UV exposure etc., and albedo can then be derived to quantitatively determine which testing material functions "best" as an albedo material.

3.5 Description and Justification of Testing Methods

3.5.1 Field Testing

Candidate polyethylene (PE) sheet materials were subjected to four weeks of continuous outdoor exposure between April 17, 2023, and May 12, 2023. The test methodology employed for field testing was based on ASTM Standard E1918-21, which outlines procedures and conditions for measurements of material albedo in an outdoor environment using an albedometer. The field site was located at GPS coordinates 35˚ 18’ 9.0648” N, 120˚ 39’ 57.6828 W, on the roof of Building 41A on the Cal Poly SLO campus. This location was selected based on its proximity to the project equipment storage room, inaccessibility to the public, and geographic features that align with ASTM Standard E1918-21 requirements. Following ASTM Standard E1918-21, the PE sheet materials were trimmed to an area of 4 m x 4 m and were left untouched throughout the testing period.[20] In addition, the albedometer setup outlined in ASTM Standard E1918-21 was followed to acquire albedo data (Figure 6). A slight deviation from the ASTM Standard that was implemented in field testing was the use of grey bricks instead of ground stakes to secure the PE sheets to the roof surface (Figure 7). In addition, extra stones were sometimes temporarily added while recording albedo measurements if the conditions were too windy and causing the sheets to flutter (Figure 7).

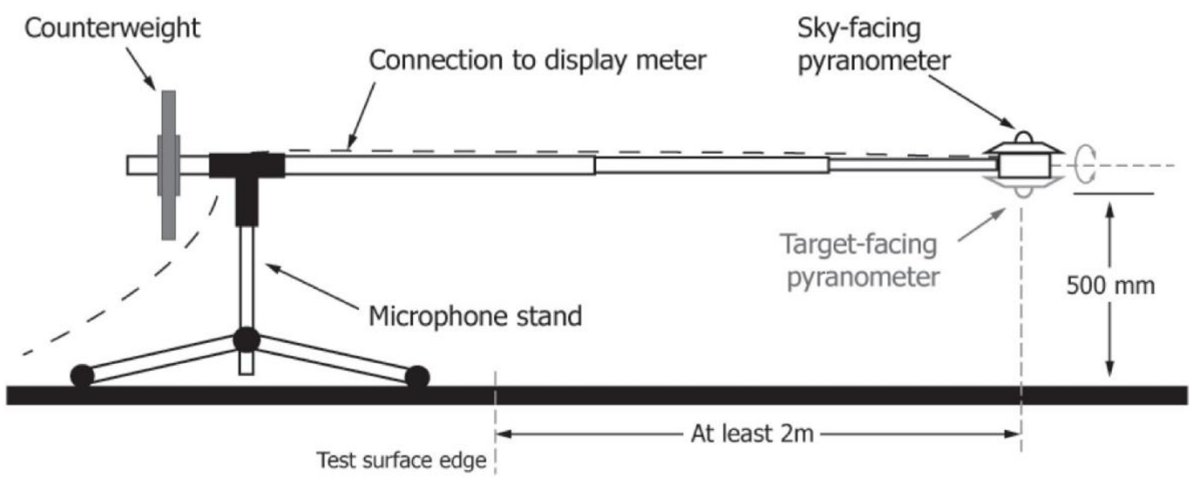


Figure 6 – Schematic of albedometer and its support frame for collection of albedo measurements in an outdoor environment based on ASTM Standard E1918-21.[20]

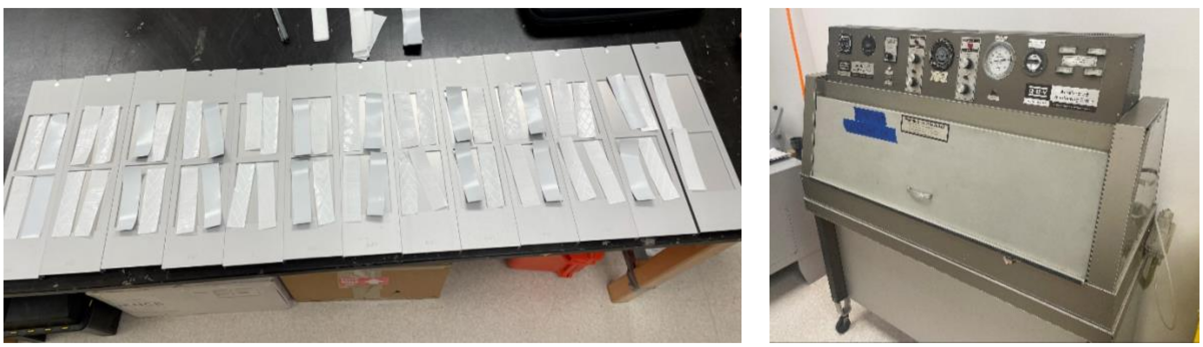
Albedo measurements at the field site were taken a minimum of twice a week throughout the 4-week testing period, with albedo measurements taken at solar altitude angles of 20˚, 25˚, 30˚, 35˚, and 40˚ for all candidate materials. For each solar altitude angle a total of 15 albedo measurements were taken to generate an average albedo value for each material at each angle. Fifteen (15) measurements were taken to account for the sometimes large fluctuations in albedo that could be seen due to dramatic changes in cloud cover during measurements. These 15 measurements provided more accurate albedo data while also allowing obvious outlier albedo values to be excluded. In addition, environmental conditions such as temperature, UV index, humidity, air quality, atmospheric pressure, and observable cloud coverage were also recorded during collection of albedo measurements. Following this field testing methodology, a total of eight averaged data points per sample spanning the solar altitude range of 20˚– 40˚ were collected to calculate statistically significant results with a 95% confidence level for further analysis.

Figure 7 – Experimental setup of albedometer and candidate 4 m x 4 m PE sheets secured with grey bricks along their perimeter on the roof of building 41A on the Cal Poly SLO campus. In the sample on the left, 3 extra stones were temporarily placed on it while recording albedo measurements if the conditions were too windy and causing the sheet to flutter.

3.5.2 Accelerated Weathering Testing

To examine the effects of long-term exposure to UV degradation on the candidate materials, accelerated weathering was implemented which followed ASTM Standards G154-16 and D5208-14. ASTM Standard G154-16 provides the criteria necessary to test polymer-based materials under accelerated environmental degradation conditions using UV light, while ASTM

Standard D5208-14 provides the required testing conditions and procedures necessary to subject the PE materials to HALT conditions.[21,22] Accelerated weathering testing was conducted in a Q-Panel Accelerated Weathering Tester (AWT) which is able to subject the PE materials to controlled cycles of UV, humidity, and heat under the testing parameters described in ASTM Standard G154-16 and D5208-14.[21,22] Accelerated weathering testing took place over a 4-week period between April 17, 2023, and May 12, 2023. Before being subjected to accelerated weathering testing, 16 samples of each candidate material were each trimmed to 25 mm x 101 mm and weighed. After trimming and weighing, the samples were placed into the AWT to begin their accelerated weathering testing (Figure 8).



(a) (b)

Figure 8 – (a) Samples mounted on an AWT plate in a repeating pattern of SR-PE, W-PE, PE across the plate in a counter-clockwise direction starting at the upper right. (b) Image of AWT after mounting all samples and beginning testing.

During the 4-week testing period, the samples were exposed to repeated cycles consisting of 20 hours of exposure to UV light at 50˚C followed by 4 hours of darkness at 30˚C. Though ASTM Standard D5208-14 suggests that humidity levels should undergo controlled fluctuations as well, this was not included in our testing as the humidity control functions of the AWT were not operational during the time of testing. The samples were left untouched throughout the 4-week testing period, but the AWT was periodically checked to ensure that the programmed cycles of UV light and temperature were operating as intended. The 4 weeks of cyclic exposure to UV light equated to approximately 4 – 12 months of natural exposure to UV according to estimates by the AWT manufacturer. After completing the 4 weeks of testing, the samples were taken from the AWT and had their masses recorded before being subjected to tensile testing.

3.4.3 Tensile Testing

To examine the effects that accelerated UV exposure had on the samples, they were subjected to mechanical testing after completing testing in the AWT. Tensile testing was conducted using an Instron Micro Series 55MT2 tensile tester (Figure 9) in accordance with ASTM Standard D3826-18, which outlines tensile testing parameters for polymer film materials subjected to UV degradation.[23] Tensile testing consisted of testing both unexposed and UV exposed specimens. A total of six samples of each type of PE sheet material (unexposed and UV exposed) were subjected to tensile testing at an extension rate of 10 mm/min per ASTM Standard D3826-18. Mechanical properties such as yield strength (σ_y), elastic modulus (E), and ultimate tensile strength (σ_{UTS}) were extracted from the tensile testing results and then averaged for each PE sheet type before and after UV exposure to compare the difference in mechanical properties.

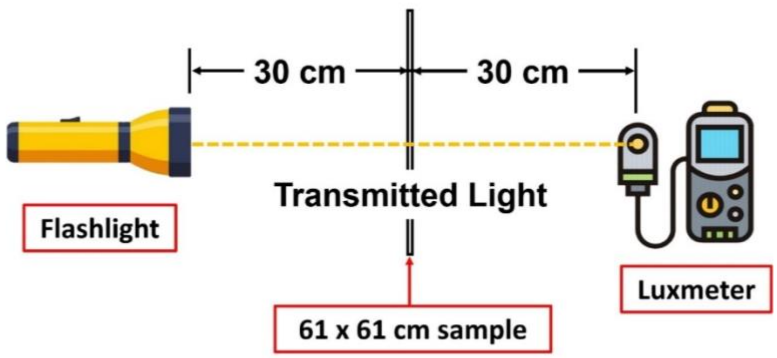
Figure 9 – Instron Micro Series 55MT2 tensile tester used in testing mechanical properties of candidate albedo materials before and after accelerated UV exposure.

3.4.4. Measuring Light Transmittance

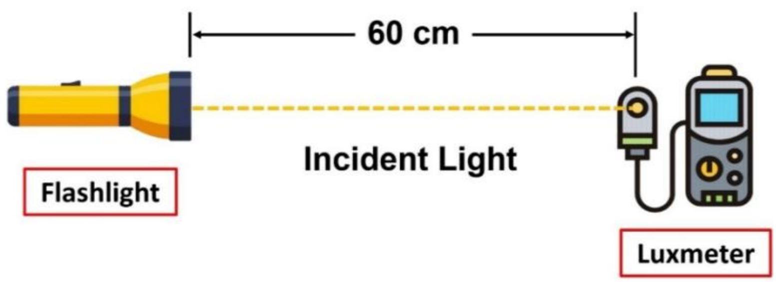
Each candidate albedo material had visibly different levels of opacity. To determine whether this variance correlated to albedo, the light transmittance of the materials was tested. Light transmittance is defined by the ratio of intensity of transmitted light over the intensity of incident light and can be calculated using Equation 1.

$$\text{Light Tranmittance (T)} = \frac{\text{Intensity of Tranmitted Light (lux)}}{\text{Intensity of Incident Light (lux)}} \qquad (1)$$

The intensity of transmitted and incident light was measured using a luxmeter application, flashlight, and 61 cm x 61 cm segments of each respective albedo material. The setup used for measuring the intensity of incident and transmitted light is shown in Figure 10.



(a)



(b)

Figure 10 – (a) Testing setup for measuring intensity of transmitted light through an albedo material (b) testing setup for measuring intensity of incident light.

4. Results

4.1. Albedo Data from Field Testing

Figure 11 displays the trend in average albedos exhibited by each PE sheet type at solar altitude angles ranging from 20˚ - 40˚. Quantitative values of the average albedo recorded shown in Table 2.

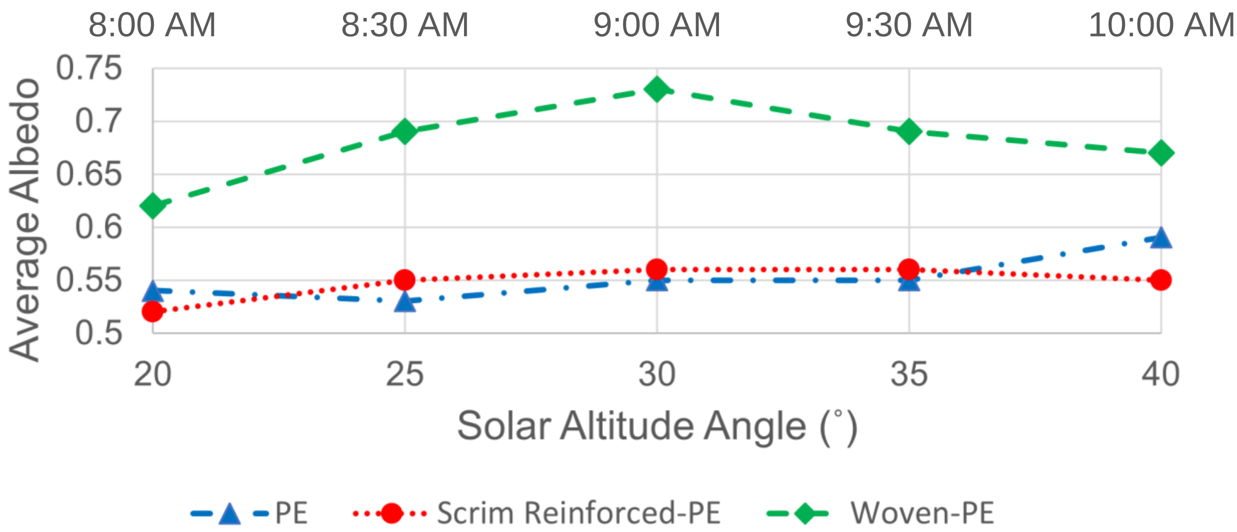


Figure 11 – Average albedo values over the course of four weeks of testing from solar altitude angles ranging between 20˚ – 40˚.

Table 3 – Average recorded albedo based on solar altitude (SA) range and fraction of maximum albedo.

Material	**Average Albedo (20˚- 40˚ SA Range)**	**% of Maximum Albedo**	**Uncertainty**
PE	0.55	81%	± 0.0042
SR-PE	0.55	81%	± 0.0059
W-PE	0.68	100%	± 0.0088

As seen in Figure 11 and Table 2, W-PE exhibited the highest albedo of 0.68, and consistently maintained the highest albedo across the entire tested solar altitude angle range. The W-PE outperformed PE and SR-PE by a margin of about 20%. Based on the calculated uncertainties, all albedo values for each candidate material are within the 95% confidence interval, which supports the results as being statistically significant. Based on these results, W-PE was shown quantitatively to be the best ground covering for maximizing albedo among the materials tested in this project.

4.2. Mechanical Testing Results Before and After Accelerated UV Exposure

Tables 3 - 5 display the measured yield strength, ultimate tensile strength, and elastic modulus of the candidate albedo materials before and after exposure to accelerated UV exposure. Darker green shading indicates the best of the three candidate materials with respect to a given mechanical characteristic, while lighter shading represents the second best of the three candidate materials with respect to a given mechanical characteristic. Stress-strain graphs from which the values of Table 3 - 5 are derived can be seen in Appendix A.

Table 4 – Comparison of average yield strength before and after accelerated weathering testing.

	Unexposed σ_y **(MPa)**	**UV Exposed** σ_y **(MPa)**	**% Change in** σ_y **after UV Exposure**	**Uncertainty**
PE	0.6980	0.7130	+ 2.126%	± 0.0426
SR-PE	5.110	4.110	- 21.69%	± 0.4463
W-PE	3.780	2.464	- 41.15%	± 0.4144

Table 5 – Comparison of average ultimate tensile strength before and after accelerated weathering testing.

	Unexposed σ_{UTS} **(MPa)**	**UV Exposed** σ_{UTS} **(MPa)**	**% Change in** σ_{UTS} **after UV Exposure**	**Uncertainty**
PE	1.187	1.191	+ 0.3364%	± 0.2063
SR-PE	5.110	4.110	- 21.69%	± 0.4463
W-PE	4.263	3.613	- 16.51%	± 0.4176

Table 6 – Comparison of average elastic moduli before and after accelerated weathering testing.

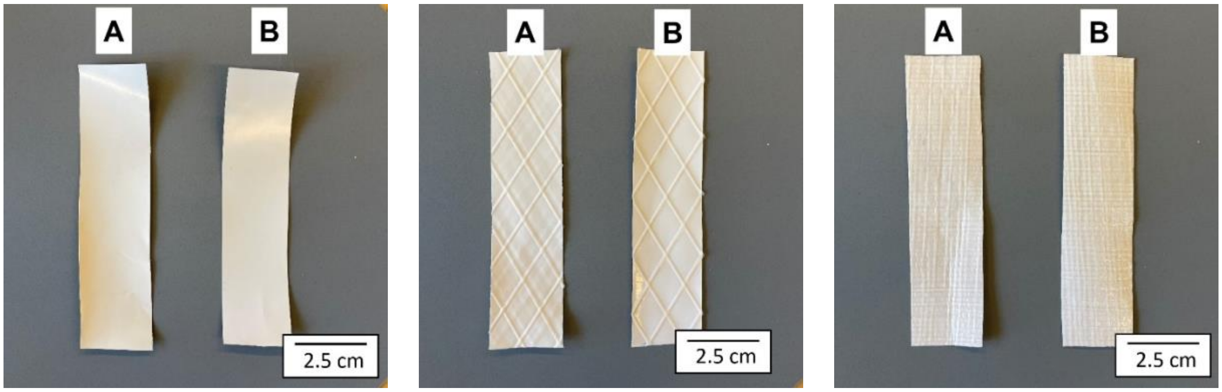
	Unexposed E **(MPa)**	**UV Exposed** E **(MPa)**	**% Change in** E **after UV Exposure**	**Uncertainty**
PE	6.700	6.074	-9.801%	± 0.7090
SR-PE	60.50	60.95	+0.7427%	± 6.206
W-PE	14.42	12.46	-14.59%	± 1.776

Based on the results of tensile testing, SR-PE exhibited the highest yield strength, ultimate tensile strength, and elastic modulus among the three candidate materials both before and after exposure to accelerated UV conditions, followed closely by W-PE and then PE. This indicates that SR-PE has superior mechanical properties in comparison to the other materials tested. However, it should be noted that even though SR-PE had the best mechanical properties, it also exhibited significant decreases in yield strength and ultimate tensile strength after accelerated UV exposure by a margin of about 22%. Its elastic modulus experienced an increase by +0.74% after accelerated UV exposure, but this can be disregarded as not statistically significant since it is within the margin of uncertainty of ± 6.2%. The decrease in ultimate tensile strength in SR-PE after accelerated UV exposure is significant, as it is a critical mechanical property that ideally must be maintained to prevent tearing of the material. Given that SR-PE experienced the highest amount of degradation in ultimate tensile strength after accelerated UV exposure, this may be an indicator that over a longer period of exposure to UV the SR-PE may degrade in a manner where its UTS decreases to be below that of W-PE. As a result, though SR-PE demonstrated superior mechanical properties, W-PE also has acceptable mechanical properties for the intended function of being staked to the ground. This is also consistent with the W-PE being thicker and denser than the other candidate materials. PE appears to be too mechanically weak in comparison to be an effective ground albedo material.

The increase in yield and ultimate tensile strengths in PE after accelerated UV exposure can be attributed to the HALS and relatively low temperature (approximately 50˚C) affecting the material. While HALS typically assists in preventing photodegradation, it can also be a catalyst for crystallization in the polymer structure when exposed to consistently high temperatures that are not above the melting temperature. The HALS present in the PE and the resultant crystallization are identified as contributing factors to the slight increase in yield strength and ultimate tensile strength seen in the PE sample.

4.3. Visual Inspection

After being subjected to 4 weeks of accelerated UV exposure, the candidate materials were visually inspected and compared with unexposed samples to determine if any discoloration occurred (Figure 12). Side-by-side comparisons of the tested albedo materials before and after UV exposure showed that there was no significant discoloration identified across all samples (Figure 12). This outcome is consistent with the ability of HALS to prevent photodegradation in these materials. In addition, since no noticeable yellowing was present in any tested samples, all of the tested materials are deemed equivalent in terms of their ability to resist photodegradation over a period of 4 weeks. As a result, the ability to resist photodegradation was not used as a determining factor for the final material recommendation of this project.

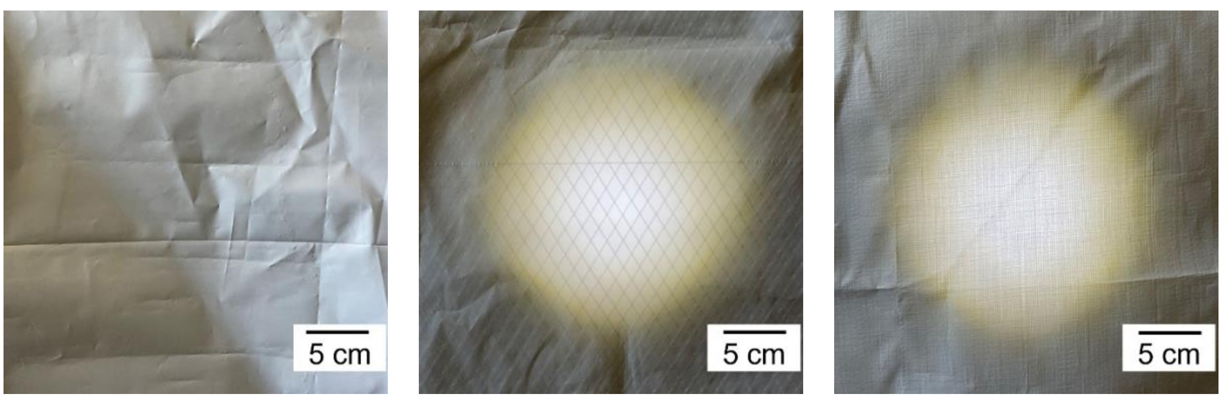


(a) (b) (c)

Figure 12 – (a) Visual comparison of [A] unexposed PE and [B] UV exposed PE, (b) visual comparison of [A] unexposed SR-PE and [B] UV exposed SR-PE, (c) visual comparison of [A] unexposed W-PE and [B] UV exposed W-PE.

4.4. Material Transmittance

The transmittance of samples that were not exposed to UV was tested according to the methodology outlined in section 3.4.4 of this report. The quantitative (as viewed with the unaided eye) and quantitative results of this testing can be seen in Figure 13 and Table 6.



(a) (b) (c)

Figure 13 – (a) Qualitative transmittance of unexposed PE, (b) qualitative transmittance of unexposed SR-PE, and (c) qualitative transmittance of unexposed W-PE.

Table 7 – Quantitative transmittance values of unexposed albedo materials.

	PE	SR-PE	W-PE
Transmittance (T)	0.293	0.793	0.627

Based on visual observations (Figure 13) and calculated transmittance values (Table 6), PE exhibited the least transmittance, followed by W-PE and SR-PE. In comparison to the ranking of albedo for the sample materials in which W-PE ranked highest followed by SR-PE and PE, it can be concluded that there is no correlation between material transmittance and albedo. As a result, if further testing is conducted with different types of materials, it is recommended that transmittance not be used as an indicator for albedo performance during initial material selection.

5. Conclusions

The woven polyethylene material consistently exhibited the highest albedo across the solar altitude angle range of 20˚ – 40˚ throughout the 4 weeks of exposure in an outdoor environment. With an average albedo of 0.68, woven polyethylene had an albedo 23% greater than the unreinforced and scrim-reinforced polyethylene materials tested. If installed at the intended sponsor location, this increase in albedo could increase solar energy production by 0.4 – 1.2%, which equates to approximately 0.8 – 2.3 MW of additional output. In addition, woven polyethylene showed no discernable yellowing or physical decomposition in either natural or laboratory accelerated degradation environments over the 4 week test period. Woven polyethylene, however, did not exhibit the highest mechanical properties, but produced adequate yield and tensile strengths required for application as a ground covering. The observed handling and installation capabilities of woven polyethylene were also qualitatively superior to the other tested materials. This was characterized by its ability to be easily trimmed to the 4 m x 4 m testing dimensions, as well as it being less susceptible to fluttering, creasing, and abrasions throughout the 4 weeks of exposure to natural conditions. These characteristics are likely attributed to the higher density and thickness of the W-PE which can increase its durability. Additionally, at 15¢/ft^2, the price of the woven polyethylene makes it cost effective for application in a bifacial photovoltaic facility. As result, we recommend that woven polyethylene is best albedo material for use in bifacial photovoltaic facility in comparison to unreinforced and scrim-reinforced polyethylene.

6. References

[1] Brennan, M.P.; Abramase, A.L.; Andrews, R.W.; Pearce, J.M. Effects of spectral albedo on solar photovoltaic devices. *Solar Energy Materials & Soar. Cells* [Online] 2014, *124*, 111-116. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/article/pii/S0927024814000658 (accessed Mar. 14, 2023).

[2] Vogt; Ruben; Gewohn; Timo; Schinke; Carsten; Brendel; Rolf. Impact of using spectrally resolved ground albedo data for performance simulations of bifacial modules. *Inst. for Solar Energy Research. Hamelin* [Online] DOI: 10.4229/35thEUPVSEC20182018-5BO.9.5. Published Online: October 1, 2018. http://researchgate.net (accessed Mar 14, 2023).

[3] Ziar, H.; Sönmez, F.F.; Isabella, O.; Zeman, M.; A comprehensive albedo model for solar energy applications: Geometric spectral albedo. *Applied Energy* [Online] 2019, *255*. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/article/pii/S0306261919315545 (accessed Mar. 14, 2023).

[4] Chiodetti, M.; Lindsay, A.; Dupeyrat, P.; Binesti, D.; Lutun, E.; Khalid, R.; Mousel, S. PV bifacial yield simulation with a variable albedo model. *EDF R&D – ENERBAT* [Online] 2016. Published Online: June 11, 2016. http://researchgate.net (accessed Mar. 14, 2023).

[5] Lv, Y.; Fan, D.; Kong, M. Reliability assessment on PV backsheets with and without considering spectral UV albedo effects: A theoretical comparison. *Solar Energy Materials and Solar Cells* [Online] 2021, *230*. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/article/ pii/S0927024821002749 (accessed Mar. 14, 2023).

[6] Stanford Solar Center. UV Light. http://solar-center.stanford.edu/about/uvlight.html (accessed Mar 14, 2023).

[7] Infrared Radiation. International Commission on Non-Ionizing Radiation Protection. https://www.icnirp.org/en/frequencies/infrared/index.html#:~:text=Infrared%20radiation%20(IR)%2C%20also,3%20%C2%B5m%2D1%20mm) (accessed Mar. 14, 2023).

[8] Hoook, S. ECOSTRESS Spectral Library. Jet Propulsion Laboratory: California Institute of Technology. https://speclib.jpl.nasa.gov/library (accessed Mar. 14, 2023).

[9] Bretz, S.; Akbari, H.; Rosenfeld, A. Practical issues for using solar-reflective materials to mitigate urban heat islands. Atmo. Envr. [Online] 1998, *32*, 95-101. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/article/pii/ S1352231097001829 (accessed Mar. 14, 2023).

[10] Fairbrother, A.; Boyd, M.; Lyu, Y.; Avenet, J.; Illich, P.; Wang, Y.; Kempe, M.; Dougherty, B.; Bruckman, L.; Gu, X. Differential degradation patterns of photovoltaic backsheets at the array level. *Solar Energy* [Online] 2018, *163*, 62-69. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/article/pii/S0038092X18300938 (accessed Mar. 14, 2023).

[11] Zhang, K.; Hamidian, A.H.; Tubić, A.; Zhang, Y.; Fang, J.; Wu, C.; Lam, P. Understanding plastic degradation and microplastic formation in the environment: A review. *Environmental Pollution* [Online] 2021, *274*. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/ article/pii/S0269749121001329 (accessed Mar. 14, 2023).

[12] Tran, H.; Kim, C.; Chen, L.; Chandrasekaran, A.; Batra, R.; Venkatram, S.; Kamal, D.; Lightstone, J.; Gurnani, R.; Shetty, P.; Ramprasad, M.; Laws, J.; Shelton, M.; Ramprasad, R. Machine-learning predictions of polymer properties with Polymer Genome. *Journal of Applied Physics* [Online] 2020, *128*. https://aip-scitation-org.ezproxy.lib.calpoly.edu/doi/full/10.1063/5.0023759 (accessed Mar. 14, 2023).

[13] Greene, J.P. 3 - Microstructures of Polymers, In Plastics Design Library. Auto. *Plastics & Composites* [Online] 2021, 27-37. https://openlibrary.org/works/OL25249737W/Automotive_Plastics_and_Composites (accessed Mar. 14, 2023).

[14] Southern California Weather History. Weather Underground. https://www.wunderground.com/ (accessed Mar. 14, 2023).

[15] Aboulkas, A.; El harfi, K.; El Bouadili, A. Thermal degradation behaviors of polyethylene and polypropylene. Part I: Pyrolysis kinetics and mechanisms. *Energy Conservation and Management* [Online] 2010, *51*, 1363-1369. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/ article/pii/S0196890409005238 (accessed Mar. 14, 2023).

[16] Radiation: Ultraviolet UV radiation. World Health Organization. https://www.who.int/news-room/questions-and-answers/item/radiation-ultraviolet-(uv) (accessed Mar. 14, 2023).

[17] UV Damage to Polymers, Environmental Effects of Ozone Depletion 1998 Assessment. Socioeconomic Data and Applications Center. https://sedac.ciesin.columbia.edu/ozone/docs/UNEP98/UNEP98p62.html (accessed Mar. 14, 2023).

[18] Careddu, N.; Marras, G. The effects of solar UV radiation on the gloss values of polished stone surfaces. *Construction and Building Materials* [Online] 2013, *49*, 828-834. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/article/pii/S0950061813008507 (accessed Mar. 14, 2023).

[19] Gopferich, A. Mechanisms of polymer degradation and erosion. *Biomaterials* [Online] 1996, *17*, 103-114. https://www-sciencedirect-com.ezproxy.lib.calpoly.edu/science/article/pii/B9780080451541500162 (accessed Mar. 14, 2023).

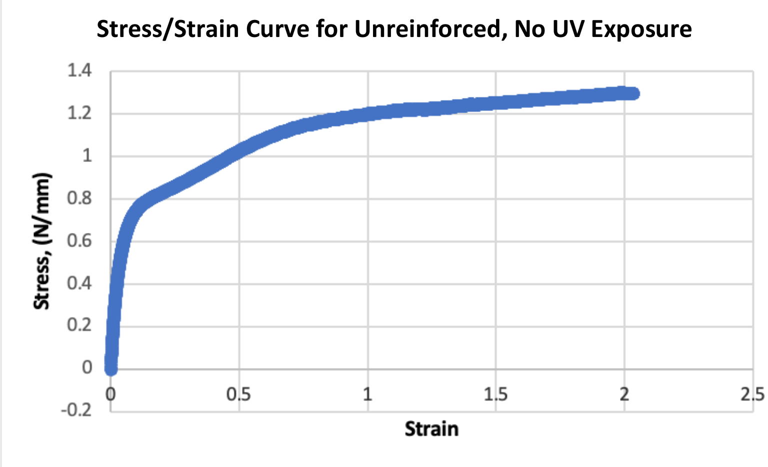
[20] ASTM Standard E1918-21, *Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field*, ASTM International, 2021

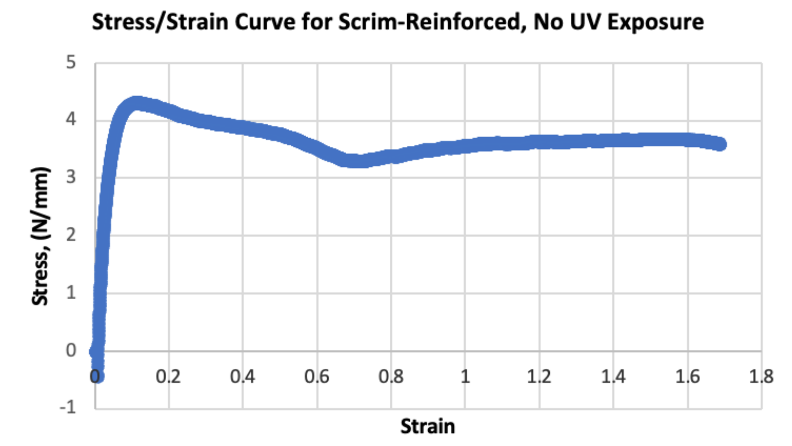
[21] ASTM Standard G154-16, *Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials*, ASTM International, 2016

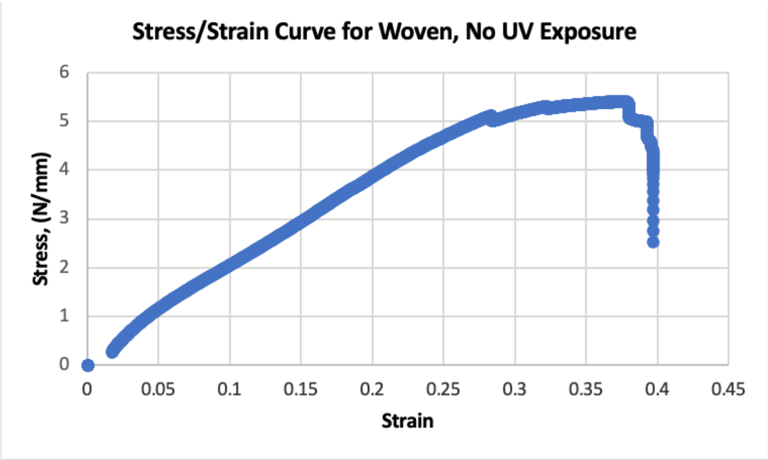
[22] ASTM Standard D5208-14, *Standard Practice for Fluorescent Ultraviolet (UV) Exposure of Photodegradable Plastics*, ASTM International, 2022

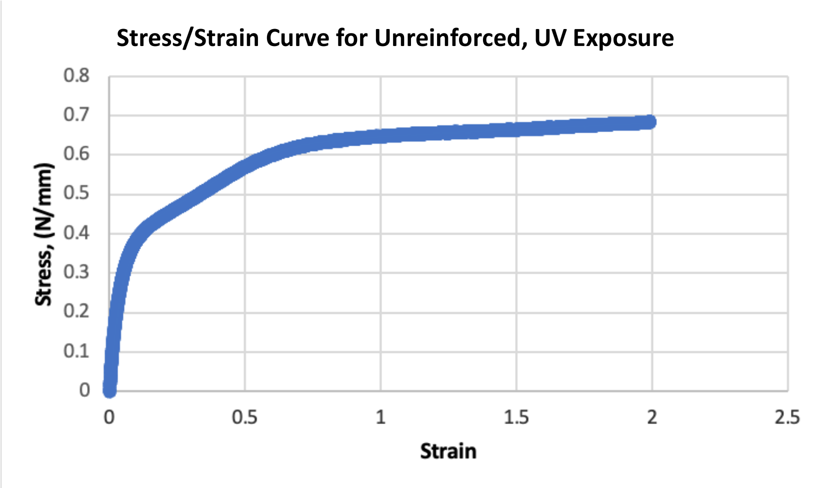
[23] ASTM Standard D3826-18, *Standard Practice for Determining Degradation End Point in Degradable Polyethylene and Polypropylene Using a Tensile Test*, ASTM International, 2018

Appendix A: Stress/strain curves for samples before and after UV exposure in the accelerated weathering tester.

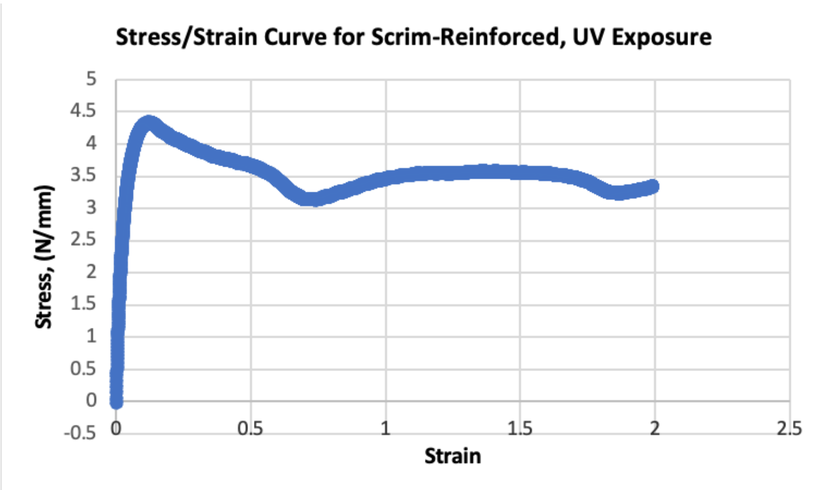




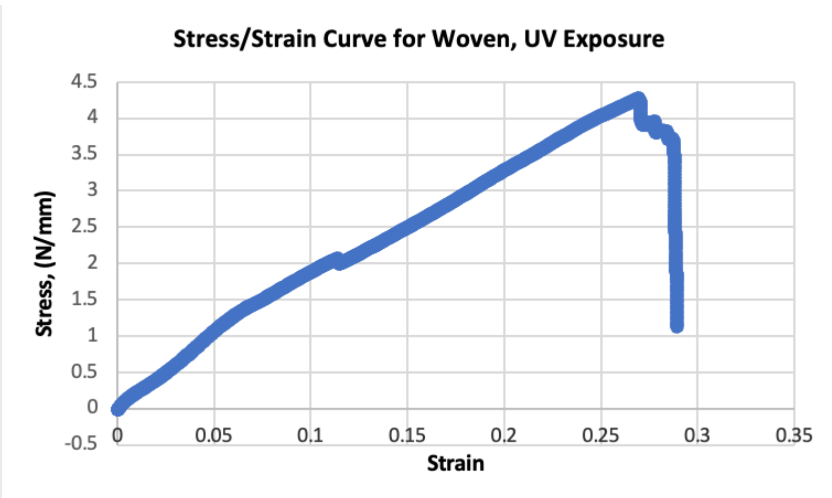




Stress/Strain Curve for Unreinforced, UV Exposure
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Stress, (N/mm)
0
0.5
1
1.5
2
2.5
Strain



Stress/Strain Curve for Scrim-Reinforced, UV Exposure
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Stress, (N/mm)
0
0.5
1
1.5
2
2.5
Strain



Stress/Strain Curve for Woven, UV Exposure
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Stress, (N/mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Strain

Appendix B: Instructions for Use of the Albedometer

Software Setup & Installation

The software used along with the albedometer and datalogger is PC400 by Campbell Scientific and can be installed from the link below:

https://www.campbellsci.com/pc400

When installing the software, ensure that the laptop you are using is fully updated as issues were encountered with the software running on an older version of Windows. Once the software is installed it must be paired with the datalogger; however, you only have to do this the first time you set it up.

Before beginning the setup, make sure your laptop is plugged into the datalogger using the micro USB to USB connection. After making sure the datalogger is charged or plugged in, make sure the datalogger is powered on by connecting the ports circled in yellow in the image below. After these have been connected, you should see a green light in the red circle below (Figure B1).

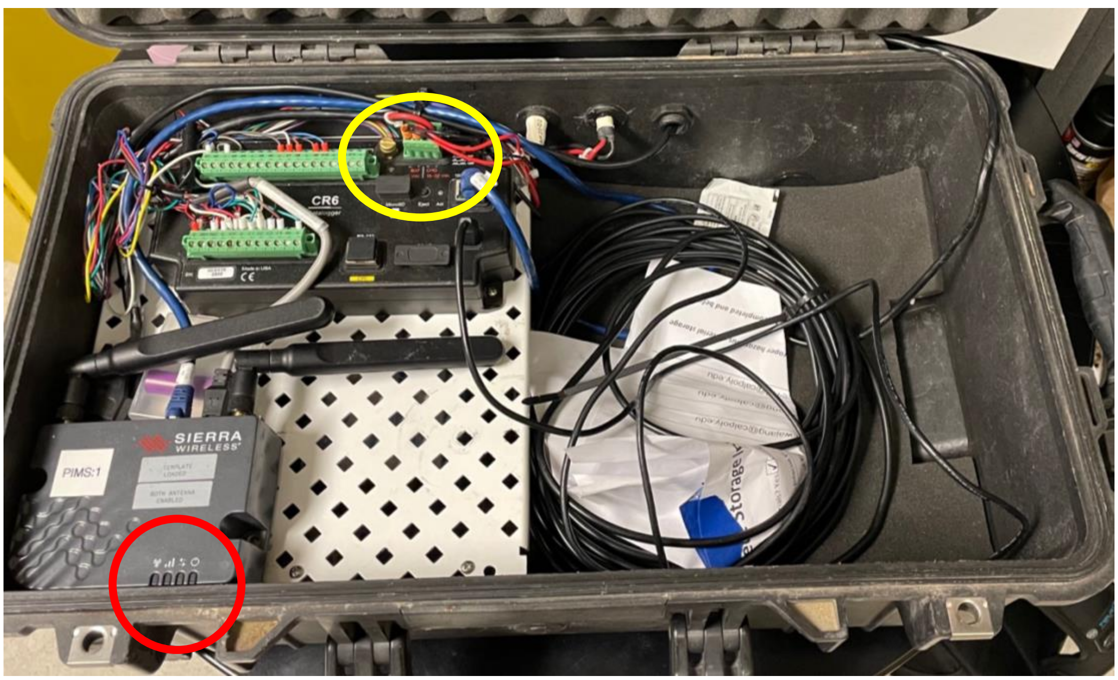


Figure B1 – Internals of datalogger with yellow circle indicating location of power connection to onboard battery and red circle indicating location of lights that will blink when connected to power and software.

To open the setup wizard, either hit the add button or go to File → Add datalogger. The screen should display the pop up shown in Figure B2a. Hit Next to continue and select the correct data logger from the list, which in our case is CR6. Select the direct connect connection type, as there is a micro USB to USB connection. Finally, choose the COM 7 selection and keep all remaining options on their preset values. Continue using the Next button throughout all the steps and perform the communication test to make sure the datalogger is connected (Figure B2). After connecting the datalogger, you are ready to setup the albedometer in your outdoor setting.

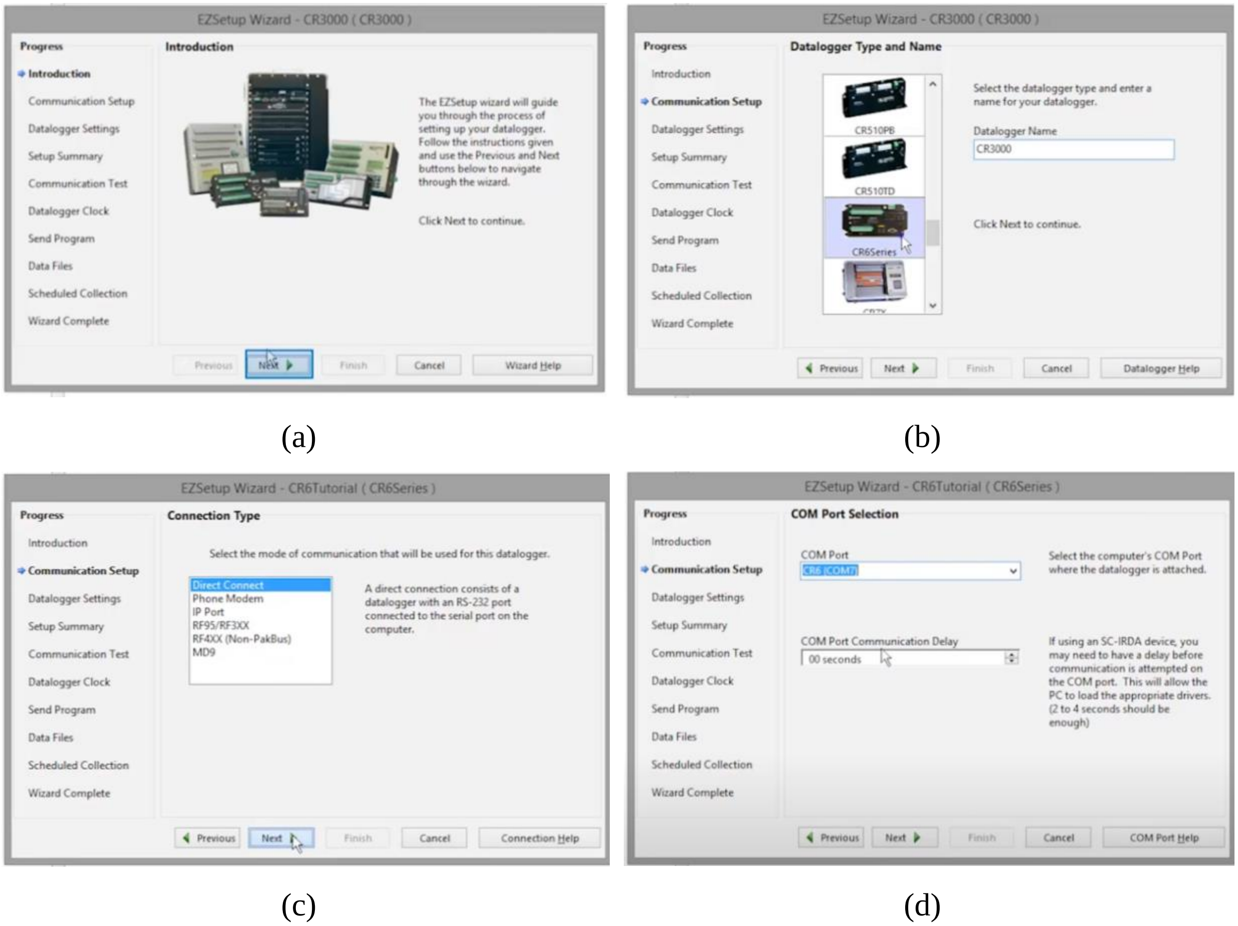


Figure B2 – EZSetup Wizard introduction prompt when first setting up datalogger on PC computer (b) Selection of CR6 series datalogger in EZSetup Wizard setup (c) Selection of direct connection type for data communication with albedometer (d) Selection of CR6 port for transfer of albedo data.

Albedometer and Tripod Setup

To set up the albedometer, begin by building the tripod stand (Figure B3). The legs of the tripod (1) can be opened by loosening the screw and pulling the leg out of the pin it is secured on. Then open the legs up, making sure the feet are all flat on the ground and secure them on the pin in the open position and tighten the screw.

Once the base is in the proper location, the neck portion of the tripod (2) can be screwed onto the threaded top of the legs. Next, the arm of the tripod (3) can be slipped over the top of the primary vertical pole and secured by tightening the bolts. The kit was missing a screw to connect the support beam (6) to the main pole of the stand, however the support beam can be used as a leg by placing it on the ground, to get the albedometer to the correct height according to the ASTM standard.

Next, the albedometer cord (4) is threaded through the arm of the tripod and secured onto the end of the pole using the included screwdriver, making sure that the words on the side of the albedometer are correctly oriented. The arm can then be extended out fully using the 3 segments, and the albedometer can be angled and tightened so that it is level, according to the level included on the albedometer. The end of the albedometer cord is connected to the yellow cord (5) included in the kit, which is then connected to the datalogger. Now the albedometer should be fully set up and you should be able to collect data.

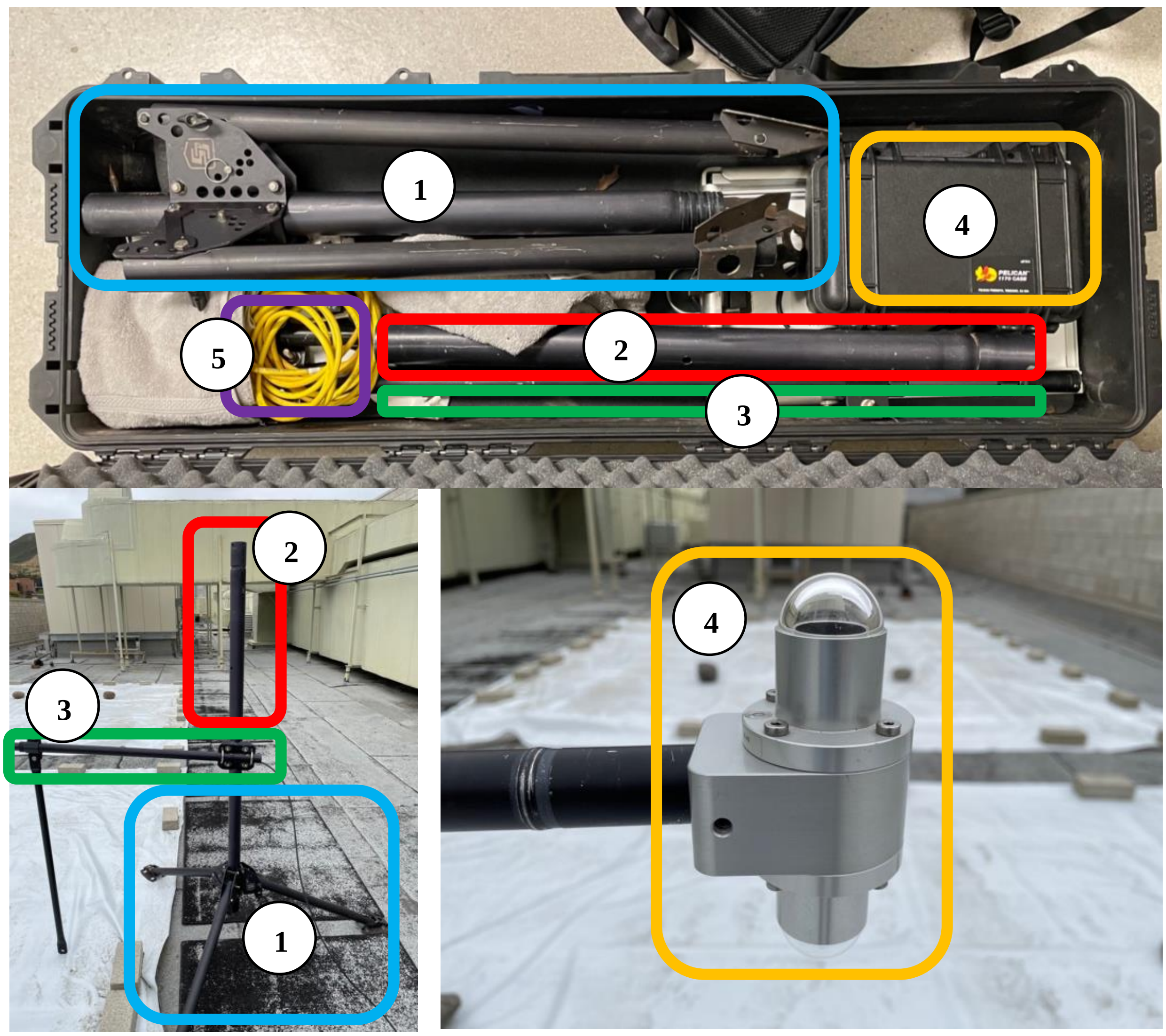


Figure B3 – Labeled images of albedometer and accompanying tripod with extended arm in storage box (top image) and when set up (bottom two images). Colored box and numbers indicate the same part of the equipment across the images.

Data Collection

To collect data, open the PC400 software once the albedometer is set up. Go to the monitor data tab, which may take a while to load but will eventually give readings of various data points including albedo, temperature, and global horizontal irradiance. These readings update every 20 seconds (the reading frequency can be changed in the settings); however, we found this to be a good data collection rate. We had difficulty finding a way to have the software collect the data and autosave it, so we did mainly manual data collection by inputting the albedo values into a separate Excel document.

Appendix C: Field Testing Safety Protocol

Materials Engineering Safety Protocol

General Information

Project Title: Effect of Ground Surface Albedo Treatments on Energy Harvesting by Bifacial PV Power Plants (Field Testing)

Academic Year: 2022-2023

Protocol Title: Field Testing of UV Effects on Albedo Materials

Student Contact(s):

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Project Sponsor:

Company	Last Name	First Name	Email	Office Phone
Clearway	Vance	James	James.vance@clearwayenergy.com	NA

Purpose of Protocol:

The purpose of this protocol is to outline the required safety procedures when setting up, maintaining, and collecting data from the field.

Risk Certification

Indicate below if any of the following hazards will NOT be present in your project. If any box is left unchecked, the assumption will be that these hazards ARE present in your protocol and further information will be required. If all boxes are checked, the faculty advisor's signature is also required on this portion of the form to confirm there are no hazards. In this case, no further information is required on this form.

Hazards include chemical hazards (solvents, acids, flammables, corrosives, oxidizers, dust, etc.), physical hazards (noise, heavy loads, falls, heat, electricity, etc.), radiological hazards (gamma rays, x-rays, UV radiation, etc.) and other hazards (flammable gasses, etc.).

Chemical Hazards: ☒

Physical Hazards: ☐

Radiological Hazards: ☐

Other Hazards: ☐

By checking any box above, I certify that this category or categories of hazards are NOT present in this protocol.

Student Name: Roxanne Jackson-Gain

Signature: **Date:** Click or tap to enter a date.

Student Name: Adam Jang

Signature: **Date:** Click or tap to enter a date.

Advisor Name: Dr. Jean Lee

Signature: **Date:** Click or tap to enter a date.

Chemical Risk Identification

Chemicals to be Used

No harmful chemicals will be used throughout the course of the testing procedure.

Potential Chemical Hazards

Not applicable.

Physical, Radiological and Other Risk Identification

Hazardous Equipment to be Used

No associated risks.

Click or tap here to enter text.

Potential Physical Hazards

- Heavy materials in the form of rock aggregates of varying sizes Click or tap here to enter text.

Potential Radiological Hazards

- Long exposure to sunlight depending on time needed to work in the field

Click or tap here to enter text.

Other Potential Hazards

No associated risks.

Click or tap here to enter text.

Risk Mitigation

Personal Protective Equipment (PPE)

Hand Protection: Gloves typically used for light/moderate outdoor construction activities (e.g., gloves made for leather, rubber, or latex dipped cloth) can be used for handling the rock aggregate materials.

Eye Protection:

Sunglasses or any other form of eye protection against UV is recommended.

Respiratory Protection:

The use of a facial mask (e.g., cloth or surgical) is recommended when handling the rock aggregate to protect against the inhalation of dust or small debris.

Ear Protection:

No ear protection required

Enter Ear Protection Details.

Skin and Body Protection:

Personnel must wear clothing that completely covers them from the chest to the toes, including full-length pants and closed-toe shoes. Please also tie back long hair and either remove or safely tuck away any dangling items such as necklaces, bracelets, hoodie strings, etc. The use of a brimmed hat that protects your eyes from sun and application of sunscreen on exposed skin are also recommended.

Hygiene Measures:

Wash hands with soap and water after working with any hazardous substances included in this protocol.

Engineering Controls

<u>ALL addition of chemicals to glassware or mixing of chemicals shall take place in a fume hood.</u> Open air curing of chemicals shall occur in a fume hood. Any curing at elevated temperatures should occur in a well-ventilated space.

Eye flush stations and/or a chemical shower shall be available where hazardous chemicals are being used. Access to a First Aid kit in labs where chemicals are being used is mandated.

All curing of chemicals under UV light will take place in a UV-opaque container with appropriate signage.

Storage of flammable or combustible liquids will take place in a well-ventilated, blast-proof storage container or refrigerator if necessary.

Liquid nitrogen must be transported in an approved drawer while wearing cryo-gloves and face shield. Never ride in an elevator with a filled liquid nitrogen drawer.

Safety systems on any piece of equipment, including systems added after manufacture, shall never be deactivated or manipulated in any way.

Handling and Storage Requirements

Consult the department technician to ensure that materials are correctly handled, and the department has adequate storage facilities for your materials.

First Aid Procedures

Based on available SDS documents indicate steps that students working in a lab should take should another student, or themselves, be injured. These procedures apply to all chemicals and equipment used unless otherwise stated.

If inhaled:

Remove to fresh air. If breathing is difficult, give oxygen. If not breathing, get medical attention immediately.

In case of skin contact:

Immediately flush skin with water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

In case of eye contact:

Immediately flush eyes with water for at least 15 minutes, lifting lower and upper eyelids occasionally. Remove contact lenses, if worn, while rinsing. Get medical attention immediately.

If swallowed:

DO NOT INDUCE VOMITING! Give large quantities of water or milk if available. Never give anything by mouth to an unconscious person. Get medical attention immediately.

In case of laceration:

Seek appropriate medical aid, notify lab technician, and administer first aid if laceration is not life-threatening. If life threatening, please call emergency services.

Spill and Accident Procedures

Chemical Spill or Medical Emergency - Dial 911

Spill: Assess the extent of danger. Help contaminated or injured persons. Evacuate the spill area. Avoid breathing vapors. If safe, confine the spill to a small area using a spill kit or absorbent material. Keep others from entering contaminated area (e.g. use caution tape, barriers, signs, etc.).

Small Spill (<1L): If you have training, you may assist in the clean-up effort. Use appropriate personal protective equipment and clean-up materials. Double bag spill waste in plastic bags, label and arrange for hazardous waste pick up.

Large Spill (>1L): Evacuate spill area. Dial 911 for assistance. Remain available in a safe, nearby location until emergency personnel arrive on scene.

Chemical Spill on Body or Clothes: Remove clothing and rinse body thoroughly in an emergency shower for at least 15 minutes. Seek medical attention. Notify supervisor, faculty advisor or project principal investigator (PI) immediately.

Chemical Splash into Eyes: Immediately rinse eyeball and inner surface of eyelid with water from the emergency eyewash station for a minimum of 15 minutes by forcibly holding eye open. Seek medical attention. Notify supervisor, faculty advisor or PI immediately.

Life Threatening Emergencies or After Hours/Weekends/Holidays: Dial 911. Note: All serious injuries must be reported to supervisor, faculty advisor or PI within 8 hours. Any and all loss of consciousness requires a 911 call.

Non-Life Threatening Emergencies: Seek medical attention. Emergency medical services in the community are available at any time at hospital emergency rooms and some emergency care facilities.

Paid students, staff or faculty should seek medical attention for all non-life threatening from MED STOP (283 Madonna Road, Suite B – M-F 8 am – 8 pm; Sa-Su 8 am – 4 pm) or Sierra Vista Hospital Emergency Room (1010 Murray Ave.; after hours)

ALL injuries must be reported to supervisor, faculty advisor or PI and campus authorities immediately. Follow procedures for reporting all injuries on the EH&S website (https://afd.calpoly.edu/risk-management/accidents-incident/nonvehicle-accident).

Waste Disposal Procedures

Label Waste: Affix a hazardous waste tag on all waste containers as soon as the first drop of waste is added to the container. Generic waste labels can be found at the EH&S website (http://afd.calpoly.edu/ehs/docs/hazwaste_label_template.pdf).

Store Waste: Store hazardous waste in closed containers, in secondary containment and in a designated location. Always keep solvent wastes and acidic wastes separated. Double-bag dry wastes. Waste should be under the control of the person generating and disposing of it.

Dispose of Waste: For general waste, use the waste storage containers provided by the department. For specialized waste, consult the department technician or project sponsor for proper disposal.

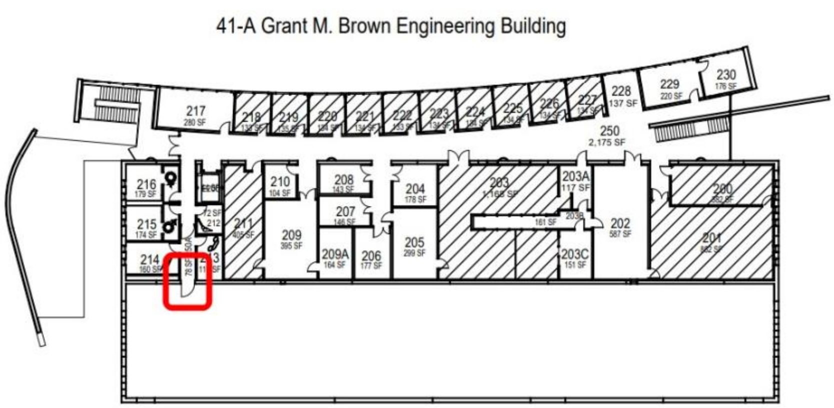
Empty Containers: Dispose as hazardous waste if container once held extremely hazardous waste (irrespective of container size). A list of these chemicals can be found on the EH&S website (https://afd.calpoly.edu/ehs/docs/extremely_hazardous_wastes.pdf). All other containers are legally empty once a concerted effort is made to remove, pour out, scrape out, or otherwise completely empty the vessel. These containers may be disposed of as recycling or common trash as appropriate.

Safety Data Sheet (SDS) Locations

Not applicable as no harmful chemicals are used throughout the procedure.

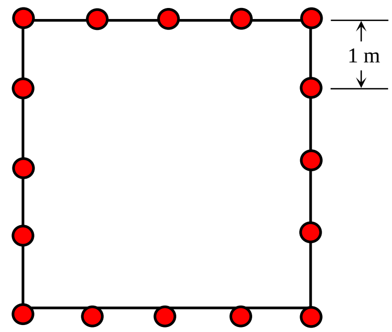
Experimental Procedure <u>**(please read BEFORE heading into field)**</u>

1. Persons performing the procedure described below should don the following PPE before beginning the procedure:
    a. Wear clothing that completely covers from the chest to the toes, including long pants and closed-toe shoes
    b. UV safety glasses
    c. Gloves typically used for light/moderate outdoor construction activities (e.g., gloves made of leather, rubber, or latex dipped cloth) if handling rock aggregate materials
    d. Full brimmed hat or "baseball" style hat for sunlight protection and to keep excess sunlight from eyes
    e. Apply sunscreen to exposed skin (sunscreen applied must have a minimum SPF of 15)
2. Please also tie back long hair and either remove or safely tuck away any dangling items such as necklaces, bracelets, hoodie strings, etc.
3. Gather the following materials:
    a. Testing materials (aggregate, plastic sheet(s), etc.)
    b. Bricks that weigh less than 3 kg each
        i. If the bricks have a reflective surface they must be modified (at the discretion of the operator) to have a matte surface
    c. Thermometer with a minimum temperature range of 5-40˚C
        i. Thermometer must have the ability to measure air temperature and should be verified for correct calibration before heading to the field site
    d. Albedometer
        i. Make sure albedometer is functional, charged, and calibrated according to manufacturer's specifications or accompanying operation manual
    e. Meteorological (MET) Station
        i. Check that all components of the MET Station are accounted for according to the parts checklist and verify that they are free of any potential physical damage before traveling to the field site
    f. Microphone stand with a reach of over 2 m; should have a non-reflective surface
        i. If the microphone stand has a reflective surface it must be modified (at the discretion of the operator) to have a matte surface
    g. Counterweight (can be iron disks/bricks whose weight adequately counterbalances the weight of the albedometer and microphone arm)
    h. Rope (e.g., nylon, polypropylene, manila, etc.)
        i. Rope must be rated to withstand a minimum load of 25 kg
        ii. Rope must be a minimum of 10 m in length
    i. A tool capable of safely cutting the rope selected in Step 2h
    j. Measuring tape that is capable of measuring length in metric units
    k. Device with internet access

        i. Ensure this device's battery is fully charged, operational, and can connect to the internet while in the field
        ii. Load the following internet links seen below to the internet connected device or scan the QR Codes below:
            1. https://www.latlong.net/convert-address-to-lat-long.html
            2.
            3. https://midcdmz.nrel.gov/solpos/solpos.html
            4.
    l. Clock (ensure the clock is correctly calibrated to the time zone of the field site and considers daylight savings time if applicable during the time of testing)
    m. Hygrometer (verify that it is operational and charged/equipped with batteries if a digital hygrometer is used)
    n. ASTM E1918-21 standard
    o. Operation manuals for the albedometer and MET Station
    p. A means of recording data (e.g., lab notebook and pen, laptop, etc.)
4. Contact the chair of the MATE Department to request permission to use the roof of building 41A located on the Cal Poly SLO campus.
    a. One you receive permission; you may be asked to sign-out and sign-in the key to the building 41A roof by the MATE administrative assistant each time you require access to the roof.
    b. The roof can be accessed via the second floor of building 41A as seen in Figure 1 below.
    c. 

        i. Figure 1 – Location of roof access point in building 41A.

5. Place a layer of testing material in the shape of a square with a footprint of 16 m^2 (4 m x 4 m) on the building 41A roof.
    a. If the material tested is a rock aggregate, the layer must have a minimum depth of 5 cm.
        i. [Future insert for information on testing site that will be used for rock aggregate]
    b. If the material is a plastic sheeting, the material depth should equal the thickness of the plastic sheeting.
        i. Using the bricks from Steps 2b, secure the plastic sheeting to the roof by first placing a brick on each corner of the 4 m x 4 m area. Place additional bricks around the perimeter of the plastic sheeting with adjacent bricks being equidistant from one another with a maximum of 1 m of separation. The brick configuration should follow the layout seen in Figure 2 below:



6. Figure 2 – Brick configuration for securing plastic sheeting to the roof.
7. Using the link from Step 2.k.ii.1, input the location of the field site and record the GPS coordinates in latitude (degrees north is positive) and longitude (degrees east is positive) format.
8. Open the link from Step 2.k.ii.2 and input the GPS data from Step 5, date of testing, set output time interval to 10, set units to minutes, time zone (east is positive), surface/barometric pressure of the site, and the ambient dry-bulb temperature (air temperature) into "Enter site location information".
    a. Leave the values under "Optional input values" alone, check off "Solar elevation angle" under "Check desired output values", and do not check any values under "Check additional desired output values".
    b. Click submit at the bottom of the page and you will be brought to a page which shows the "Solar elevation angle" for the given date in time intervals of 10 minutes.
    c. Examine the list of times and "Solar elevation angle" from this page and identify the time(s) where "Solar elevation angle" is equal to 10˚, 20˚, 30˚, and 40˚, respectively, within an accuracy of ±0.99˚.
        i. The time at which these solar elevation angles occur will vary from day-to-day so Steps 6a—c will need to be repeated every day the field site or building 41A roof is visited for data collection.

ii. In addition, the times in which these elevation angles are obtained will occur twice a day: Once before noon (between the hours of 8:00 AM – 12:00 PM) and again in the afternoon (between the hours of 12:00 PM – 5:00 PM).

iii. At the discretion of the operators, data points that align with the 10˚, 20˚, 30˚, and 40˚ solar elevation angles can be collected during the morning period or in the afternoon period.

1. However, for any given day of data collection the series of four data points (10˚, 20˚, 30˚, and 40˚) cannot be intermixed between the two timeframes mentioned in Step 6.c.iii (ex., do not collect a 10˚ data point in the morning and then collect 20˚, 30˚, and 40˚ in the afternoon).

iv. This process should be conducted before going to the field site or building 41A roof to ensure that the selected day is viable for data recording.

v. All data recording can only take place within the time frame derived from Step 6c.

9. Take a photo of the entire test setup (with the testing material, bricks, albedometer, microphone stand, etc. all in view)
10. Take an overhead photo of the material.
    a. The photo can be of any 2 m x 2 m section of the test material and should NOT include the shadow of the camera, camera operator, or any other external factors such as the albedometer, microphone stand, roof, etc.
    b. The photo must also be taken at an angle normal to the material surface. The height at which this photo is taken must be recorded.
    c. Record the day and time when the photo is taken.
    d. For all subsequent photos taken throughout testing, the height of the camera, section of material photographed, physical camera used, and camera settings must be as similar as possible.
11. Set up the counterweight, microphone stand, and albedometer in accordance with the procedure outlined in ASTM E1918-21 and the accompanying albedometer/MET Station operation manuals
    a. The counterweight(s) can either be hung on the microphone stand if its shape allows or an appropriate length of rope can be tied between the counterweight(s) and microphone stand arm to hang the counterweights.
    b. The arm-mounted albedometer should be positioned in a manner where it is directly above the center of the 4 m x 4 m material layer at height of 0.5 m.
    c. The horizontal distance from the albedometer to the nearest edge of the test surface must be at least 2 m.
    d. The physical stand of the mount should not be in contact with the testing material.
12. Record the atmospheric conditions of temperature, humidity, time of day, albedo, UV index, and cloud coverage using the thermometer, MET Station, clock, albedometer, and device with internet access, respectively.

    a. All testing/data collection must take place between the time stamps derived from Steps 6a-c (assuming the weather conditions are not raining or extremely overcast).
    b. A minimum of 4 data points should be taken at the time stamps derived from Steps 6a-c which correlate to solar elevation angles of 10˚, 20˚, 30˚, and 40˚.
    c. DO NOT at any point look directly into the sun when observing/recording the cloud coverage conditions of the test site.
13. Repeat Step 10 a minimum of three times a week (if weather conditions allow) at the times of day derived from Steps 6a-c, being sure to record all the necessary atmospheric conditions as mentioned in Step 10. Also take a photo of the testing material with every data collection point as specified in Steps 8a-d.
14. When data recording is completed, remove any trash or artificial debris that may have been deposited on top of the test material. Also straighten any edges of the test material that may have shifted to maintain the 4 m x 4 m area. Leave the bricks on the testing material. DO NOT attempt to wash the testing material with water or otherwise clean the testing material.
15. Collect PPE and devices used for measurements and data recording. Take extra precautions when packing the albedometer and MET Station.
16. Safely leave the field testing and wash your hands.
    a. If leaving the building 41A roof, ensure that both doors leading to the roof are locked when you exit.
17. Return the PPE and testing/measurement tools to their proper storage location.
18. Return the key used to access the building 41A roof to the MATE administrative assistant and sign the check-in sheet for the key.

NOTES

1. This safety protocol is only valid *after* it is signed by all students working on a project and the project advisor/PI.
2. By signing this protocol, the students acknowledge that they will follow this protocol verbatim. Failure to follow any element of the protocol will transfer liability for spills or injuries to the students.
3. The faculty advisors signature acknowledges that this protocol is reasonably safe and that, if followed, no harm will come to the students. Should students be injured while following this protocol, liability shall reside with the faculty advisor and/or University per CSU policy.
4. Any deviation from this safety protocol requires approval from the supervisor, faculty advisor or PI.

Authorization

Student Signatures

Last Name	First Name	Signature	Date
Jackson-Gain	Roxanne		Select Date.
Jang	Adam		Select Date.

Faculty Advisor Signature

By signing here, I acknowledge that this protocol has been reviewed and approved by a Cal Poly faculty member responsible for the conduct of the procedures described in this protocol.

Last Name	First Name	Signature	Date
Lee	Jean		Select Date.

Appendix D: Accelerated Weathering Testing Safety Protocol

Materials Engineering Safety Protocol

General Information

Project Title: Effect of Ground Surface Albedo Treatments on Energy Harvesting by Bifacial PV Power Plants (Laboratory Testing)

Academic Year: 2022-2023

Protocol Title: Laboratory Testing of UV Effects on Albedo Materials

Student Contact(s):

Last Name	First Name	Department	Email	Cell Phone
Jackson-Gain	Roxanne	MATE	jacksong@calpoly.edu	(805)698-6771
Jang	Adam	MATE	wajang@calpoly.edu	(626)552-5869

Advisor Contact(s):

Last Name	First Name	Department	Email	Office Phone
Lee	Jean	MATE	jlee473@calpoly.edu	(805)756-6571

Project Sponsor:

Company	Last Name	First Name	Email	Office Phone
Clearway	Vance	James	James.vance@clearwayenergy.com	NA

Purpose of Protocol:

The purpose of this protocol is to outline the required safety procedures when setting up, maintaining, and collecting data from the laboratory.

Risk Certification

<u>Indicate below if any of the following hazards will NOT be present in your project.</u> If any box is left unchecked, the assumption will be that these hazards ARE present in your protocol and further information will be required. If all boxes are checked, the faculty advisor's signature is also required on this portion of the form to confirm there are no hazards. In this case, no further information is required on this form.

Hazards include chemical hazards (solvents, acids, flammables, corrosives, oxidizers, dust, etc.), physical hazards (noise, heavy loads, falls, heat, electricity, etc.), radiological hazards (gamma rays, x-rays, UV radiation, etc.) and other hazards (flammable gasses, etc.).

Chemical Hazards: ☒

Physical Hazards: ☐

Radiological Hazards: ☐

Other Hazards: ☐

By checking any box above, I certify that this category or categories of hazards are NOT present in this protocol.

Student Name: Roxanne Jackson-Gain

Signature: **Date:** Click or tap to enter a date.

Student Name: Adam Jang

Signature: **Date:** Click or tap to enter a date.

Advisor Name: Dr. Jean Lee

Signature: **Date:** Click or tap to enter a date.

Chemical Risk Identification

Chemicals to be Used

No harmful chemicals will be used throughout the course of the testing procedure.

Potential Chemical Hazards

Not applicable.

Physical, Radiological and Other Risk Identification

Hazardous Equipment to be Used

No associated risks.

Click or tap here to enter text.

Potential Physical Hazards

- Heavy materials in the form of rock aggregates of varying sizes Click or tap here to enter text.

Potential Radiological Hazards

- Exposure to UV light

Click or tap here to enter text.

Other Potential Hazards

No associated risks.

Click or tap here to enter text.

Risk Mitigation

Personal Protective Equipment (PPE)

Hand Protection: Gloves typically used for light/moderate outdoor construction activities (e.g., gloves made for leather, rubber, or latex dipped cloth) can be used for handling the rock aggregate materials.

Eye Protection:

Sunglasses or any other form of eye protection against UV is recommended.

Ear Protection:

No ear protection required

Enter Ear Protection Details.

Respiratory Protection:

The use of a facial mask (e.g., cloth or surgical) is recommended when handling the rock aggregate to protect against the inhalation of dust or small debris.

Skin and Body Protection:

Personnel must wear clothing that completely covers them from the chest to the toes, including full-length pants and closed-toe shoes. Please also tie back long hair and either remove or safely tuck away any dangling items such as necklaces, bracelets, hoodie strings, etc. The use of a brimmed hat that protects your eyes from sun and application of sunscreen on exposed skin are also recommended.

Hygiene Measures:

Wash hands with soap and water after working with any hazardous substances included in this protocol and when leaving the lab.

Engineering Controls

ALL addition of chemicals to glassware or mixing of chemicals shall take place in a fume hood. Open air curing of chemicals shall occur in a fume hood. Any curing at elevated temperatures should occur in a well-ventilated space.

Eye flush stations and/or a chemical shower shall be available where hazardous chemicals are being used. Access to a First Aid kit and safety Red Binder in labs where chemicals are being used is mandated.

All curing of chemicals under UV light will take place in a UV-opaque container with appropriate signage.

Storage of flammable or combustible liquids will take place in a well-ventilated, blast-proof storage container or refrigerator if necessary.

Liquid nitrogen must be transported in an approved drawer while wearing cryo-gloves and face shield. Never ride in an elevator with a filled liquid nitrogen drawer.

Safety systems on any piece of equipment, including systems added after manufacture, shall never be deactivated or manipulated in any way.

Handling and Storage Requirements

Consult the department technician to ensure that materials are correctly handled and the department has adequate storage facilities for your materials.

First Aid Procedures

Based on available SDS documents indicate steps that students working in a lab should take should another student, or themselves, be injured. These procedures apply to all chemicals and equipment used unless otherwise stated.

If inhaled:

Remove to fresh air. If breathing is difficult, give oxygen. If not breathing, get medical attention immediately.

In case of skin contact:

Immediately flush skin with water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

In case of eye contact:

Immediately flush eyes with water for at least 15 minutes, lifting lower and upper eyelids occasionally. Remove contact lenses, if worn, while rinsing. Get medical attention immediately.

If swallowed:

DO NOT INDUCE VOMITING! Give large quantities of water or milk if available. Never give anything by mouth to an unconscious person. Get medical attention immediately.

In case of laceration:

Seek appropriate medical aid, notify lab technician, and administer first aid if laceration is not life-threatening. If life threatening please call emergency services.

Spill and Accident Procedures

Chemical Spill or Medical Emergency - Dial 911 and 756-6661

Spill: Assess the extent of danger. Help contaminated or injured persons. Evacuate the spill area. Avoid breathing vapors. If safe, confine the spill to a small area using a spill kit or absorbent material. Keep others from entering contaminated area (e.g. use caution tape, barriers, signs, etc.).

Small Spill (<1L): If you have training, you may assist in the clean-up effort. Use appropriate personal protective equipment and clean-up materials. A spill kit should be available in any lab where chemicals are used. Double bag spill waste in plastic bags, label and arrange for hazardous waste pick up by contacting the department technician.

Large Spill (>1L): Evacuate spill area. Dial 911 and EH&S at 756-6661 for assistance. Remain available in a safe, nearby location until emergency personnel arrive on scene.

Chemical Spill on Body or Clothes: Remove clothing and rinse body thoroughly in an emergency shower for at least 15 minutes. Seek medical attention. Notify supervisor, faculty advisor or project principal investigator (PI) immediately.

Chemical Splash into Eyes: Immediately rinse eyeball and inner surface of eyelid with water from the emergency eyewash station for a minimum of 15 minutes by forcibly holding eye open. Seek medical attention. Notify supervisor, faculty advisor or PI immediately.

Life Threatening Emergencies or After Hours/Weekends/Holidays: Dial 911. Note: All serious injuries must be reported to supervisor, faculty advisor or PI within 8 hours. Any and all loss of consciousness requires a 911 call.

Non-Life Threatening Emergencies: Seek medical attention at the campus Health Center. Emergency medical services in the community are available at any time at hospital emergency rooms and some emergency care facilities.

Paid students, staff or faculty should seek medical attention for all non-life threatening from MED STOP (283 Madonna Road, Suite B – M-F 8 am – 8 pm; Sa-Su 8 am – 4 pm) or Sierra Vista Hospital Emergency Room (1010 Murray Ave.; after hours)

ALL injuries must be reported to supervisor, faculty advisor or PI and campus authorities immediately. Follow procedures for reporting all injuries on the EH&S website (https://afd.calpoly.edu/risk-management/accidents-incident/nonvehicle-accident).

Waste Disposal Procedures

Label Waste: Affix a hazardous waste tag on all waste containers as soon as the first drop of waste is added to the container. Generic waste labels can be found at the EH&S website (http://afd.calpoly.edu/ehs/docs/hazwaste_label_template.pdf).

Store Waste: Store hazardous waste in closed containers, in secondary containment and in a designated location. Always keep solvent wastes and acidic wastes separated. Double-bag dry wastes. Waste be under the control of the person generating and disposing of it.

Dispose of Waste: For general waste, use the waste storage containers provided by the department. For specialized waste, consult the department technician for proper disposal by EH&S.

Empty Containers: Dispose as hazardous waste if container once held extremely hazardous waste (irrespective of container size). A list of these chemicals can be found on the EH&S website (https://afd.calpoly.edu/ehs/docs/extremely_hazardous_wastes.pdf). All other containers are legally empty once a concerted effort is made to remove, pour out, scrape out, or otherwise completely empty the vessel. These containers may be disposed of as recycling or common trash as appropriate.

Safety Data Sheet (SDS) Locations

Not applicable as no harmful chemicals are used throughout the procedure.

Experimental Procedure

1. Persons performing the procedure described below should don the following PPE before beginning the procedure:
    a. Wear clothing that completely covers them from the chest to the toes, including long pants and closed-toe shoes
    b. UV safety glasses
    c. Latex or nitrile gloves depending on allergen restraints
2. Gather the following materials:
    a. Test materials (e.g., plastic sheeting)
    b. Ruler or other measuring instrument that can measure millimeters or centimeters
    c. Non-permanent writing instrument (dry erase marker, pencil, etc.)
    d. Cutting tool that can cut the selected test materials
    e. ASTM G154-16 standard
    f. ASTM D5208-14 standard
    g. QUV Accelerated Weathering Tester Operating Manual (AWT-OM)
    h. CR-10 Calibration Radiometer
    i. Scale with minimum accuracy up to 0.001 g
    j. Camera
    k. A means of recording data (e.g., lab notebook and pen, laptop, etc.)
3. Gain access to the Accelerated Weathering Tester (AWT) located in building 41A – Room 205 on the Cal Poly SLO campus.
4. Review the safety warnings in the AWT-OM (located on pages 4-6) and always handle the
5. Check whether the AWT is connected to the main water line or has water already in its center basin.
    a. If the AWT is not connected to the main water line, follow Section 3.6 in the AWT-OM for instructions on how to connect it to the main water line.
    b. If the AWT has water already in the basin and is connected to the main water line, then check the cleanliness of the water. If a layer of precipitates or solids has formed on the bottom of the basin with a thickness of approximately 3 mm or greater follow section 12.4.2 in the AWT-OM for instructions on how to clean it.
6. Follow Sections 12.2-12.2.2 in the AWT-OM to calibrate the Solar Eye sensors of the AWT.
    a. This will require using the CR-10 Calibration Radiometer which is also located in building 41A – Room 205.
7. The AWT can accommodate a total of 96 individual samples each having a maximum area of 75 mm x 150 mm. Divide 96 by the total number of <u>different</u> sample types being tested (for example if testing 3 different types of samples divide 96 by 3). This calculation will give you the number of test samples you will need to produce for each different type of material.
    a. To adhere to the tensile testing requirements (ASTM D3826) that will be used to tensile test these samples, each sample must have an area of 25 mm x 102 mm. Using a measuring instrument and non-permanent writing implement, measure and trace the calculated number of (25 mm x 102 mm) samples for each sample type.

   b. Only one (1) 25 mm x 102 mm sample should be placed in each available sample holder in the AWT.
8. Carefully cut these test samples out using a cutting instrument.
9. After cutting out all test samples weigh each sample using a scale and record their initial weights along with the date.
10. After weighing each sample take photos of them prior to installing them in the AWT.
    a. The photos should clearly image the test samples and should be centered directly above the center of the sample's footprint while minimizing the view of any surrounding or nearby items (e.g., floor, tabletop, etc.).
    b. The photo should be taken at an angle normal to the test sample's surface.
    c. The camera position and height at which the requirements outlined in Steps 10a-b are met should be recorded and used for all subsequent photos taken of the testing materials.
    d. No external shadows (camera, camera operator, lab equipment, etc.) should be visible in the photos.
    e. The same camera, camera settings, and lighting settings must be used for all photos taken throughout the course of the testing.
11. Following Section 11.0 in the AWT-OM, install the test samples onto the aluminum sample holders of the AWT.
12. Following the QUV Program Mode Schematic on page 21 of the AWT-OM and Section 7.6, program a cycle run for the AWT to operate as follows:
    a. For 20 hours a day the AWT will run at 50˚C with the UV bulb on and an irradiance set point of 0.83 with a humidity of 60%.
        i. For information on how to input these settings on the control panel, please refer to Sections 7.1-7.4 in the AWT-OM.
    b. After the 20-hour period, the AWT should be set to lower the temperature to 40˚C for 4 hours with the UV bulb off (irradiance set point will not matter/will be zero) and a humidity level of 30%.
        i. For information on how to input these settings on the control panel, please refer to Sections 7.1-7.4 in the AWT-OM.
13. Once the cycle run according to Step 12a-b has been programmed, follow the "Selecting a Step to Run" section in Section 7.6 of the AWT-OM for instructions on how to start your testing.
14. Check to see that the AWT is operating normally/as expected and return daily during the times when the cycle transitions into and out of the 4-hour period when the temperature is set to 40˚C with the UV bulb off.
    a. While wearing UV safety glasses, look at the top of the AWT (through the door slats) during these times to make sure that the UV bulb is off as expected.
    b. Also check the analog gauges to ensure that irradiance, temperature, and humidity are all at the appropriate levels according to Step 12a-b.
15. Maintain these cycling testing conditions for a minimum of 4 weeks, checking daily if possible (with the exclusion of holidays or other times when the laboratory is not accessible).

   a. If an error message should appear while testing, please refer to AWT-OM Section 13.5 for possible solutions.
   b. If the issue persists, please notify the MATE Laboratory Technician for further assistance.
16. After the 4-week testing period, remove each test sample from the AWT using clean gloves. Immediately take photos of each test sample according to the instructions in steps 10a-e. Then weigh each sample using a scale, and record their weights along with the date.
17. After checking the status of the AWT and samples return all safety equipment to their appropriate storage areas, turn off the laboratory lights, and make sure to lock 41A- 205 when leaving.

NOTES

1. This safety protocol is only valid *after* it is signed by all students working on a project and the project advisor/PI.
2. By signing this protocol, the students acknowledge that they will follow this protocol verbatim. Failure to follow any element of the protocol will transfer liability for spills or injuries to the students.
3. The faculty advisors signature acknowledges that this protocol is reasonably safe and that, if followed, no harm will come to the students. Should students be injured while following this protocol, liability shall reside with the faculty advisor and/or University per CSU policy.
4. Any deviation from this safety protocol requires approval from the supervisor, faculty advisor or PI.

Authorization

Student Signatures

Last Name	First Name	Signature	Date
Jackson-Gain	Roxanne		Select Date.
Jang	Adam		

Faculty Advisor Signature

By signing here, I acknowledge that this protocol has been reviewed and approved by a Cal Poly faculty member responsible for the conduct of the procedures described in this protocol.

Last Name	First Name	Signature	Date
Lee	Jean		Select Date.

Appendix E: Tensile Testing Safety Protocol

Materials Engineering Safety Protocol

General Information

Project Title: Effect of Ground Surface Albedo Treatments on Energy Harvesting by Bifacial PV Power Plants (Tensile Testing)

Academic Year: 2022-2023

Protocol Title: Tensile Testing of UV Effects on Albedo Materials

Student Contact(s):

Last Name	First Name	Department	Email	Cell Phone
Jackson-Gain	Roxanne	MATE	jacksong@calpoly.edu	(805)698-6771
Jang	Adam	MATE	wajang@calpoly.edu	(626)552-5869

Advisor Contact(s):

Last Name	First Name	Department	Email	Office Phone
Lee	Jean	MATE	jlee473@calpoly.edu	(805)756-6571

Project Sponsor:

Company	Last Name	First Name	Email	Office Phone
Clearway	Vance	James	James.vance@clearwayenergy.com	NA

Purpose of Protocol:

The purpose of this protocol is to outline the required safety procedures when setting up and collecting data from the tensile testing using the Intron Tensile Tester.

Risk Certification

Indicate below if any of the following hazards will NOT be present in your project. If any box is left unchecked, the assumption will be that these hazards ARE present in your protocol and further information will be required. If all boxes are checked, the faculty advisor's signature is also required on this portion of the form to confirm there are no hazards. In this case, no further information is required on this form.

Hazards include chemical hazards (solvents, acids, flammables, corrosives, oxidizers, dust, etc.), physical hazards (noise, heavy loads, falls, heat, electricity, etc.), radiological hazards (gamma rays, x-rays, UV radiation, etc.) and other hazards (flammable gasses, etc.).

Chemical Hazards: ☒

Physical Hazards: ☐

Radiological Hazards: ☒

Other Hazards: ☒

By checking any box above, I certify that this category or categories of hazards are NOT present in this protocol.

Student Name: Roxanne Jackson-Gain

Signature: **Date:** Click or tap to enter a date.

Student Name: Adam Jang

Signature: **Date:** Click or tap to enter a date.

Advisor Name: Dr. Jean Lee

Signature: **Date:** Click or tap to enter a date.

Chemical Risk Identification

Chemicals to be Used

No harmful chemicals will be used throughout the course of the testing procedure.

Potential Chemical Hazards

Not applicable.

Physical, Radiological and Other Risk Identification

Hazardous Equipment to be Used

Instron Tensile Tester

Click or tap here to enter text.

Potential Physical Hazards

- Possible pinch hazard from machinery Click or tap here to enter text.

Potential Radiological Hazards

No associated risks.

Click or tap here to enter text.

Other Potential Hazards

No associated risks.

Click or tap here to enter text.

Risk Mitigation

Personal Protective Equipment (PPE)

Hand Protection:

No hand protection required.

Eye Protection:

Safety glasses are required at all times when in the laboratory environment.

Ear Protection:

No ear protection required

Enter Ear Protection Details.

Skin and Body Protection:

Personnel must wear clothing that completely covers them from the chest to the toes, including full-length pants and closed-toe shoes. Please also tie back long hair and either remove or safely tuck away any dangling items such as necklaces, bracelets, hoodie strings, etc. The use of a brimmed hat that protects your eyes from sun and application of sunscreen on exposed skin are also recommended.

Hygiene Measures:

Wash hands with soap and water after working with any hazardous substances included in this protocol and when leaving the lab.

Engineering Controls

<u>ALL addition of chemicals to glassware or mixing of chemicals shall take place in a fume hood.</u> Open air curing of chemicals shall occur in a fume hood. Any curing at elevated temperatures should occur in a well-ventilated space.

Eye flush stations and/or a chemical shower shall be available where hazardous chemicals are being used. Access to a First Aid kit and safety Red Binder in labs where chemicals are being used is mandated.

All curing of chemicals under UV light will take place in a UV-opaque container with appropriate signage.

Storage of flammable or combustible liquids will take place in a well-ventilated, blast-proof storage container or refrigerator if necessary.

Liquid nitrogen must be transported in an approved drawer while wearing cryo-gloves and face shield. Never ride in an elevator with a filled liquid nitrogen drawer.

Safety systems on any piece of equipment, including systems added after manufacture, shall never be deactivated or manipulated in any way.

Handling and Storage Requirements

Consult the department technician to ensure that materials are correctly handled and the department has adequate storage facilities for your materials.

First Aid Procedures

Based on available SDS documents indicate steps that students working in a lab should take should another student, or themselves, be injured. These procedures apply to all chemicals and equipment used unless otherwise stated.

If inhaled:

Remove to fresh air. If breathing is difficult, give oxygen. If not breathing, get medical attention immediately.

In case of skin contact:

Immediately flush skin with water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

In case of eye contact:

Immediately flush eyes with water for at least 15 minutes, lifting lower and upper eyelids occasionally. Remove contact lenses, if worn, while rinsing. Get medical attention immediately.

If swallowed:

DO NOT INDUCE VOMITING! Give large quantities of water or milk if available. Never give anything by mouth to an unconscious person. Get medical attention immediately.

In case of laceration:

Seek appropriate medical aid, notify lab technician, and administer first aid if laceration is not life-threatening. If life threatening please call emergency services.

Spill and Accident Procedures

Chemical Spill or Medical Emergency - Dial 911 and 756-6661

Spill: Assess the extent of danger. Help contaminated or injured persons. Evacuate the spill area. Avoid breathing vapors. If safe, confine the spill to a small area using a spill kit or absorbent material. Keep others from entering contaminated area (e.g. use caution tape, barriers, signs, etc.).

Small Spill (<1L): If you have training, you may assist in the clean-up effort. Use appropriate personal protective equipment and clean-up materials. A spill kit should be available in any lab where chemicals are used. Double bag spill waste in plastic bags, label and arrange for hazardous waste pick up by contacting the department technician.

Large Spill (>1L): Evacuate spill area. Dial 911 and EH&S at 756-6661 for assistance. Remain available in a safe, nearby location until emergency personnel arrive on scene.

Chemical Spill on Body or Clothes: Remove clothing and rinse body thoroughly in an emergency shower for at least 15 minutes. Seek medical attention. Notify supervisor, faculty advisor or project principal investigator (PI) immediately.

Chemical Splash into Eyes: Immediately rinse eyeball and inner surface of eyelid with water from the emergency eyewash station for a minimum of 15 minutes by forcibly holding eye open. Seek medical attention. Notify supervisor, faculty advisor or PI immediately.

Life Threatening Emergencies or After Hours/Weekends/Holidays: Dial 911. Note: All serious injuries must be reported to supervisor, faculty advisor or PI within 8 hours. Any and all loss of consciousness requires a 911 call.

Non-Life Threatening Emergencies: Seek medical attention at the campus Health Center. Emergency medical services in the community are available at any time at hospital emergency rooms and some emergency care facilities.

Paid students, staff or faculty should seek medical attention for all non-life threatening from MED STOP (283 Madonna Road, Suite B – M-F 8 am – 8 pm; Sa-Su 8 am – 4 pm) or Sierra Vista Hospital Emergency Room (1010 Murray Ave.; after hours)

ALL injuries must be reported to supervisor, faculty advisor or PI and campus authorities immediately. Follow procedures for reporting all injuries on the EH&S website (https://afd.calpoly.edu/risk-management/accidents-incident/nonvehicle-accident).

Waste Disposal Procedures

Label Waste: Affix a hazardous waste tag on all waste containers as soon as the first drop of waste is added to the container. Generic waste labels can be found at the EH&S website (http://afd.calpoly.edu/ehs/docs/hazwaste_label_template.pdf).

Store Waste: Store hazardous waste in closed containers, in secondary containment and in a designated location. Always keep solvent wastes and acidic wastes separated. Double-bag dry wastes. Waste be under the control of the person generating and disposing of it.

Dispose of Waste: For general waste, use the waste storage containers provided by the department. For specialized waste, consult the department technician for proper disposal by EH&S.

Empty Containers: Dispose as hazardous waste if container once held extremely hazardous waste (irrespective of container size). A list of these chemicals can be found on the EH&S website (https://afd.calpoly.edu/ehs/docs/extremely_hazardous_wastes.pdf). All other containers are legally empty once a concerted effort is made to remove, pour out, scrape out, or otherwise completely empty the vessel. These containers may be disposed of as recycling or common trash as appropriate.

Safety Data Sheet (SDS) Locations

Not applicable as no harmful chemicals are used throughout the procedure.

Experimental Procedure

1. Persons performing the procedure described below should don the following PPE before beginning the procedure:
    a. Wear clothing that completely covers them from the chest to the toes, including long pants and closed-toe shoes
    b. Safety glasses
2. Gather the following materials:
    a. Material to be tested under tensile load (e.g., plastic sheeting)
    b. Extensometer
    c. Tool for measuring length (e.g., ruler, caliper, etc.)
    d. Safety shield for Instron Tensile Tester
    e. Access information for PC connected to Instron Tensile Tester
    f. A means of recording data (e.g., lab notebook and pen, laptop, etc.)
    g. A USB drive
    h. ASTM D3826 standard
3. Measure the length, width, and thickness of your testing material using a measuring tool.
    a. The areas of the samples undergoing tensile testing should be modified/cut to 25 mm x 102 mm in accordance with ASTM D3826.
    b. A minimum of four samples of each type of plastic sheeting exposed to UV radiation (simulated or natural) should be tested along with a control sample of the plastic sheeting which has not been exposed to UV.
    c. If a UV-exposed sample fails prematurely due to an external flaw, disregard it and prepare another sample until four representative samples have been tested along with the control sample.
4. Record your measurements from Step 3.
5. Turn on the Intron Tensile Tester and the adjacent PC that controls/collects data from the Instron Tensile Tester.
6. Open the PC application that controls and records the tensile testing data for the Instron Tensile Tester.
7. Open the upper and lower clamps to a degree that allows for the testing material to be placed between the two clamps.
8. "Jog" the two clamps of the machine to be at an appropriate distance to place the material in between them.
    a. This function can be done via the accompanying Instron software on the PC or on the physical machine itself.
9. Hand tighten the two clamps so that the material sample is securely affixed between them.
10. Carefully affix the extensometer onto the testing material making sure that it is parallel to the vertical axis of the material.
11. Manually zero the starting strain position of the tensile test using the Instron software.
12. Input all necessary measurements of the testing material sample into the Instron software which were previously recorded from Step 3.
13. Set the strain rate to 0.1 mm/mm minute.

14. Place the safety shield in front of the Instron Tensile Tester.
15. Press the “Start” button in the Instron software to begin the tensile test.
16. Wait for the material to reach failure/fracture and stop the test using the Intron software.
17. Save the digital data using a USB storage device.
18. Repeat Steps 7-17 as needed.
19. Carefully remove the safety shield, extensometer, and fractured test material from the Instron Tensile Tester.
20. Once data has been recorded, return all safety equipment and lab equipment associated with the Instron Tensile Tester to their proper locations. Properly dispose fractured test material. Wash your hands, and make sure to turn off both the tensile tester and the PC.

NOTES

1. This safety protocol is only valid *after* it is signed by all students working on a project and the project advisor/PI.
2. By signing this protocol, the students acknowledge that they will follow this protocol verbatim. Failure to follow any element of the protocol will transfer liability for spills or injuries to the students.
3. The faculty advisors signature acknowledges that this protocol is reasonably safe and that, if followed, no harm will come to the students. Should students be injured while following this protocol, liability shall reside with the faculty advisor and/or University per CSU policy.
4. Any deviation from this safety protocol requires approval from the supervisor, faculty advisor or PI.

Authorization

Student Signatures

Last Name	First Name	Signature	Date
Jackson-Gain	Roxanne		Select Date.
Jang	Adam		Select Date.

Faculty Advisor Signature

By signing here, I acknowledge that this protocol has been reviewed and approved by a Cal Poly faculty member responsible for the conduct of the procedures described in this protocol.

Last Name	First Name	Signature	Date
Lee	Jean		Select Date.

Appendix F: Roof Access Safety Protocol

Effect of Ground Surface Albedo Treatments on Energy Harvesting by Bifacial PV Power Plants

Safety Procedure

Author: **Adam Jang**

Date written: **March 6, 2023**

Approvals			
Authorizing Party	**Name**	**Signature**	**Date**
Responsible Faculty			
EH&S			
Safety Coordinator or Dean			
Responsible Faculty			
Responsible Faculty			
Responsible Faculty			
Responsible Faculty			
Responsible Faculty			
Responsible Faculty			
Responsible Faculty			

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Purpose

The purpose of this document is to outline the potential dangers that the Senior Project group consisting of Roxy Jackson-Gain and Adam Jang may encounter while accessing the roof of Building 192 on the Cal Poly SLO campus, and to document procedures designed to mitigate the risks of such activities. Responsible faculty members are instructed to edit this document such that all potential dangers are addressed.

Responsibilities

Environmental Health and Safety (EHS)

EHS will be responsible for providing safety consultation, and where applicable, training, to faculty. This is to include, but not limited to, providing feedback for new processes, reviewing procedures, periodically inspecting facilities, and answering questions in the area of risk mitigation.

Responsible Faculty Member (RFM)

The RFM will clearly communicate to students that safety comes first, and unsafe practices will not be tolerated.

. The Responsible Faculty Member(s) (RFM) must:

a. Provide insight and guidance for activity planning.
b. Be trained on roof and fall protection safety
c. Ensure any faculty overseeing students during the activity have been trained on roof and fall protection safety.
d. Instruct students in the recognition, avoidance, and response to unsafe conditions, including hazards associated with non-routine activities and emergency procedures prior to implementation of activity.
e. Be aware of all activities conducted on the roof.
f. Ensure that training is performed and documented.
g. In the event of an incident, file a report with their department and a copy to Environmental Health and Safety.

Students

Students have the responsibility to:

- Read and comply with all safety rules and procedures set in place by faculty and Cal Poly.
- Inform faculty of hazards without fear of reprisal.
- Attend safety briefings, and understand and comply with all applicable safety requirements.
- Ask questions when there is concern about an unknown or hazardous situation.
- Any student participating in an activity may call an abort at any time, which will halt all activity until the problem is addressed. The activity may continue once the problem has been addressed and verbal approval has been given by the responsible faculty member.
    - Certain temporary holds may be predetermined for procedures. For example, during the activity, strong winds or adverse weather causes safety barriers to fall

or roof surface to become unsafe. Other examples include fear of heights, or mental or physical discomfort.

HAZARD ASSESSEMENT – Refer to example given in Appendix A

Hazards Summary – To be completed by Responsible Faculty Member

Summarize all hazards. Full procedures should also be listed below for activities with a hazard class II or greater

Name	Description	Type	Class	Controls
Ex. (refer to Appendix A) Launching Weather balloon	*Helium used in launching balloons can displace oxygen in the air*	*Asphyxiation*	*II*	*Administrative controls: handle with care, strict training requirements PPE: nitrile gloves*
Accessing Roof	Using a stairway with guardrails to access the roof.	Falling	I	Responsible faculty member to assist students if available (after initial visit)
Walking/conducting experiments on the roof	Walking on the roof within the defined perimeter, there is mechanical equipment and roof drains that can be a tripping hazard	Tripping/falling	I	Cones and tape will be placed to limit access to an area away from the roof edge. Students will be made aware of the mechanical components/roof drains and will have these coned off as well.
Adverse weather	Rain or cold weather may make the roof surface slippery	Slipping/falling	I	Students will be responsible for identifying slippery surface on the roof before proceeding with any testing
Placement of bricks	To secure the testing samples of the experiment bricks will be used which may a pinching or drop hazard	Pinching/dropping object	I	Students will be required to wear leather or other abrasive resistant gloves when handling the bricks and can only handle a maximum of two (2) bricks at a time when on the roof

Setting up testing equipment	Testing equipment weighs approximately 45 lbs. and has a span of 7 feet	Pinching/heavy object	I	Students will be required to wear leather or other abrasive resistant gloves when handling the equipment and should only set it up in pairs

Hazard detailed list - To be completed by Responsible Faculty Member

Summarize any activity that has a hazard classification II or greater

No hazards are II or greater.

EHS requirements:

1. Faculty supervising students on the roof must complete on-site roof safety training prior to access. One key to open the roof will be given to the Responsible Faculty Member.
2. Faculty will request safety cones and barrier/caution tape at seven (7) or more feet from the leading edge. Students and faculty are not allowed to cross this barrier.

Accident and Emergency Procedures:

Life Threatening Emergencies or After Hours/Weekends/Holidays: Dial 911. Note: All serious injuries must be reported to supervisor, faculty advisor or PI within 8 hours. Any and all loss of consciousness requires a 911 call.

Non-Life Threatening Emergencies: Seek medical attention. Emergency medical services in the community are available at any time at hospital emergency rooms and some emergency care facilities.

Paid students, staff or faculty should seek medical attention for all non-life threatening from MED STOP (283 Madonna Road, Suite B – M-F 8 am – 8 pm; Sa-Su 8 am – 4 pm) or Sierra Vista Hospital Emergency Room (1010 Murray Ave.; after hours)

ALL injuries must be reported to supervisor, faculty advisor or PI and campus authorities immediately. Follow procedures for reporting all injuries on the EH&S website (https://afd.calpoly.edu/risk-management/accidents-incident/nonvehicle-accident).

Project Manager Requirements: NA

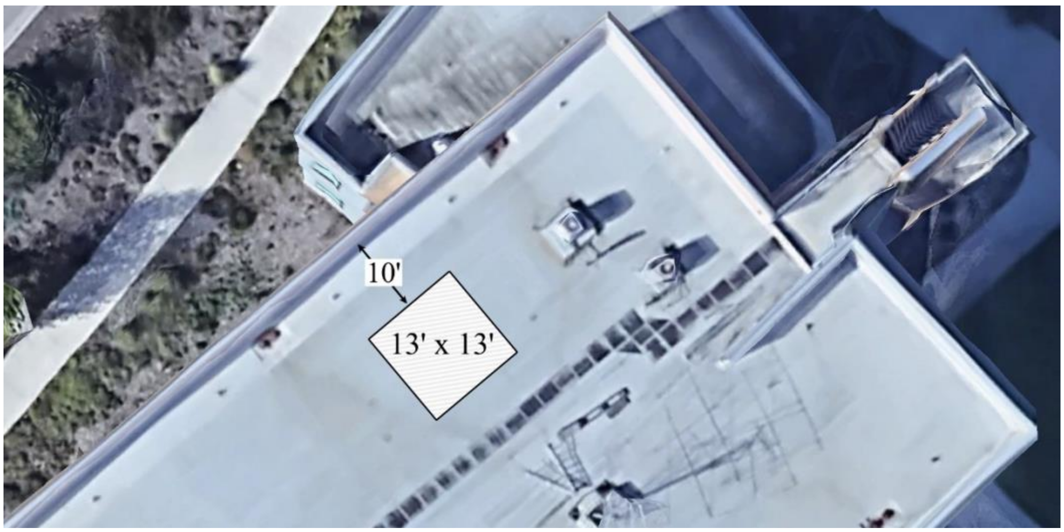
Safety Procedure - Must be completed by Responsible Faculty Member

1. **Name of activity:** Senior Project Extended Use of Building 192 Roof
2. **Estimated date/ duration of activity:** March 13 – May 1 (Weekdays, 10:00 am – 2:00 pm)
3. **Risk likelihood (expected, probable, improbable, unexpected):** improbable
4. **Risk Severity (minimum threat, minimum injury, serious injury death):** minimum threat
5. **Class of activity (I,II,III, IV):** I
6. **Description of activity:** Students will access the roof on a semi-regular basis to collect environmental and albedo data from a stationary 13’ x 13’ flat sample that will be secured to the roof for a period of approximately 8 weeks.
7. **Dangers inherent in activity (specify what material or attribute of the system makes the activity dangerous and why. Cite reputable sources e.g., OSHA, DOT):** *Current access is through a locked access door, which is open to the elements. The roof does not have a guardrail and a safety perimeter will be implemented to prevent students and faculty from being within 8’ of the roof edge.*
8. **Controls used:** After receiving safety training for operating on the roof students will only access the roof when in groups of two (2) or more. In addition, students will notify the faculty advisor 24 hours in advance of the days/times they will be accessing the roof before going to the site. Cones and tape will be used to keep students in an area at least 8’ away from the edge.
9. **Detailed procedures (checklist can be used):**

Safety Procedures Checklist for Accessing Roof:

Check	Procedure
	Use key to open access door.
	Carefully survey the roof area for any large debris, stagnant water (puddles), or other mechanical components that can act as a tripping/slip hazard. If possible, either clean or tape/cone off areas that can be considered trip/slip hazards.
	Set up cones and tape aligned with the edge of the roof (8-10’ from roof edge).
	One responsible faculty member will be present to confirm that the tape and cones are adequately far enough from the roof edge at the required minimum distance of 8’ (only during initial visit to the roof).

Safety Procedures Checklist for Project Activity

Check	Procedure
	Inform faculty advisor of intent to access the roof at a given day/time with a minimum of 24 hours' notice. Provides names of students who will be accessing the roof.
	Check roof's surface for any debris or wet spots before taking data measurements.
	Ensure that the sample is flat against the roof's surface and secured with bricks. The sample will be placed in the area seen in Figure 1 below.  Figure 1 – Aerial view of Building 192 with approximate location of 13' x 13' sample at a distance of 10' away from the roof's edge.
	Carefully bring testing equipment (albedometer, hygrometer, thermometer, laptop) to the roof via the access door.
	Set up testing equipment in accordance with ASTM Standard E1918-21.
	Collect and record data in accordance with ASTM Standard E1918-21.
	Carefully return the testing equipment to their accompanying protective cases.
	Check the cones/tape that create the safety boundary for the experiment to ensure that they are still intact and at the required distance from the roof's edge or other hazards.
	Collect all equipment used and prepare to leave the roof.
	Lock access door to the roof before returning testing equipment to its designated storage location.
	Notify faculty advisor of completion of that day's testing and that the roof access door has been locked.

Appendix F1 – Hazard Assessment Reference and Example

Risks

Activity Hazard Assessment and Matrix

Risk Assessment Matrix				
	Death	Serious Injury	Minor Injury	Minimum Threat
Expected	IV	IV	IV	III
Probable	IV	IV	III	II
Improbable	IV	III	II	I
Unexpected	III	II	I	I

The following Risk Assessment Matrix is divided into columns which detail the severity of a possible anomaly, and rows which define the probability that the anomaly will take place.

The rows are defined as follows:

- **Expected**: It is very likely that the anomaly will occur. Engaging in the activity is expected to yield adverse results.
- **Probable**: An anomaly is likely to occur with time. While not expected, it is likely to occur with many iterations of the activity.
- **Improbable**: An anomaly is unlikely, but still reasonably possible to occur with many iterations of the activity.
- **Unexpected**: It is unexpected that an anomaly will occur with any number of iterations of the activity

The columns are defined as follows:

- **Death:** Death is one of the possible outcomes of an anomaly.
- **Serious Injury**: Dismemberment or serious bodily harm that requires professional medical attention is one of the possible outcomes of an anomaly. (i.e. severe cuts which may require stiches or staples, severe burns)
- **Minor Injury**: Small cuts or lacerations that may require first aid, but do not require professional medical attention.
- **Minimum Threat**: An anomaly does not require any form of medical attention.

The contents of the cells define the class of activity each combination of probability and severity will require. They are defined as follows:

- **Class IV**: This activity has a very high level of risk. Clubs and IRAs will never, under any circumstances, engage in an activity that is a Class IV activity.
- **Class III**: This activity has a high level of risk.
- **Class II**: This activity has a moderate level of risk.

- **Class I**: This activity has a low level of risk.

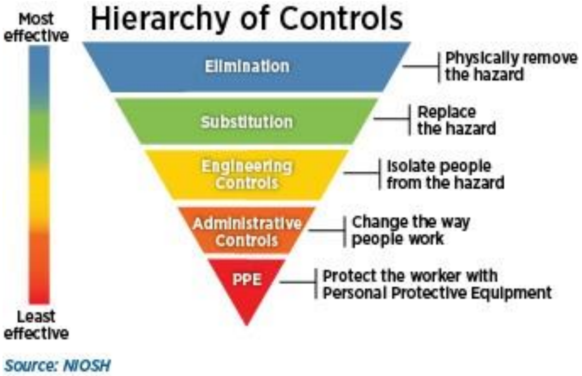
In order to determine the risk level of an activity, the Risk Assessment Matrix will be used. The activity will be identified and broken down into basic tasks. Each task will be given a risk classification using the Risk Assessment Matrix. Then, methods for risk control will be identified, and a final risk classification will be given to each task. The activity as a whole will have the same risk classification as the task with the highest final level of risk.

Risk Mitigation

Each level of classification has different requirements to ensure safety. The higher the classification, the more work that is required to ensure the safety of the individuals involved. The *Activity Plan* required will be determined by the activity's classification level, where Class III requires the most rigorous *Activity Plan*.

	Class III	Class II	Class I
Required Steps	Activity Plan must be approved by the Responsible Faculty Member or advisor, and other appropriate resources (such as EHS), and notification will be given to the advisor and EHS as appropriate 48 hours prior to carrying out the procedure.	Activity Plan must be approved by the Responsible Faculty Member or advisor. To run this activity, notification will be given 24 hours in advance to the advisor.	Activity Plan must be approved by the SSO.

Controls



Elimination – Remove the hazard.

Substitution – Replace the hazard with a safer procedure or product.

Engineering Control - isolate or separate the worker from the hazard with guards, etc.

Administrative Controls – Have workers follow written guidelines or procedures when other controls are not feasible. Supervision or oversight may be required.

Personal Protective Equipment (PPE) – Protect the worker with equipment. Worker is still exposed so administrative controls may be necessary.

Hazard Identification

Types of hazards include but are not limited to:

- Slips, Trips and Falls
- Sharp objects
- Wet or slippery surfaces
- Weather conditions (windy, rain, other)

Appendix F2 - Detailed Safety Procedure Example

Name of activity: ex. Weather balloon Launching

Estimated date/ duration of activity: Spring 2020

Risk likelihood (expected, probable, improbable, unexpected): unexpected

Risk Severity (minimum threat, minimum injury, serious injury death): Serious injury

Class of activity (I,II,III, IV): II

Description of activity: Helium used in launching balloons can displace oxygen in the air

Dangers inherent in activity (specify what material or attribute of the system makes the activity dangerous and why. Cite reputable sources ie DOT):

helium (dot); Helium-4; He; o-Helium; UN 1046,Helium USP

> This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200). Helium is an odorless and colorless gas when released into the air. If inhaled into the body through the nose or mouth in high concentrations it causes oxygen deprivation. Oxygen deprivation health effects includes dizziness, light headiness, lack of coordination, confusion, seeing spots, unable to follow directions and in extreme situations loss of consciousness. Avoid transporting helium cylinders in the passenger compartment of a vehicle as this increases the risk for oxygen deprivation in the event of an accident or leak of the cylinder. Do not place your mouth on any tubes or valves connected to a helium tank.

Controls used:

- **PPE:** Nitrile or other forms of latex gloves must always be worn during inflation and handling of the balloon to keep skin oils off the latex of the balloon. Helium does not present a hazard to the skin from absorption of material into the dermal layer.
- **Administrative controls:** No personnel who has not completed and signed off on the Compressed Gas Safety training module located under Cal Poly's Skill Soft tab, and who has not signed off on this SOP checklist may handle any compressed helium tanks. This SOP needs to be readily accessible to everyone during Helium Transportation/Filling and Weather Balloon Launching

Relevant specialized first aid information:

- **First Aid** for person exposed to large concentrations of helium: Person will appear confused, lack coordination, drop equipment, feel faint, see spots, and be unable to follow directions. Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention (911) if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Detailed Procedures:

PROCEDURE DETAILS:

This procedure is formatted as a checklist; please print out a hardcopy and use it as such. During the launch procedure, please make hand-written notes of any deviations from nominal behavior, if any errors are found, or if any additions or changes must be made to the procedure to allow for better subsequent operations. All corrections, additions, or changes must be recorded as soon as possible, and all old versions collected and disposed of properly to prevent use of out of date documentation.

A: HELIUM ACQUISITION

	A1: 200 cubic foot tanks of compressed helium will be ordered through MATE tech Eric Baton and delivered to Cal Poly between ATL and Buildings 41A and 41B.
	A2: Tank(s) upon arrival will be checked to make sure valve and valve cap are attached and functioning properly. Tank will be checked for damage or leaks.
	A3: Using a cylinder cart, transport the tank from the tank drop off area in between building 41B and ATL, to a suitable transport vehicle (truck). ALWAYS have two people lifting tank from each end when moving from cart to vehicle.

B: HELIUM CYLINDER TRANPORTATION

	B1: Attach tanks in an upright position to truck bed using winches and tie down webbing
	B2: Be sure to bring cylinder/tank cart with you and secure it.
	B3: Tanks are not allowed to be transported horizontally within a vehicle in case of leaks to prevent inhalation (SEE FIRST AID MEASURES IF INHALED)
	B4: Once secured, take a direct route to the new location and do not make any intermediate stops along the way. Avoid heavy traffic routes.
	B5: Upon arrival, unload cylinder cart, then helium cylinder with TWO people minimum, lifting from each end of the tank. Place in the gas cart, close the chain and transport to launch location.