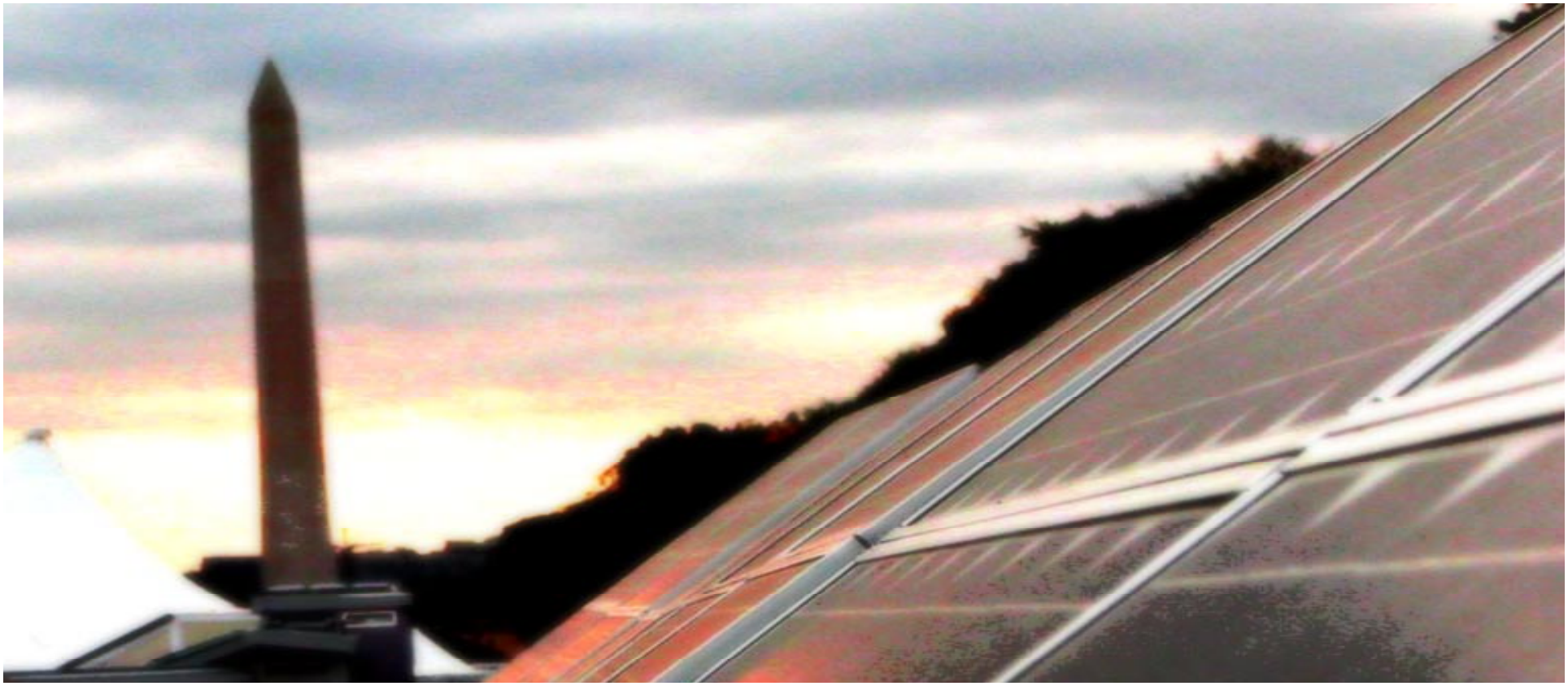

Roof Integrated Photovoltiac Panels
United Solar Ovonic & Acrylife

Ross Marks

UNI-SOLAR
United Solar Ovonic

Executive Summary

United States is entering an energy crisis in which utility costs are rising, and demand rapidly increasing. Foreign energy sources play a vital yet unreliable role in the US energy markets. Technical problems in production or political instability abroad will cause the energy market to react instantly and harshly resulting in higher prices for consumers.

Developing technologies that take advantage of clean renewable energy sources are vital in reducing green houses gasses and stimulating the economy. With globalization, and jobs once held in the US going abroad, investments must be made in the domestic alternative energy market to stimulate new job growth in the US, and the same time reduce US dependency on foreign energy.

With the evolution of technology, photovoltaic solar panels are becoming the most promising alternative form of renewable energy. Photovoltaic panels function on a wide scale, small enough to power watches, large enough for the electric grid, and everything in between. As acceptance grows and solar panels become more widely used, the cost of this alternative form of energy will decrease rapidly. High manufacturing costs are currently preventing solar panels from becoming a competitive alternative to the nation's electric grid. The current manufacturing costs for solar panels are $2.80 per watt, for solar panels to be competitive the cost must be reduced to $1.85 per watt.

This project addresses the development of roof integrated photovoltaic panels. Specifically the focus is on the issue of combining a polyvinyl roof membrane with amorphous solar photovoltaic panels. Fully integrating the roof membrane with photovoltaic panels greatly reduces overall project costs, transportation and installation costs, while at the same time increases distribution channels.

The report explores the design parameters involved with integrating amorphous solar panels with a polyvinyl roof membrane. Marketing for roof integrated photovoltaic systems are investigated to define the scope of the design solutions. One design solution is developed and presented. Analysis of the solution is described. In addition to the design solution alternative solutions are discussed.

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Introduction

Purpose

The purpose of this thesis is to design a system for integrating United Solar photovoltaic panels to an Acrylife polyvinyl chloride membrane to be used on low-sloped roofs. There are several issues that have to be examined when combining the two products. Attaching the panels to the roof becomes an issue due to the nature of PVC. Simple adhesives will not maintain adequate bonding for the desired product life of twenty years. The method used to attach the photovoltaic panels to roof becomes an issue if an adhesive cannot be developed to last the desired lifetime. Next is the issue of the electrical connection of the photovoltaic panel. What that connection is, and how it is made will play a critical role in the versatility of the system. Wiring also becomes an issue when looking at the scale of implantation on the roof. How the wire runs will be organized and what that system will be. The final issue is organizing all the solutions into one viable solution, which is code compliant and financially feasible.

Goals

To design a code compliant, integrated photovoltaic roofing system that can be manufactured; which combines United Solar Ovonic photovoltaic panels, with an Acrylife polyvinyl chloride membrane.

To produce an actual working prototype of this system and patent it.

To develop a marketing framework for this system.

Objectives

Determine best manner in which to attach the photovoltaic panels to the PVC membrane and achieve a cost effective product life.

Design an aesthetically pleasing, user friendly, mass producible, and safe casement for electrical connections and wiring conduit for the photovoltaic panels.

Develop and integrated marketing communications plan utilizing a systems approach.

Overview of the US Energy Industry

United States faces an energy crisis long in the making. Throughout the country utility costs are rising, with demand is also rapidly increasing. In addition to the California electricity crisis, consumers face unparalleled rises in natural gas and gasoline prices. Total U.S. primary energy consumption is projected to increase from 97 quadrillion British Thermal Unites (Btu) in 2001 to 139 quadrillion Btu by 2025 Currently the United States consumes 9 million barrels of oil per day, and that number is expected to reach as high as 30 million barrels per day by 2025. These trends account for an increased improvement in energy production and consuming technologies. The US is at the mercy of events and decisions over which we often have no control. With mild winters and summers, with no refinery or pipeline break downs, and abundant supply from abroad, the US does not feel a dependency. However, as is often the case, when anything goes wrong; the markets react instantly and harshly as we confront the higher prices and volatility that have become by now an almost reliable cyclical phenomenon (1).

Government subsidiaries in the solar industry are a necessary vehicle key to the rapid commercialization of solar power in the United States. This funding is needed to drive down manufacturing costs to be competitive on the utility grid market (2). A National Energy Policy (NEP) has been established to address the growing energy needs of the United States. The policy addresses alternative fuel sources, increased efficiency, renewable fuel standards, and tax provisions. Coupled with government subsidiaries, the NEP includes a consumer tax credit for the purchase of hybrid and fuel cell vehicles, and the production of electricity from environmentally friendly sources, such as wind, biomass, and solar (1).

Developing technologies that take advantage of the clean abundant energy of the sun is an important aspect in reducing greenhouse gasses and helps to stimulate the economy. With the evolution of technology, solar panels are becoming the most promising product to lessen US dependency on the electric grid. As acceptance grows and solar panels become more widely used, the cost of this alternative form of energy is decreasing rapidly. One example is Photovoltaic (PV) cells, which convert sunlight directly into electricity. These are made of semiconductors such as crystalline silicon or various thin-film materials. Photovoltaics can provide tiny amounts of power for watches, large amounts for the electric grid, and everything in between (4). Photovoltaic panels are composed photovoltaic cells, which are grouped together to form module, which is then framed and wired at which point it is referred to as a photovoltaic panel.

With globalization and jobs once held in the United States going abroad, investments must be made in the domestic alternative energy market to stimulate new job growth in the US, and the same time reduce US dependency on foreign energy (3). The Solar Energy Technology program focuses research on advanced solar devices that can provide the nation with a widely available domestic energy source. This will help the US meet electricity needs and reduce the stress on our critical electricity infrastructure. For 2005 $80 million is budgeted for research to reduce the manufacturing cost of photovoltaics from $2.10/watt in 2003 to $1.85/watt by 2005. The program is focused on next-generation technologies such as thin-film photovoltaic cells and leap-frog technologies such as polymers and nanostructures (5).

The Southwest contains enormous solar power potential, comparable in scale to the huge hydropower resource of the Northwest. A desert area 10 miles by 15 miles could provide 20,000 megawatts of power, and the electricity needs of the entire United States could theoretically be met by a photovoltaic array 100 miles a side. (6)

Overview of United Solar Ovonics

History

United Solar Ovonic sees itself as a world leader in thin-film amorphous photovoltaic technologies. A wholly owned subsidiary of Energy Conversion Devices, the company has years of experience with photovoltaics and holds 350 U.S. patents and 800 foreign patents. United Solar hold the basic patents covering the continuous roll-to-roll manufacturing of thin-film amorphous silicon alloy multi-junction solar cells and related products. United Solar offers a wide range of solar electric panels, which are unique, flexible, and lightweight. This technology has been proven over decades under the most extreme conditions imaginable, including satellites, ocean buoys and military applications. (7)

United Solar offers several types of photovoltaic systems for consumer, residential, commercial, and government use. These systems vary in size and scale, according to the needs of the client. To address the needs of the residential consumers, United Solar has developed the brand line Smart Roof. Smart Roof is a building integrated photovoltaic system, which includes all components necessary to establish a grid tie in PV system. Included with this are consultants to aid in the design and installation of each system. (7)

Future

United Solar aims to be a high-end complete engineered solar solutions provider in the alternative energy market. They want their name to be associated with "System Performance." The aim of United Solar is to be one of the top 5 providers of solar systems in the United States and abroad.

The solar industry can be classified as an oligopoly, with BP, Shell Oil, Sharp, and Kyocera being the major industry players (2). GE is new to the industry with the acquisition of a small US manufacturer of solar panels. United Solar is a small firm in comparison to its competitors, many of whom top the lists of the worlds largest companies. In addition, most companies working in the industry have not shown profit. There are only a few small profitable niche markets, such as off shore oilrigs, remote high way signs, and remote water pumping stations. As a major breakthrough BP expects to see a profit in its solar division by the end of 2004. Along with the expansion of GE in the industry the market place is going to be highly competitive for United Solar.

United Solar offers full photovoltaic array systems with data acquisition software and hardware for the monitoring the system and performance. The technology used, amorphous PV, offers more energy output at lower light levels and high PV cell temperature. One key feature United Solar has over its competitors are for its PV panels to be fully roof integrated.

Target Market Analysis

The main form of communications in the Solar Powered industry are personal, face to face marketing, some trade magazines, and direct mail. The magazines and trade journals are not as effective as desired by the industry. Larger firms, such as Shell Solar, and BP Solar have the ability and financial power to engage in large-scale advertising campaigns. The larger firms also support sponsorships, and event sponsorships. (8)

For the most part, the target market is broken down by geographic location. With in the United States, California, New York, New Jersey, Massachusetts, and Connecticut are the current geographic target.

Within these five states, 80% of the PV's sold are in California. 70% are for residential, 30% are commercial and within the commercial market, only 10% are for new construction. For the commercial market the main focus is on retro and re-roofing jobs in owner occupied buildings that are 15 years or older.

PV's are still in the early adopters phase of the product life cycle. So far the main early adopters are government, municipals, and education. (8)

Integrated Marketing Communications Plan

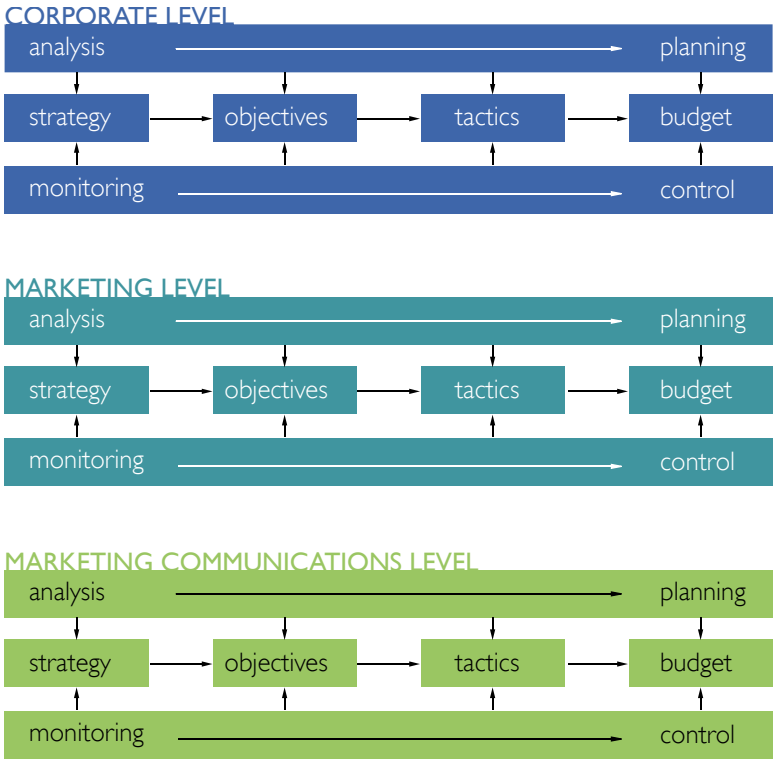
Marketing Project Statement

The following section is an integrated marketing communications (IMC) plan for United Solar. The plan is based on a systems approach in which strategies, objectives, and tactics are clearly defined. An IMC plan provides the framework needed for the implementation of a unified marketing campaign at various levels of the company. This organizes the company's communications efforts in a synergistic manner to provide the target market with a consistent message (9).

IMC plans are based on a process hierarchy, starting at the top, corporate level, and working down to the bottom, marketing communications level according to the fiugre on the right. Each level of the hierarchy contains an ordered mix of elements; strategy, objectives, tactics, and budget. Analysis and planning are done throughout the mix, as are monitoring and contol. Strategy defines an overall goal that can be achieved through the implementation of certain methods. Objectives are the quantification of these strategies to provide a clear definition of the strategy. The tactics are the methods used to meet these objectives. (9)

This marketing plan was done in order to define the scope of the project. Establishing the goals of the company, target market, and marketing tactics; narrows the project scope to better design a product that address the needs of the various stakeholders. It also helps in identifying product attributes that should be emphasized in the design of the product.

For the purpose of this project certain assumptions about the solar industry, energy market, and United Solar were made. Research involved for a true fully integrated marketing communications plan was not feasible within the scope of this project. This report outlines the framework for an ideal marketing communications plan based on assumptions about the industry. Data used to perform the analysis can be changed, and the analysis quickly revised.



Corporate

Strategy

The corporate image for United Solar is to be the high-end solar solutions company. The United Solar brand UniSolar will be promoted and be associated with high quality, excellent service, and complete solutions.

With the increasing demand for energy in the United States, coupled with the increasing strain on the countries electrical infrastructure and budget, United Solar predicts tremendous growth in the Photovoltaic Solar Industry. The company estimates PV's as being in the early stages of the product life cycle. United Solar's goal is to be one of the top five providers of solar panels in the United States, and to be one of the top ten suppliers world wide. The United Solar brand will be associated with high quality, excellent service, and complete solutions.

After conducting a multifactor portfolio matrix analysis on United Solar's current position, and market position, and accounting for the companies goals, a growth strategy is the best course of action for the company. At present time market growth potential is very high, which is being nourished by federal and state energy programs. Experts predict the market will expand very rapidly in the coming years, and is expected to reach $4.3 billion by 2013.

Objectives

In accordance with United Solar's goals to be one of the top two suppliers of PV modules, sales will have to increase 30% within an eighteen month period. To position themself in their competitive industry, United Solar market share will have to increase as well. Currently market share varies from state to state, however the company aims to increase overall market share by 20% within an eighteen month period.

Tactics

To achieve these set objectives, United Solar will have to dedicate resources to marketing, research and development, and engineering. Marketing is essential to achieving the increase in sales and market share set by the company. United Solar is competing against companies with very strong brand equity. Substantial resources will have to be allocated to build the UniSolar brand before significant returns will be realized. When products are in the early stages of the product life cycle, substantial capital is needed to increase brand awareness and educate consumers. High costs being a major barrier to the commercialization and the advancement of this industry, engineering is important in minimizing the costs of manufacturing and maximizing technological efficiency in order to pass savings on to the consumer to encourage sales. The alternative energy industry is still young and technology is advancing at such a rapid rate, that research and development is essential to maintain a competitive edge, and increase appeal of the product.

Marketing

Strategy

United Solar is a world leader in thin-film solar panel technologies. There are several advantages and disadvantages to this technology as compared to the conventional silicon crystalline solar panels. The benefits include panels that are lighter weight, glass free, cheaper to produce, greater durability, and more tolerable to shading. The only major disadvantage is the lower efficiency rating then a typical crystalline solar panel. While there are several product attribute advantages United Solar has over the competition, no single attribute was found to be very appealing to the industry as a whole.

Assembling a Means-End Chain model provides a clear visual layout to plot the course of action in determining a marketing strategy. The model hierarchical structure breaks the product down by attributes, consequences, and values. The model illustrates the product attributes and their relation to instrumental and terminal values (see page 8). To position UniSolar as being affordable could have an adverse effect on the brand positioning. Brand position should be centered on product attributes, and consumer benefits. According to the means-end chain model, reliability corresponds to the most consumer benefits directly. Affordability should not be left out of the mix, but it should not be the focal point of brand positioning. Therefore marketing efforts should focus on product differentiation by intangible attribute focusing on reliability as the marketing strategy for the company. United Solar should position the brand UniSolar at the top of the market. In addition, combining the product mix into one system would be advantageous for United Solar. The company could then market the brand UniSolar as a " Complete Reliable American Photovoltaic System." The consumer benefits of having a complete high-end system from one source would be accentuated.

Objectives

To achieve the goals set by the corporate level growth strategy United Solar will have to expand their market. Currently only owner occupied commercial buildings 15 years or older are targeted within their commercial market. Increases in the communication budget are necessary to better address new construction, and redevelop a plan to address existing buildings. Expanding the scope of existing buildings and adding new search criteria, for example utility rates, energy needs, community, location, security needs, and public image, will widen the range of the commercial market. Increasing efforts of targeting the design, and the building industries should be made to increase the rate of PVs being used in new construction.

Marketing

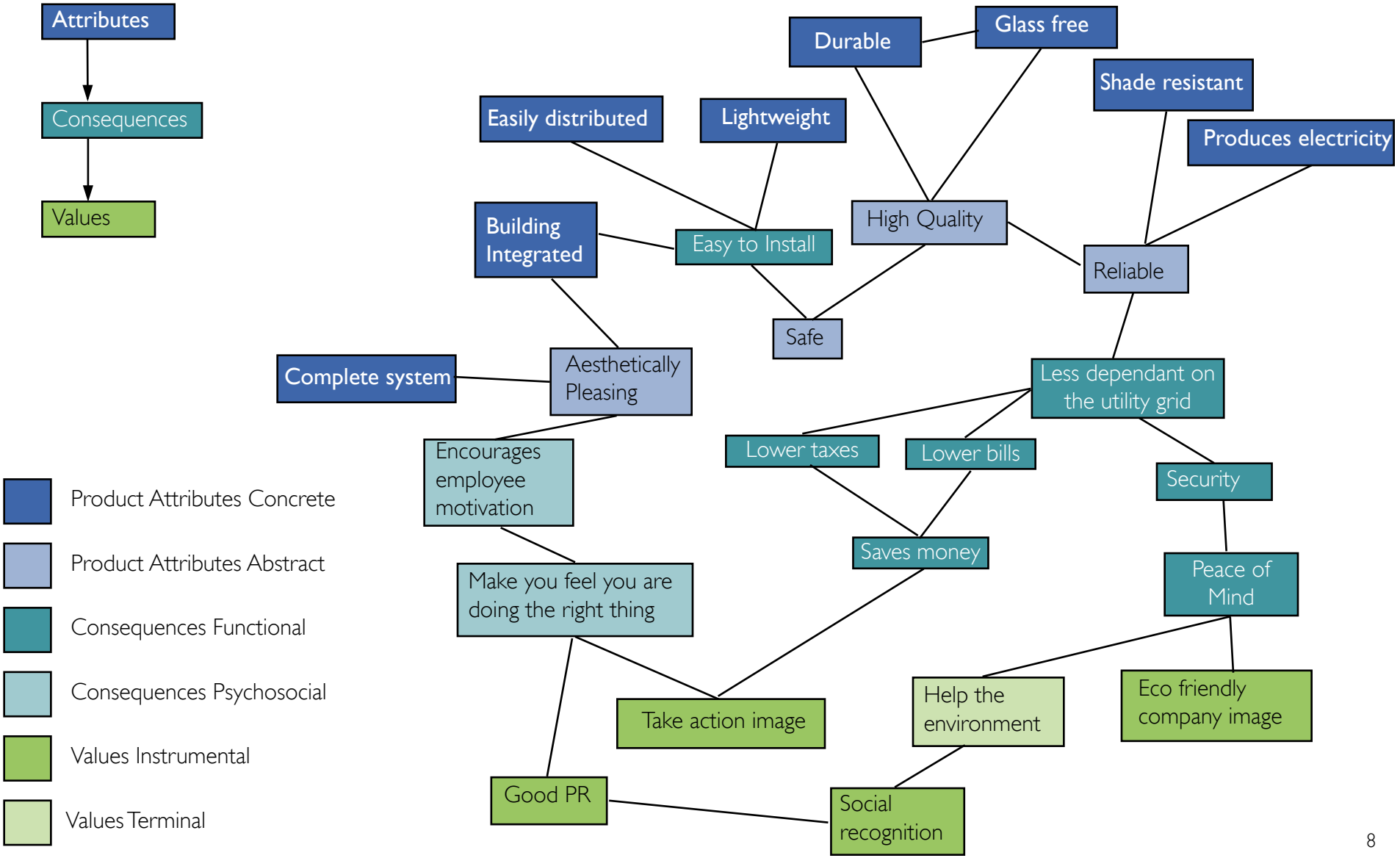
Tactics

Achieving these marketing objectives will require United Solar to emphasize cost and durability relating to the most desired product attributes. An association between the brand UniSolar and system performance must be established in the minds on the consumers. With the need to increase the commercial market, channels of distribution must also be enlarged. New channels of distribution must be established to facilitate in the sale and distribution of the PVs. United Solar should establish at least two secure symbiotic vertical relationships with companies that are well established in the commercial market.

Monitoring and Control

Research of the customer's perceptions of United Solar and the brand UniSolar should also be conducted before any major effort begins. Five months into the marketing effort follow up research will be essential to determine the effectiveness of the marketing efforts and weather there was any change in the consumers perceptions of the company and the brand. The follow up research must also reassess the most effective attributes to promote. Marketing must also work with engineering and development to build on the most effective attributes.

Means End Chain Model



Marketing Communications

Strategy

Photovoltaics can be classified as high involvement products that require significant capital investment. When shopping consumers identify several manufacture's of panels and base their selection on the most benefits offered. While involvement is high, photovoltaics have a low emotional involvement. The consumers will actively seek information while shopping for panels, so an informative strategy will be the best route for the advertising campaign. Since this a new product the advertising will require a variety of media, and message repetitions. This will be consistent with the corporate level growth strategy, and marketing level focus on reliability.

Objectives

With the onset of larger competition to the market, the marketing communications level objective should be to increase brand awareness by 100% within 4 months. United Solar will be the first in the industry to launch a campaign for the commercial market with the sole objective to increase brand awareness. The campaign will focus on brand name, being made in America, by an American company and, to lesser extent key intangible product features. Research has shown that viewers pay more attention to an advertisement when the country of origin is stated and therefore increase chances of the brand being in the consumers evoked set (9). Being that United Solar is an American company, and given the current economy, emphasizing country of origin will strengthen their position relative to the larger firms that are all foreign owned subsidiaries. This will be a large-scale effort, which will require significant resources.

Coinciding with the objective to increase brand awareness, an increase in brand preference by 50% within 6 months is also needed. The greater percentage of the market with favorable attitude towards the United Solar brand, the better situated the company is in the future, and the stronger the brand equity. The industry has been around for over thirty years now, today the industry is slated to grow quickly, brand leaders will dominate, and playing catch up is not an option.

In addition the company must also make money so an increase in purchase decisions by 25% within 12 months is necessary. Good relations with distribution channels must be established for this reason. United Solar must emphasize reseller support, reseller incentives, and training for sales personal. This will also aid in the word of mouth communication, which exists in the tight knit alternative energy community.

Quality Function Deployment Chart

Overview

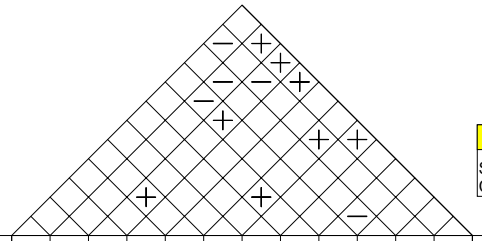
The quality function deployment is a systematic matrix technique to identify product attribute requirements and secondly allocate resources to meet the requirements. Quality function deployment (QFD) is a loose translation of the original Japanese name where it was invented in the 1970's. QFD charts cover product development from design generation through to the generation of manufacturing instructions. The system has been positive impact on improving product quality, and reducing lead-time (10).

The method is based on relating customer requirements to the specifications needed to meet the requirements. Customer needs are listed on the right hand column and given weights according to their importance. Corresponding specifications are listed along the top row. Essentially the QFD identifies the links between the requirements and specifications using a matrix grid layout. Different symbols are used to identify links between the two. The triangular region above the top row illustrates relationships existing between specifications. A synergistic relationship is signified with a plus (+) sign, while a compromise is signified with a minus (-) sign. Specifications are also given a quantitative means of measurement. This translates the specifications to a measurable unit on which to gauge the design. Based on these measurements resource allocation can be made to focus on the most important customer requirements. It also allows for a competitive analysis to allow benchmarking on a product attribute level (10).

United Solar QFD

When defining product specifications, twelve customer needs were identified. The customer needs are the ability to meet electric needs, the ability to align with the sun, must be easy to install, should have a broad spectrum of applications, it must have a user friendly interface, has to be able to withstand roof conditions, looks should be pleasing, it must be able to withstand the elements, it should be light weight, should withstand wind uplift, help save money, and be roof integrated. Using these needs the following product specifications were established to provide a means of measurement. Power supplied, degree of flexibility, setup time, number of compatible roof systems, ease of function, durability based on an in house durability scale, attractiveness, waterproofing UV index, weight, wind speed, cost, and number of parts. The summary of the relationship between the customer needs and product specifications can be seen on the next page. A full QFD chart can be found in Appendix A.

Quality Function Deployment Chart



Tradeoffs	
Synergy	+ 1.0
Compromise	– -1.0

Direction of Improvement		
Maximize	↑	1.0
Target	○	0.0
Minimize	↓	-1.0

Customer Need vs. Specification Matrix		
Complete Correlation	●	5.0
Strong Correlation	◕	4.0
Medium Correlation	◑	3.0
Weak Correlation	◔	2.0
Minimal Correlation	○	1.0

		Importance (Customer Needs)	SPECIFICATIONS:	Power Supplied	Degree of flexibility	Setup Time	Number of Compatible Roof systems	Ease of Function	Durability Scale	Attractiveness	Waterproof/UV index scale	Weight of Product	Wind speed	Cost	Number of Parts	COMPETITIVE BENCHMARKING:	United Solar	BP Solar	Shell Solar	GE	Koycera	Sharp Solar	Max = 4.0 ● United Solar ☆ BP Solar △ Koycera ✕ Sharp Solar ■ Shell Solar + GE Min = 0.0	
				1	2	3	4	5	6	7	8	9	10	11	12		2	3	4	5	6	7		
Direction of Improvement	1			↑	↑	↓	↑	↑	↑	○	○	↓	↑	↑	↓									
CUSTOMER NEEDS:	1																							1
Ability to meet electric needs	2	5.0		●							○	◑			○		◕	●	◕	◑	◑	◕		2
Ability to align with the sun	3	2.0			●	○		◑	○			○	○		◑		○	◕	◕	◑	◔	◑		3
Must be easy to install	4	4.0			◑	●		◑				◑	○		●		●	◔	◔	◔	◑	◑		4
Should have a broad spectrum of applications	5	3.0		◑		○	●	○							◔		◕	◕	◕	◑	◑	◑		5
User friendly interface	6	2.0			●	◑	◑	●				○	○				◕	◔	◔	◕	◔	◔		6
Has to be able to withstand roof conditions	7	5.0				◔			●	◑	●	◑	◑	○	◔		◑	◔	◑	◑	◔	◑		7
Looks should be pleasing	8	1.0					●	◑		●					○		◕	◑	◔	●	◑	◔		8
Must withstand the elements	9	5.0							◑	○	●	○	○		◑		◔	◕	◑	◑	◔	◑		9
Is lightweight	10	3.0				●		○	○			●	●		◕		◕	○	◔	◕	◑	◔		10
Should with stand wind uplift	11	4.0			◑				○			◑	●		◔		◔	●	◕	◑	◔	◕		11
Help save money	12	5.0		◕		◑		◔	◑		○	○		●			◕	◑	◔	◕	◑	◑		12
Roof integrated	13	2.0		◔	◕	●	●	◑	○	◕	○	◔	◕	◕	●		●	○	◔	◕	○	◔		13

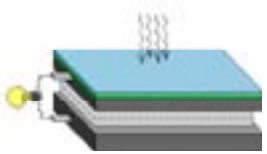
Component Product Descriptions

Acrylife

Acrylife is mechanically attached, fully adhered to commercial, industrial and institutional roofs with standard roofing approvals. The membrane is fashioned specifically for installation over metal, concrete, wood, gypsum and tectum in conjunction with approved insulation boards and appropriate attachment methods. All seams are hot-air welded to form a monolithic, watertight membrane roof system (11).

Acrylife roof membrane meets the Energy Star standard for cool roofs. The smooth white PVC roof can be 60 degrees cooler than a typical black roof. The highly reflective nature of the roof membrane means less heat build-up, less architectural stress, and roof material degradation (11).

Amorphous Photovoltaic



Photovoltaic panels use the particle nature of sunlight to knock electrons from a semiconductor material, commonly silicon. Two types of silicon with different physical properties are sandwiched together to control the free electrons knocked lose. Electrons flowing between the two layers of silicon produce electricity.

Using thin-film, vapor-deposited amorphous silicon UniSolar can reduce the materials cost in a solar cell. Because a-Si absorbs light more efficiently solar cell thickness can be 100 times less, thereby significantly reducing materials cost. PV products utilizing this technology can be very lightweight, flexible and durable. There are no parts that can be broken during shipping which makes it easy to transport to remote rural areas, thus saving shipping costs. Due to it's durability it can be installed without breakage.

Problems

Typical roof installations of United Solar amorphous photovoltaic panels involve an industrial adhesive or mechanical fastener. Mechanical fasteners are undesirable in this case because they puncture the membrane thereby eliminating the integrity of the waterproof membrane. Adhesives have not been able to hold up to the nature of polyvinyl chloride over the desired life. Both the Acrylife roof membrane and the United Solar PV panels have a product life of twenty years. When non-PVC materials are adhered to the PVC membrane, the PVC molecules migrate overtime breaking down adhesive integrity. Various adhesives, and techniques have been investigated, but fail to meet the twenty-year life under exterior conditions. Research is being done to explore the idea of developing an adhesive with a barrier to control molecular migration overtime. Developing this adhesive would greatly improve product quality.

Design

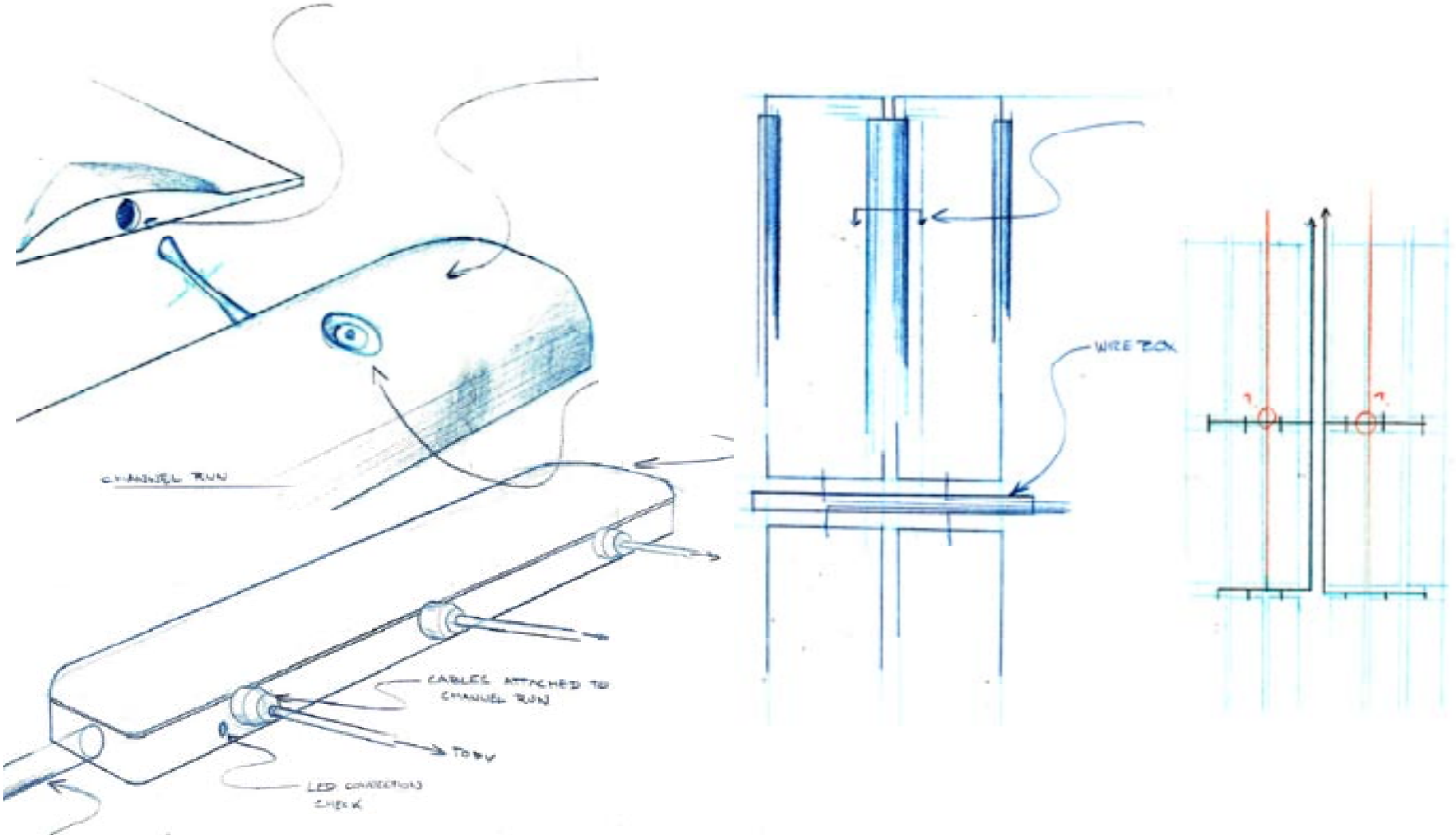
The design directive is to work out a means to fasten the photovoltaic panels to the PVC roof membrane, improve electrical connection, and develop a system in which to manage wires.

Electrical connections deal with connecting the photovoltaic panel to the electrical system. This addresses the manner of which the panel is wired up, and what that physically is. Existing electrical connections are bulky, unattractive, and poorly attached. Consistent with United Solar's desired position the connection system should be simple to use, reliable, and elegant.

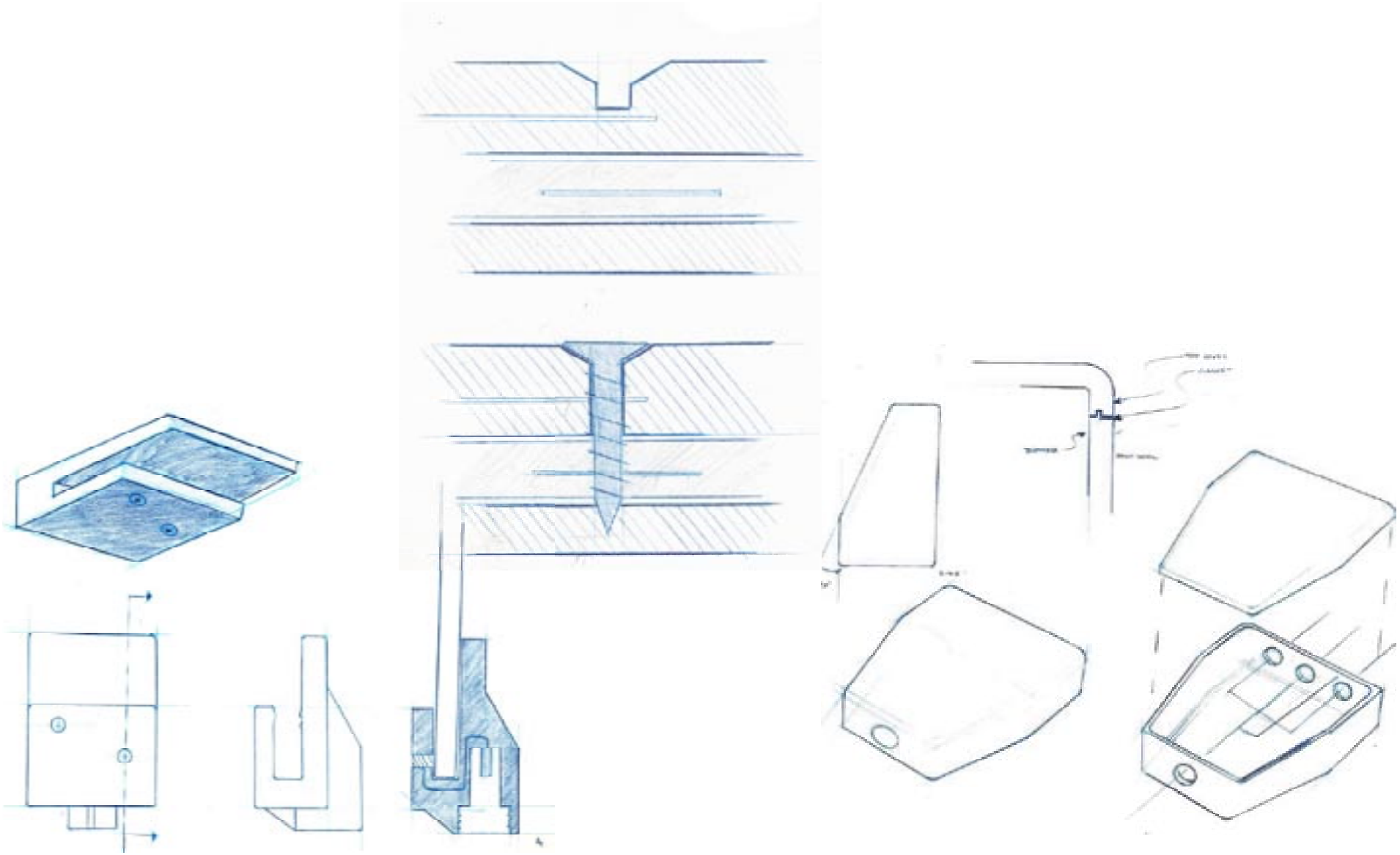
Another issues with the electrical system is wire management. When the system is relatively small, composed of only a few panels, wires are not an issue. However on a larger scale, several hundred panels, wire management becomes an issue. A system must be designed to handle wires on various scales, and protect them from exterior elements. The system must also account for working conditions of a roof. Low-sloped roofs are frequently walked on, and various trade professions are involved with the installation of a typical roof. Wires pose a dangerous trip hazard, and shock hazard if inappropriately managed.

As discussed earlier the means of attaching the photovoltaic panels to the roof is a critical element in the system. If an adhesive cannot be developed, then alternate means must be explored. Depending on the layout of the system, the panels could be under significant uplift forces. These forces are a common condition on low-sloped roofs, and play a critical role in the development of a fastening system.

Early Concepts



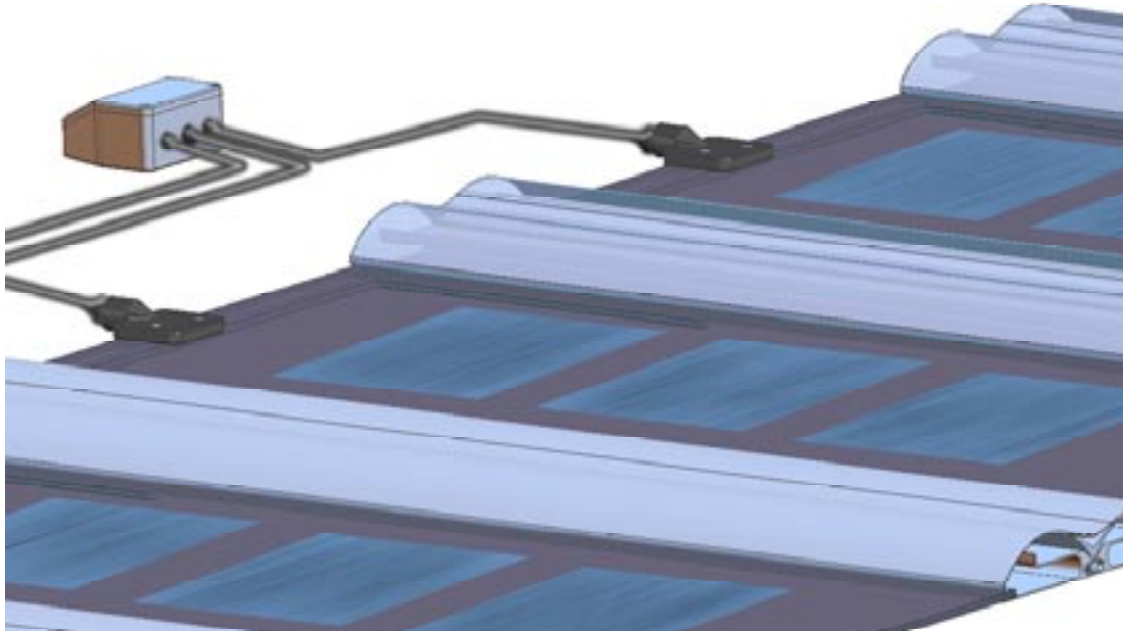
Refinement



Final Concept

Criteria

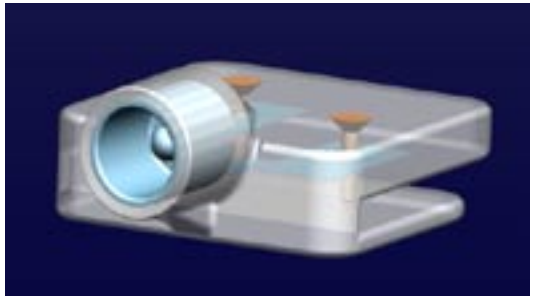
The final design is based on the following assumptions. One; an adhesive will not be developed which can adequately hold the photovoltaic panels to the PVC membrane. Therefore a mechanical alternative must be designed that can securely hold the photovoltaic panels to the PVC membrane. Two; the panels will be installed onsite once the PVC membrane is installed on the roof. Three; the electrical connections will be adequate to handle the loads of the photovoltaic panels.

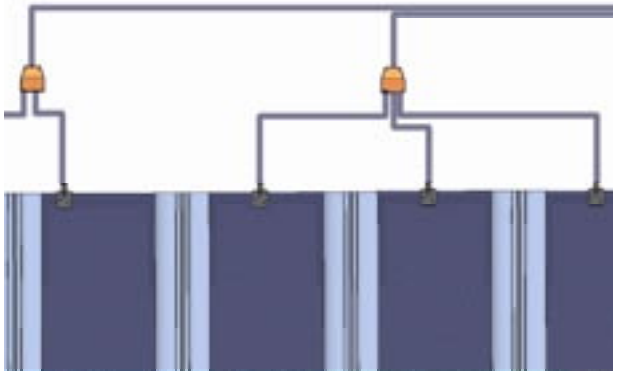


System Description

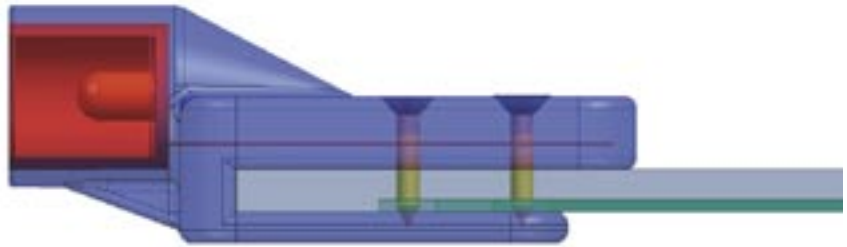
The final design is a system composed of three main parts, excluding the wires, and existing products. Parts are as follows; the clip, the junction box, and the extrusion. The extrusion holds the photovoltaic panels to the PVC membrane and is composed of two parts, the top and bottom. When the top half is fastened to the bottom half the photovoltaic panel is securely held. The clip is the electrical connection to the panel. It was designed with the versatility to be attached anywhere along the exterior edge of the photovoltaic panel. A MC Exterior Quick connect, similar to common DC connectors, is used to make the wire connection to the clip. The junction box receives the wires from the clips and provides a means of wire management. Two to six panels can be wired to one junction box, which has one wire running to the charge controller for all the panels. Junction boxes offer the flexibility to be wired in any manner, thus not limiting to the electrical layout of the system. Other then securing the panels to the roof the extrusions also function as a wire run. Multiple junction boxes can feed into one extrusion that serves to protect the wires, and make the roof a safe working environment while running wires long distances. Parts were designed to be modular which gives the system the flexibility to function on various scales. Three panels are designed to fit on to one four feet wide roll of Acrylife.

Once the Acrylife membrane is fully installed, then the installation of the photovoltaic panels can begin. First the bottom half of the extrusion is laid down and adhered to the PVC membrane, in manner reflecting the layout of the photovoltaic panels. Secondly the photovoltaic panels are put in place using the bottom of the extrusion as a guide. Clips are then attached to the photovoltaic panels consistent with the wiring needs of the system. Next, the top of the extrusion is fastened to the bottom, thereby securing the photovoltaic panels. Finally the clips are wired to the junction boxes, and the junction boxes are then wired to the main electrical system.

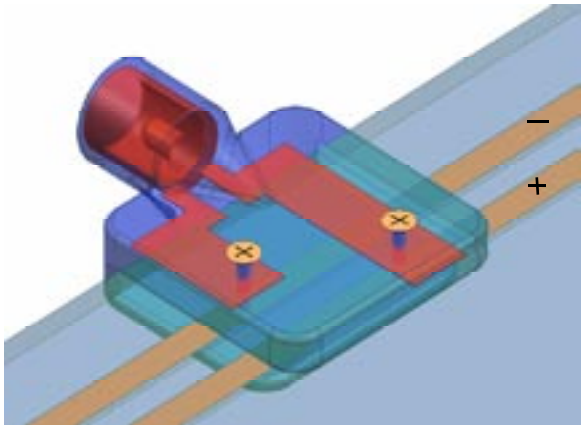


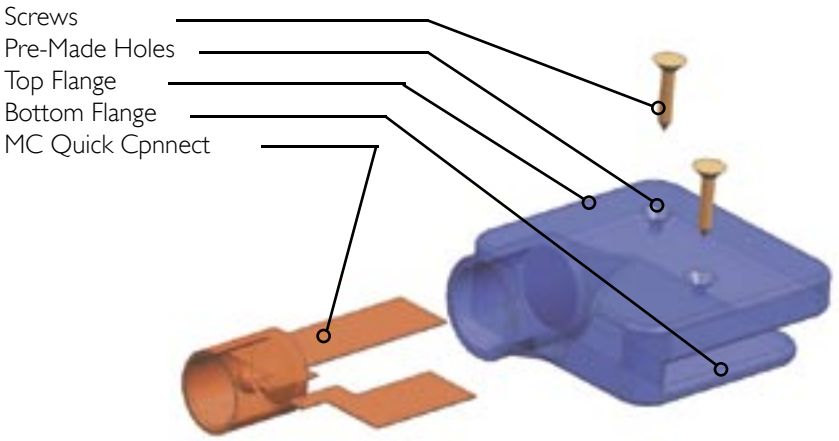


Clip

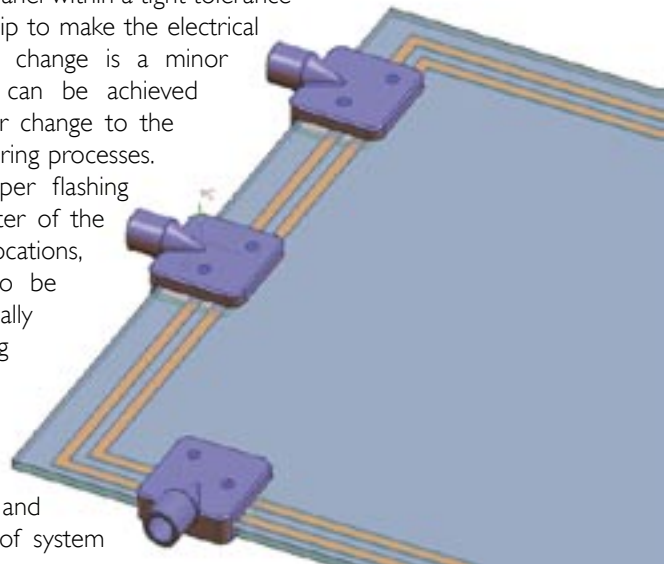


The clip is an injection molded part. MC Quick connect connectors are molded in to the part. Clips are designed so as to screw in to the panel. The screws function to hold the clip securely in place, and make the electrical connection. Pre-made holes on the top flange of clip will act as a template for the screws. Screws will penetrate the top flange of the clip, will then pierce the photovoltaic panel making the electrical connection with the copper flashing. The bottom flange of the clip will act a secure base to receive the screws when the panel is pierced.



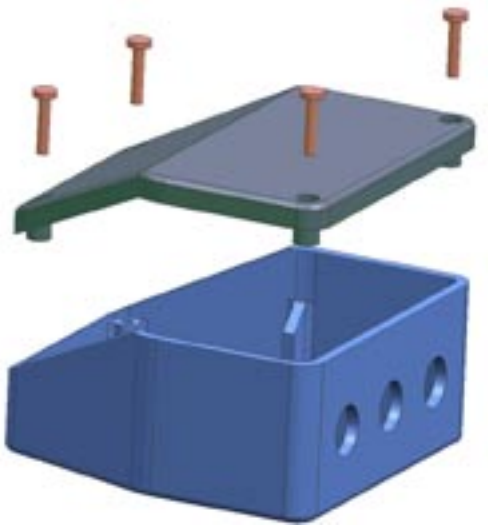


The layout of the panel will have to be altered to allow the clip to make the electrical connections. Negative and positive copper flashing will have to be run along the perimeter of the panel within a tight tolerance to allow for the clip to make the electrical connection. This change is a minor alteration, which can be achieved without any major change to the current manufacturing processes. Running the copper flashing along the perimeter of the panels, in select locations, allows the clip to be attached to virtually any location along the edge of the panel. Doing so allows for easier and more efficient wiring, and greater flexibility of system layout.

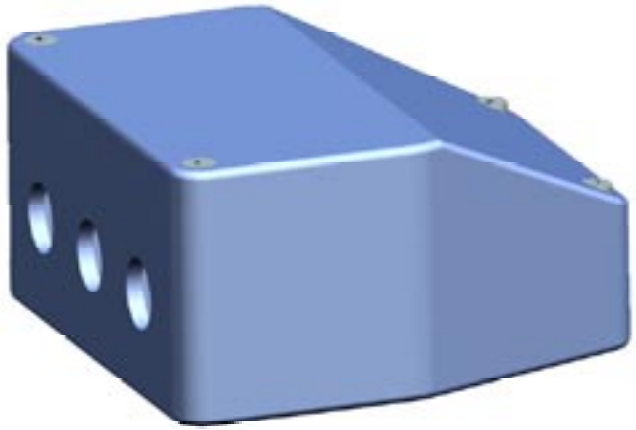


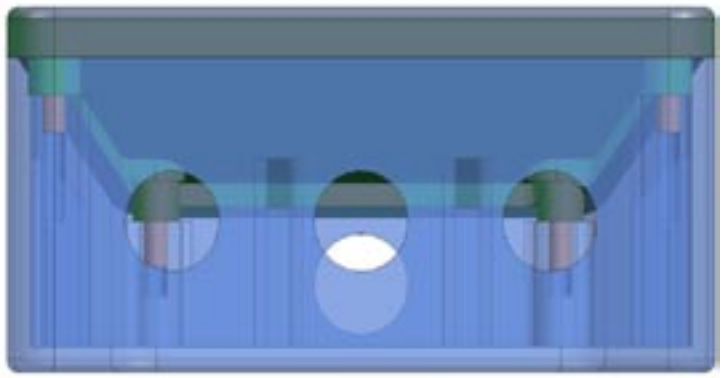
Junction Box

The junction box functions as a standard electrical box and for all intensive purposes a stand box could be substituted. The design was based on the versatility needed, roof and safety concerns, and UniSolar brand positioning. Working on the roof can be a very dangerous environment, the US department of labors occupational safety and health administration (OSHA) sets fourth very stringent guidelines for doing so. The junction box poses a dangerous trip hazard to workers on the roof. Minimizing the trip hazard the box poses makes the working environment safer. Also in terms of brand positioning a specially designed junction box is more align with high-end solutions image.

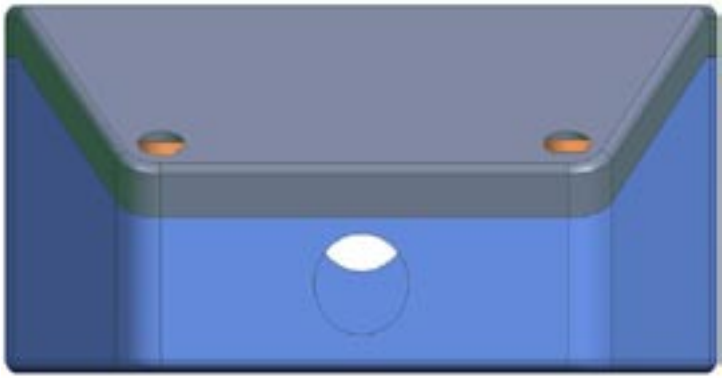


All the electrical components can be placed inside the box. Each box can be wired differently depending on the need, weather it is in parallel or in series. Boxes are designed to accept 2 to 6 panels each. This also gives the installers greater flexibility in wiring up the panels. The boxes can be prepared on the ground before wiring the panels, then workers can go though and plug in the panels when they are ready to be wired. Panel connections will lead into the box through the holes in the back of the box. The boxes will be configured for the MC quick connect system. Once the all the panels are connected to the box, one wire leads out of the front of box to the main electrical system.



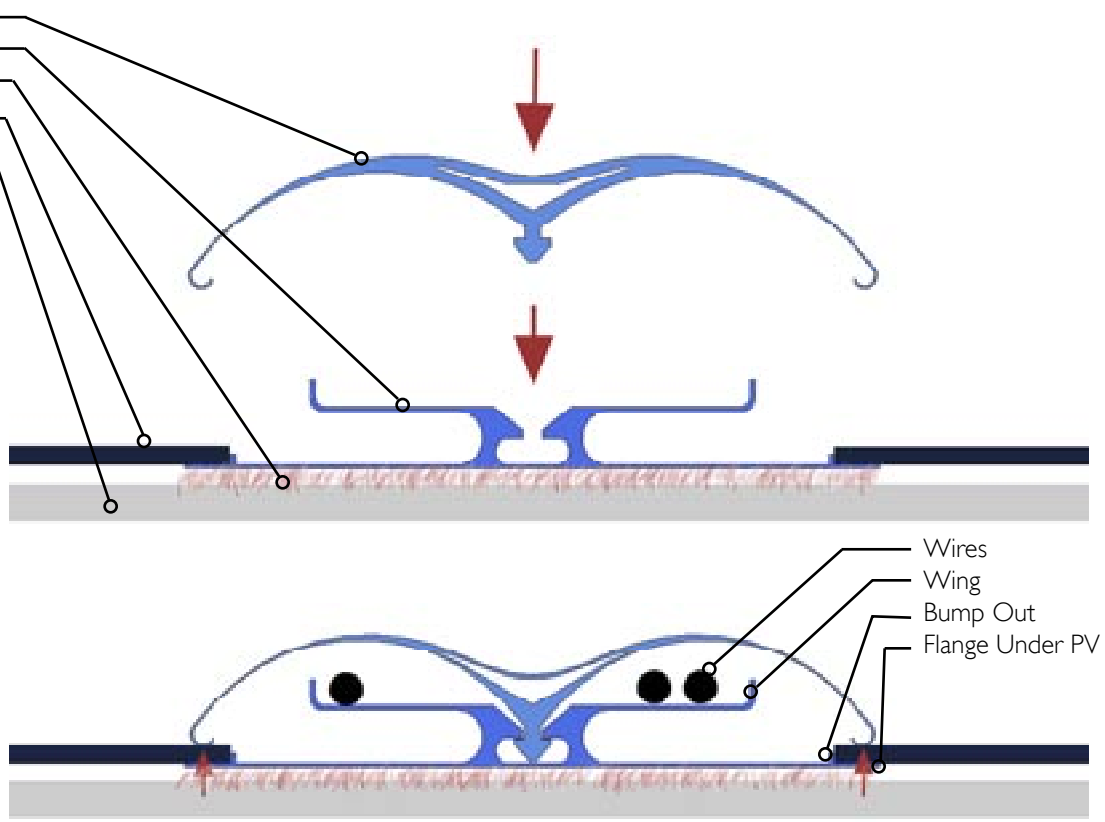


back

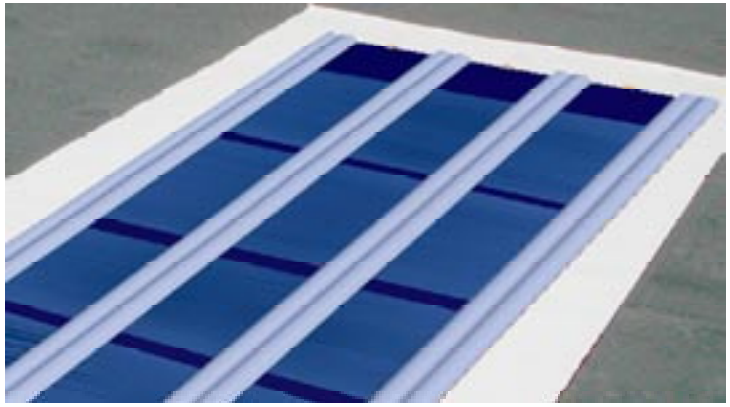


front

Extrusion



The extrusion pieces are extruded polyvinyl chloride. Using PVC as the material for the extrusion, allows for the bottom piece to be adhered to the PVC roof membrane. Once the bottom piece is adhered to the roof membrane it is securely in place, and will last for the desired lifetime of the product. The photovoltaic panels are then laid down in between two bottom extrusions. On the edge of each extrusion is a little bump out to be used as a guide to place the panels. The panel edge should join with the bump out. This will place the panel in the right position to reduce shading, and ensure proper grip. After the panel is placed, the top extrusion can then be attached. Roughly five pounds of pressure are required to click the top extrusion into place. The deformation of the wings pushing down on the panels are what clamps the panels securely to the roof.



The bottom extrusion also has wings that serve two purposes. Firstly the wings act as a means to release the top extrusion from the bottom. Secondly the wings are a means of holding the wires, and raising them off the surface of the roof.

After the bump out on the bottom extrusion there is a small flange. The current system has one panel with an extrusion on each edge. When looking at large scale implementation of this system, the extrusions add up and account for a lot of material. Ideally if three panels could be attached together along their long axis, then only two extrusions will be need for three panels. This would greatly reduce the number of extrusions needed. However when doing so wind uplift becomes an issue. The flange on the bottom extrusion, allows for the placement of an element which can counter act the wind uplift if three panels are attached together.

Finite Element Methods Analysis

A finite element method (FEM) analysis was conducted on the computer model extrusion parts. In this analysis one foot sections were taken, given real material properties, with realistic forces applied. To better simulate structural forces, constraints were added to limit the movement of the extrusion parts. The overall analysis gives a visual representation of the issues occurring within the extrusion parts. Under the test conditions the following results were obtained, displacement, stress, strain, applied load, and reactive forces.

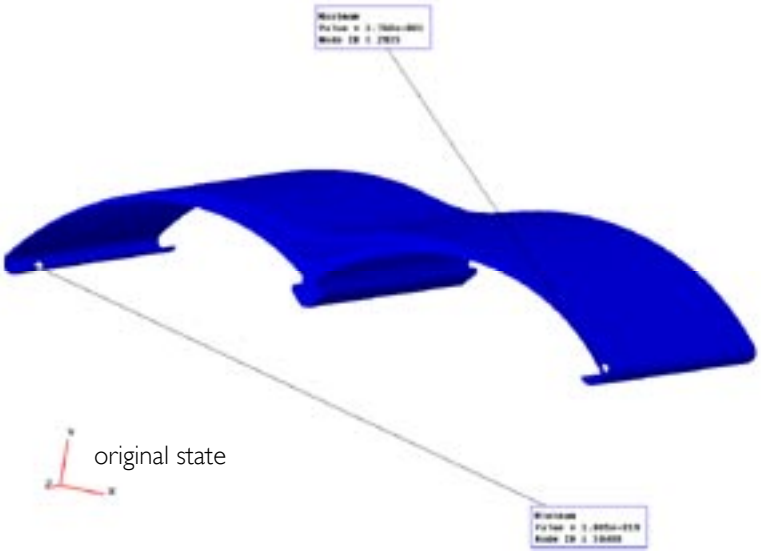
Two tests were performed on the top part. The first test involved a downward force of ten newtons along the top center axis of the extrusion part. The bottom faces of the curves at the ends of the wings were constrained and not allowed to move vertically. This simulates the counter active force of the panel reacting to the downward force of the extrusion. The test showed what parts of the top extrusion were under stress from the downward force, and how that affects the rest of the part. The second test involved applying five newtons on each end of the wing of the extrusion. A vertical constraint was placed on the top face of the fastening system, to simulate how the bottom would hold the top extrusion in place.

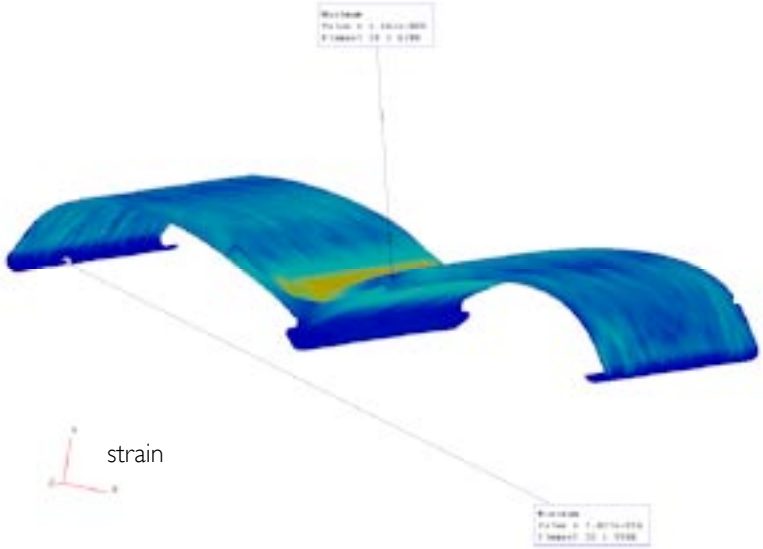
Two tests were also performed on the bottom part. A downward force of five newtons was applied to the wings of the part, while a vertical constraint was applied to the bottom face of the part. This simulates pushing down on the wings and illustrates how the part will react to the force. The second test involved applying five newtons each to the faces on the bottom upper end of the fastening mechanism. Again the same constraint was applied to the bottom face. This test was to simulate the internal issues of constraining the top part.

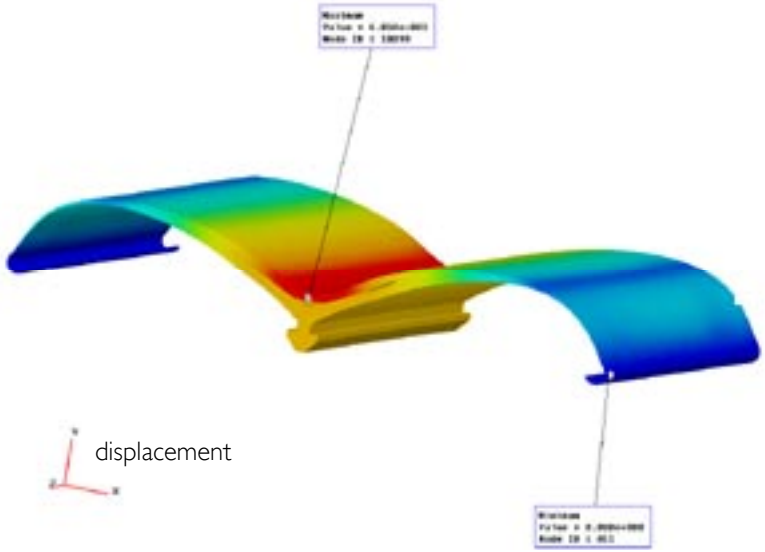
Tests of this nature were also done on early versions, and help shape the current design. These tests can be used to further minimize the material in certain locations and provide a more stable durable product. These tests can only give the designer a better idea of the forces acting within the part it's self. Many other factors have to be accounted for that were not included in these tests. Given the roof conditions, temperature, elements, radiation, and time become an issue. Many of these can be accounted for through material selection. However the cyclical nature of large temperate fluctuations overtime are difficult to simulate.

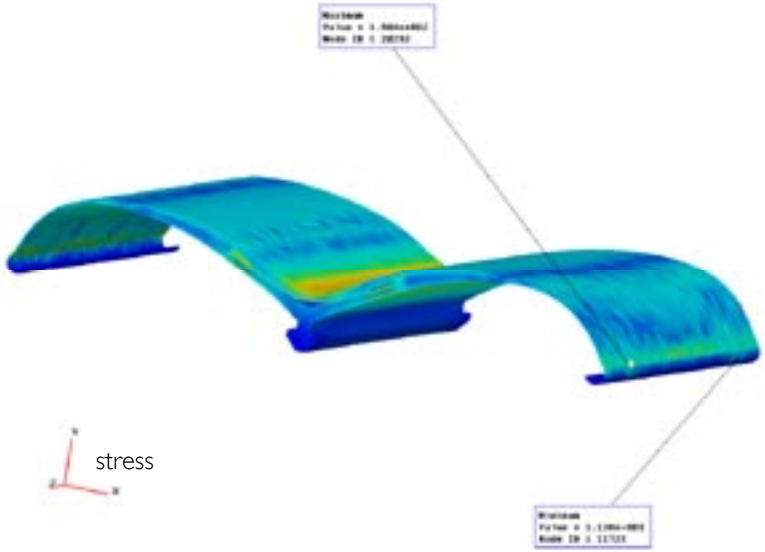
Extrusion FEM

Top Half
Down Force



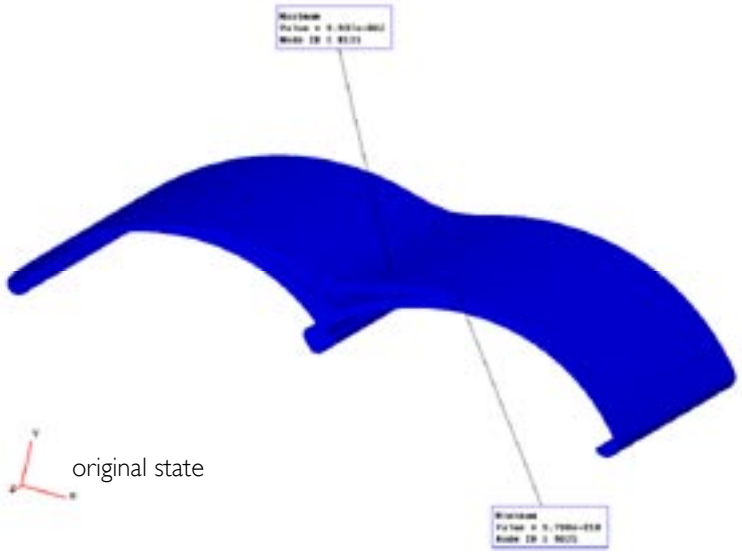


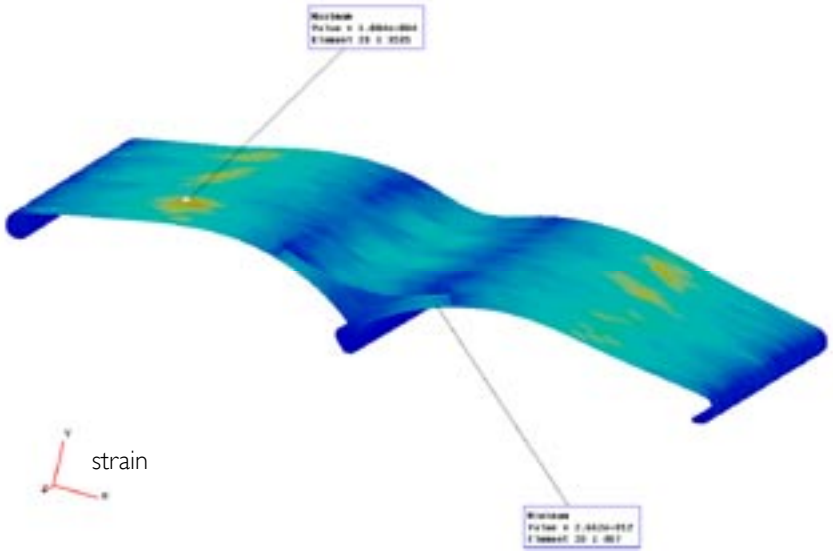


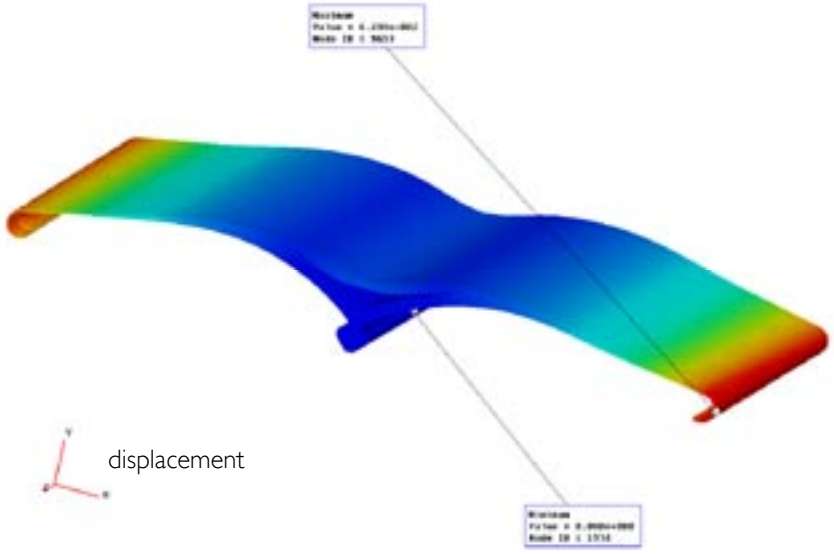


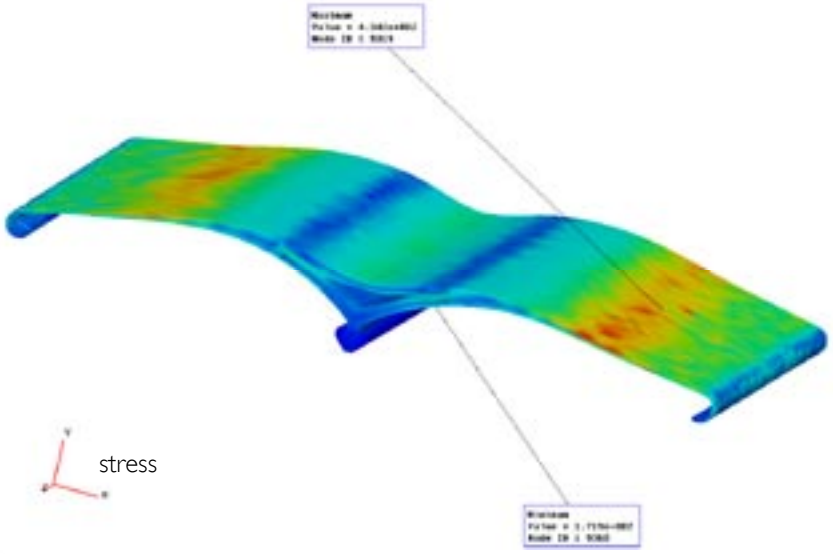
Extrusion FEM

Top Half
Up Force



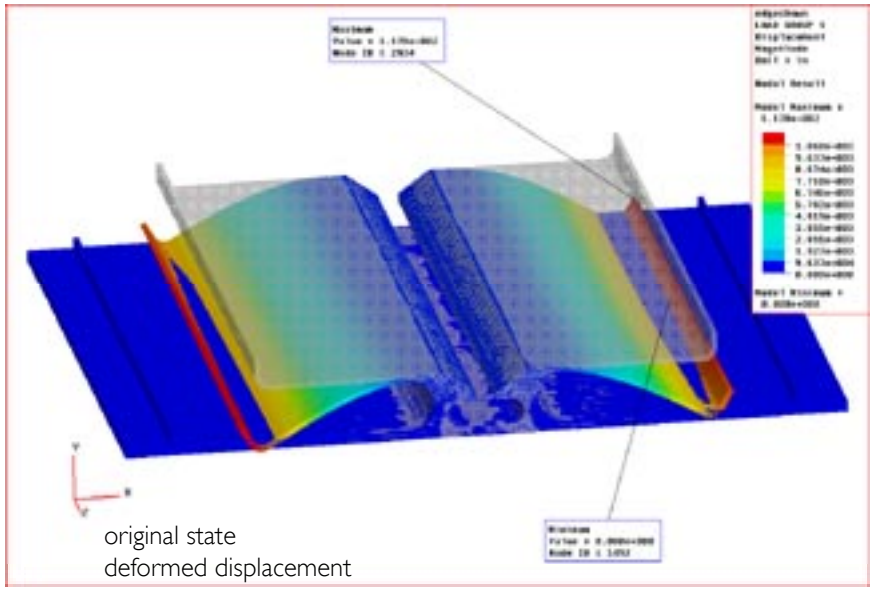




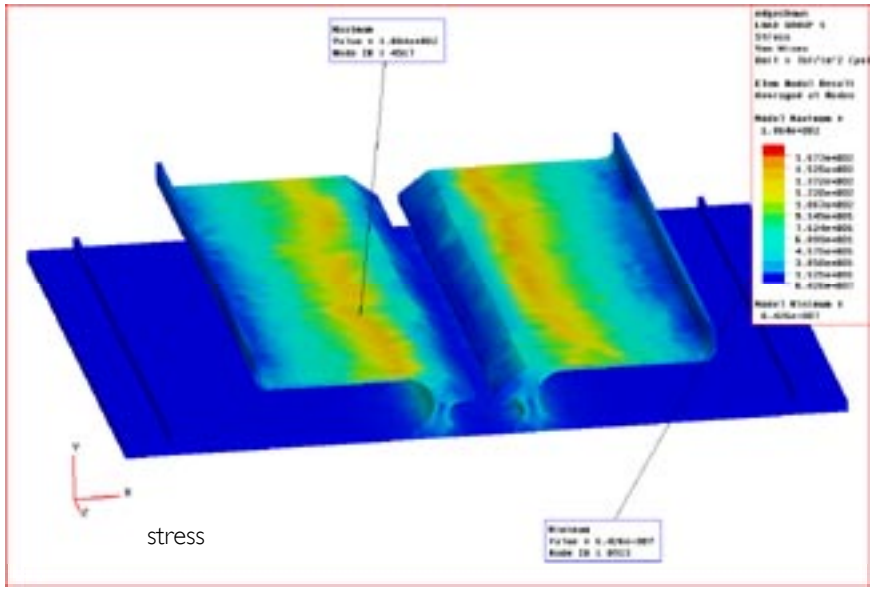


Extrusion FEM

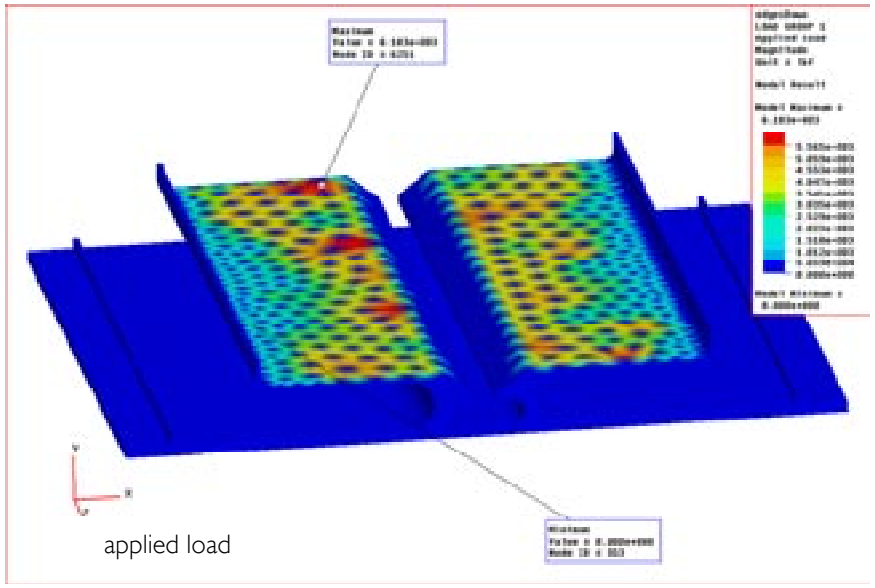
Bottom Half
Down Force



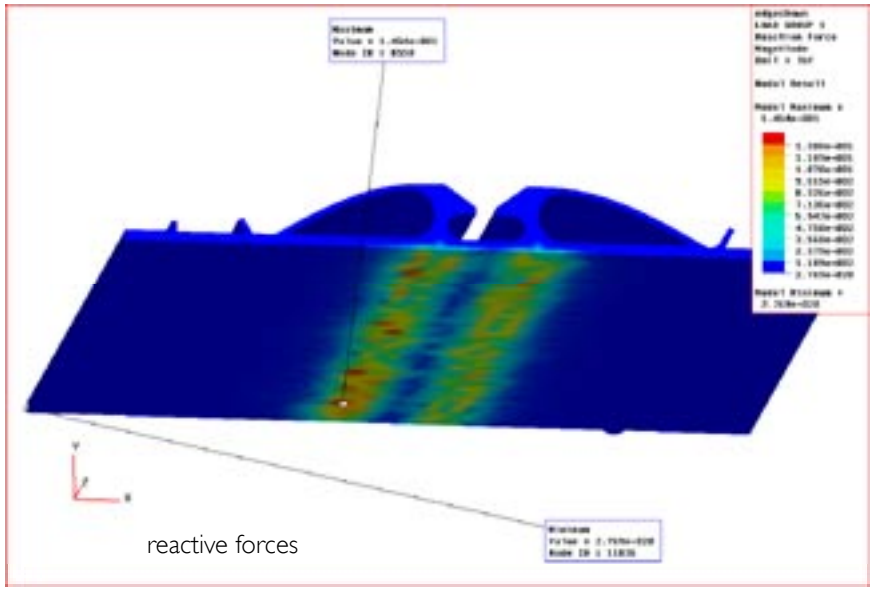
original state
deformed displacement



stress



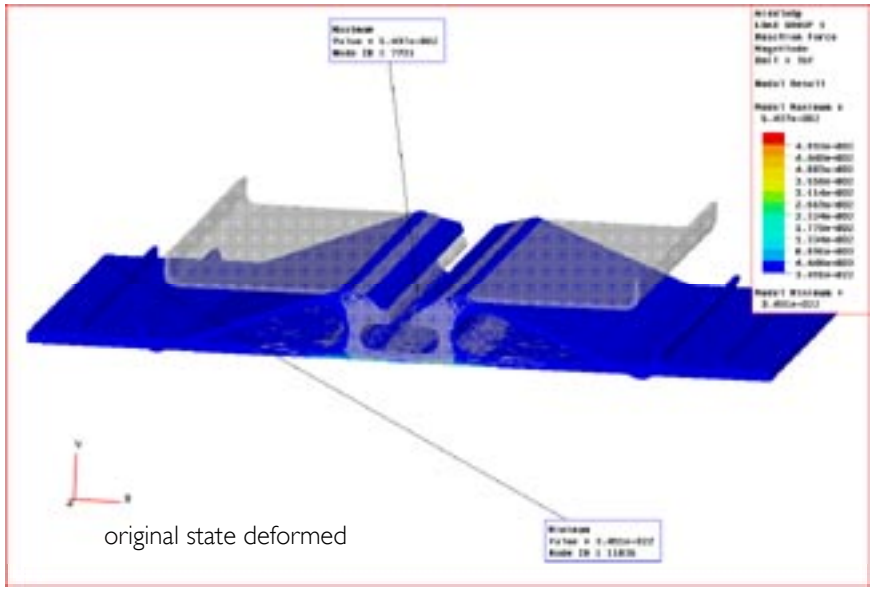
applied load



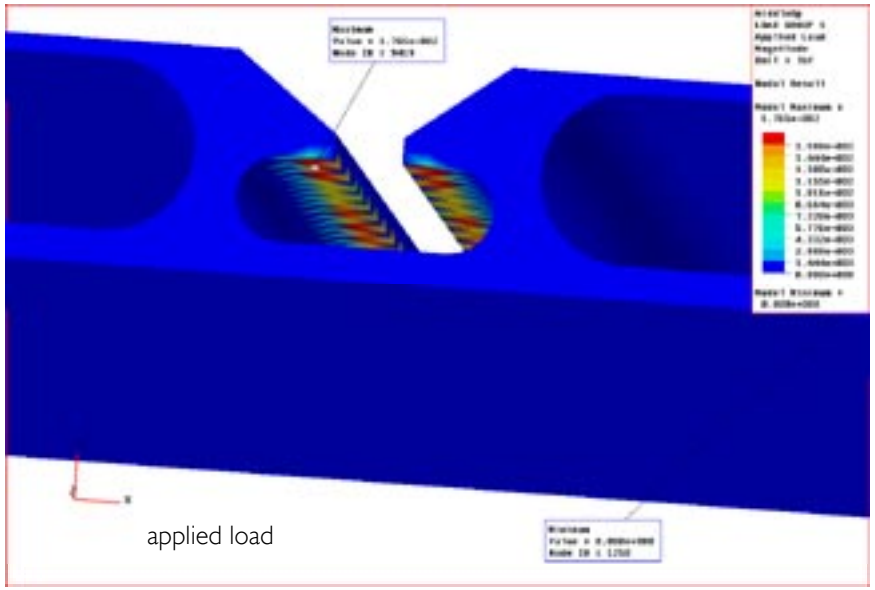
reactive forces

Extrusion FEM

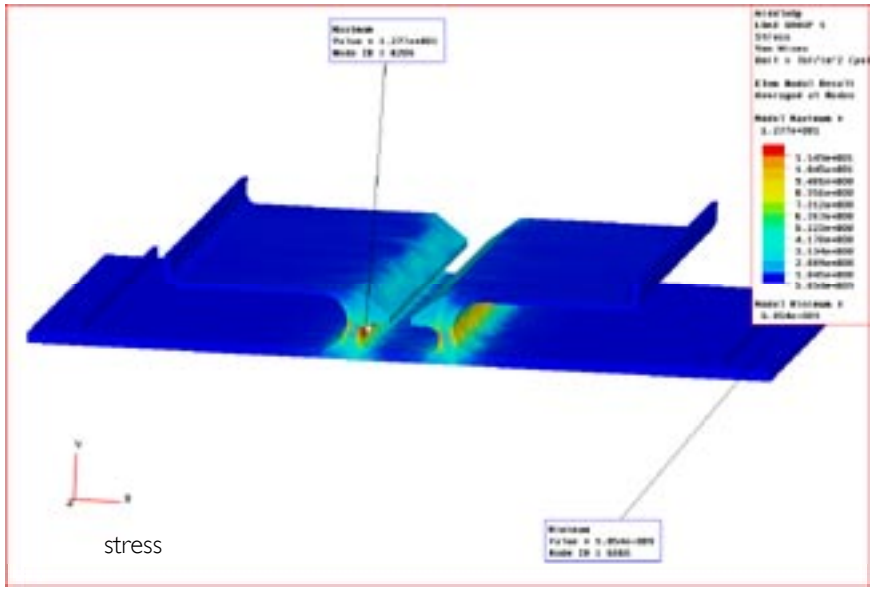
Bottom Half
Up Force



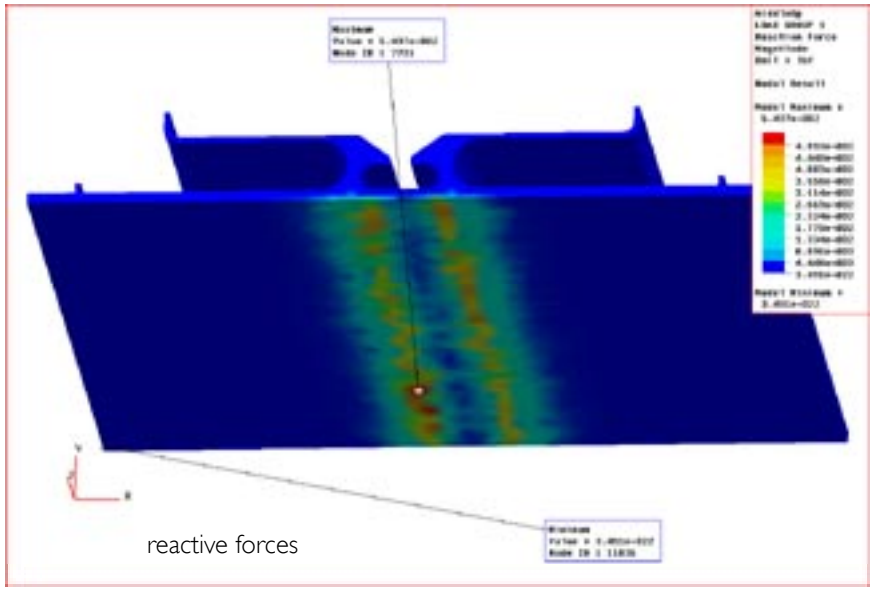
original state deformed



applied load

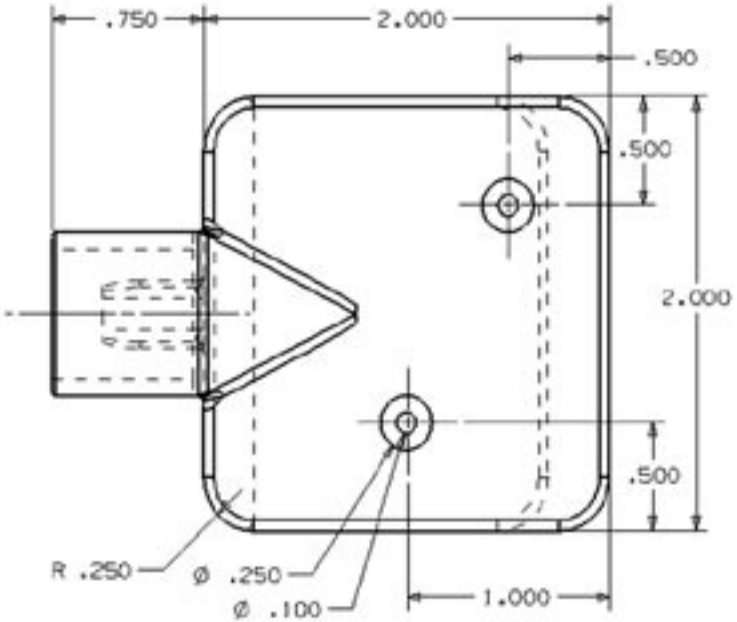


stress

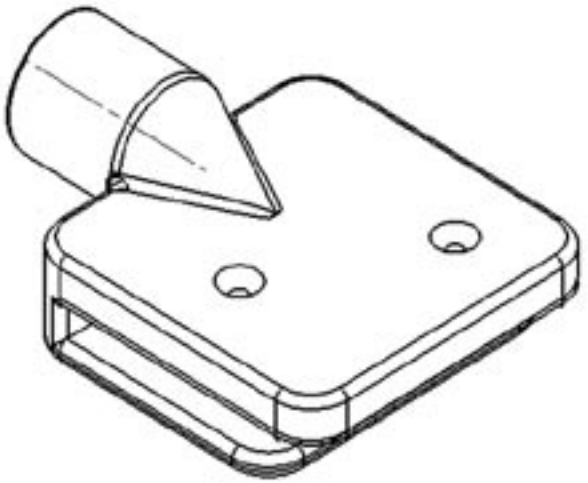


reactive forces

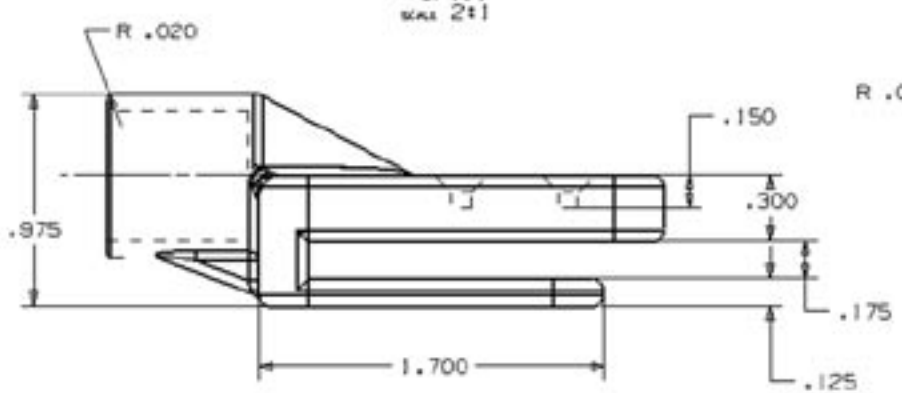
Clip Engineering Drawings



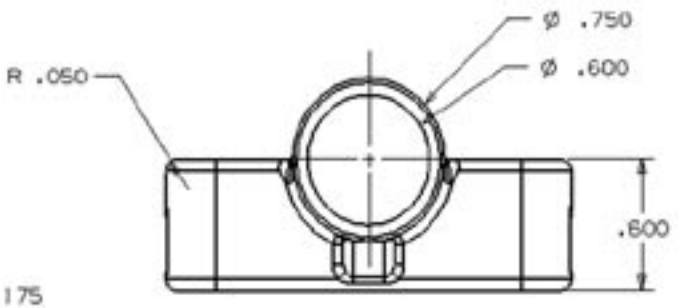
TOP@1 1
SCALE 2:1



TFR-ISO@1 0
SCALE 2:1

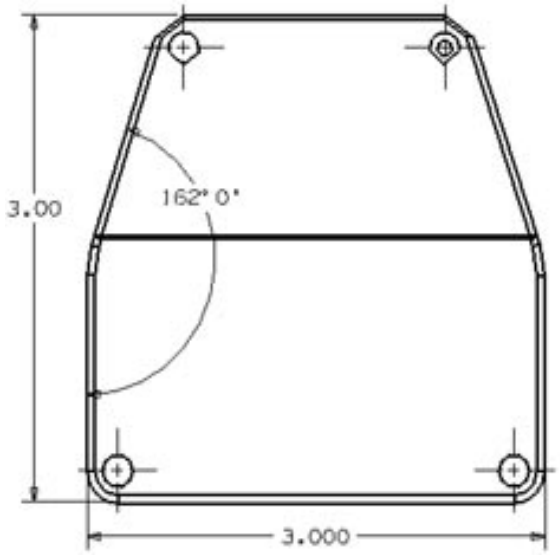


FRONT@1 3
SCALE 2:1

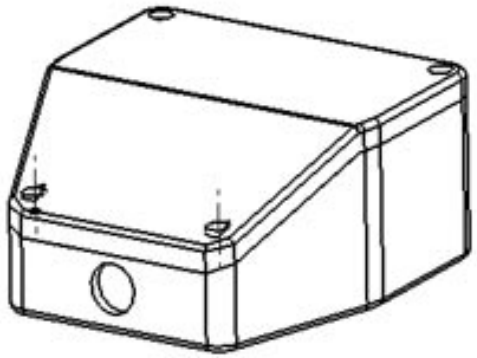


LEFT@1 2
SCALE 2:1

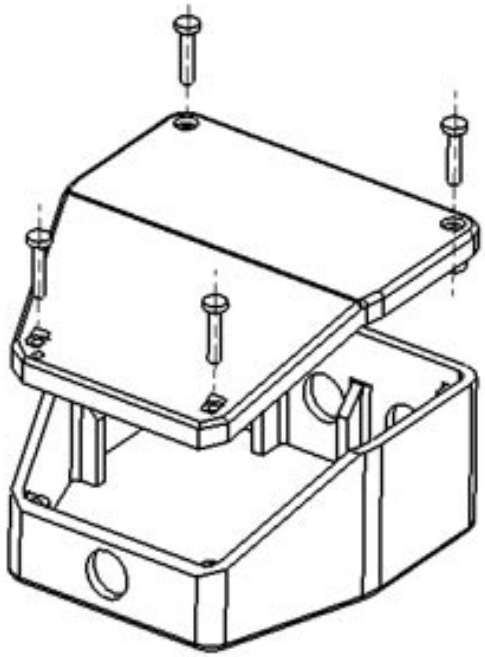
Junction Box Engineering Drawings



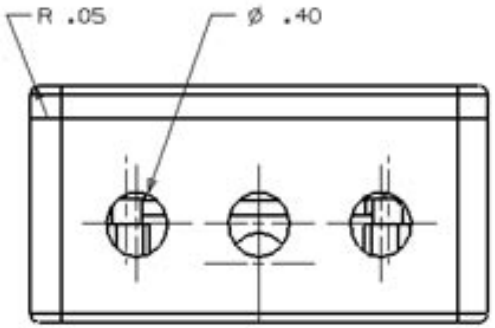
TOP@7
SCALE 3:2



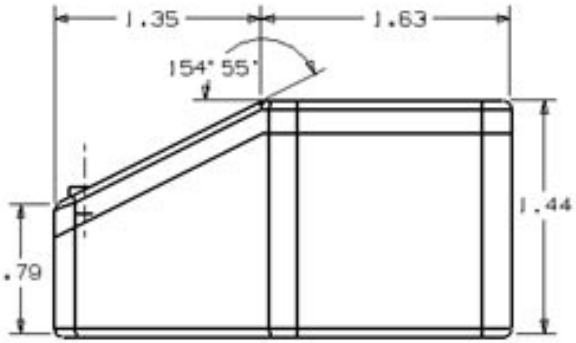
SCALE 5:4



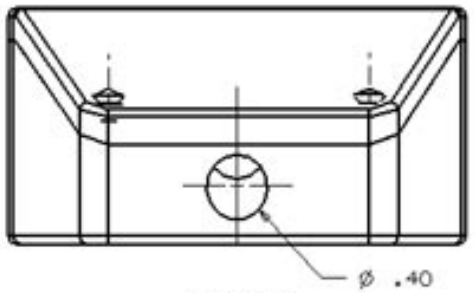
SCALE 5:4



FRONT@8
SCALE 3:2

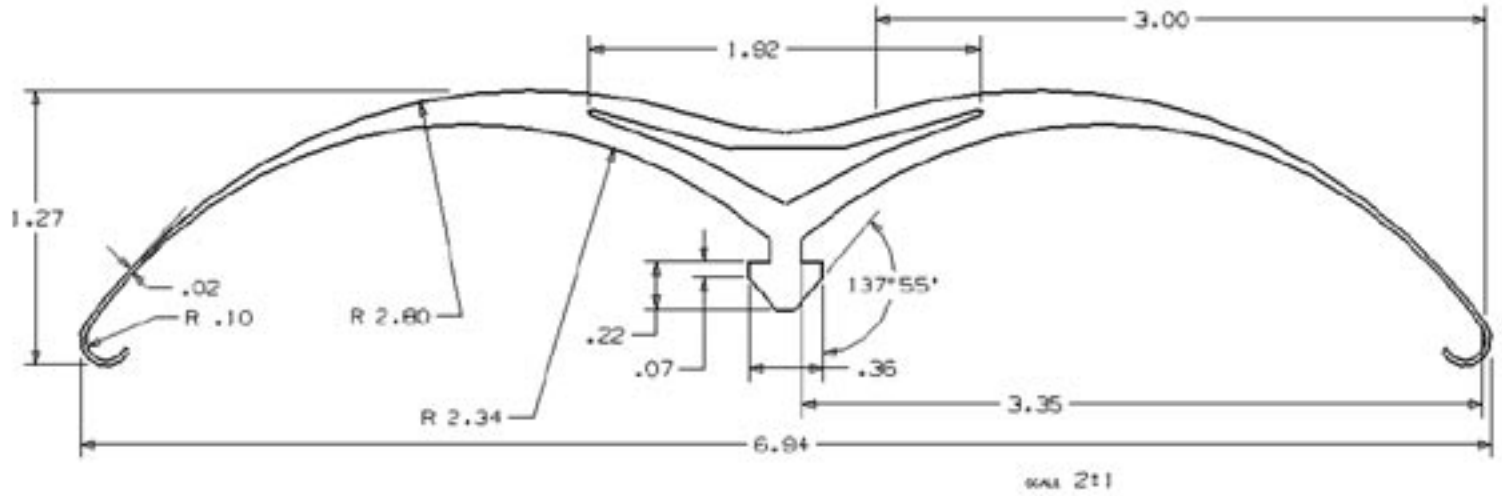


LEFT@9
SCALE 3:2



BACK@14
SCALE 3:2

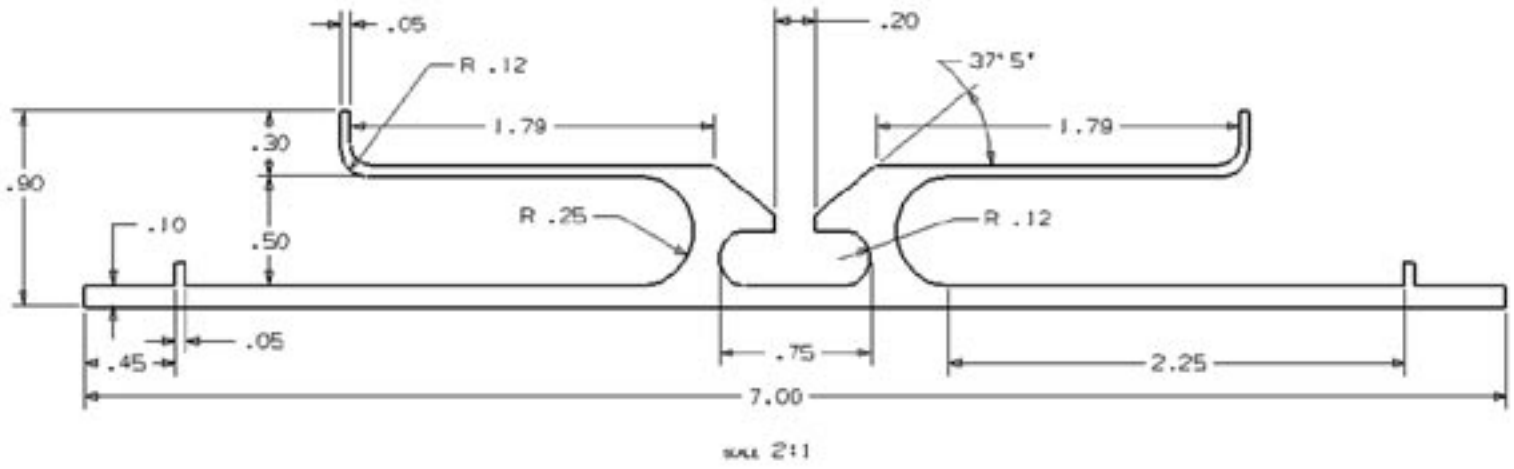
Top Extrusion Engineering Drawings



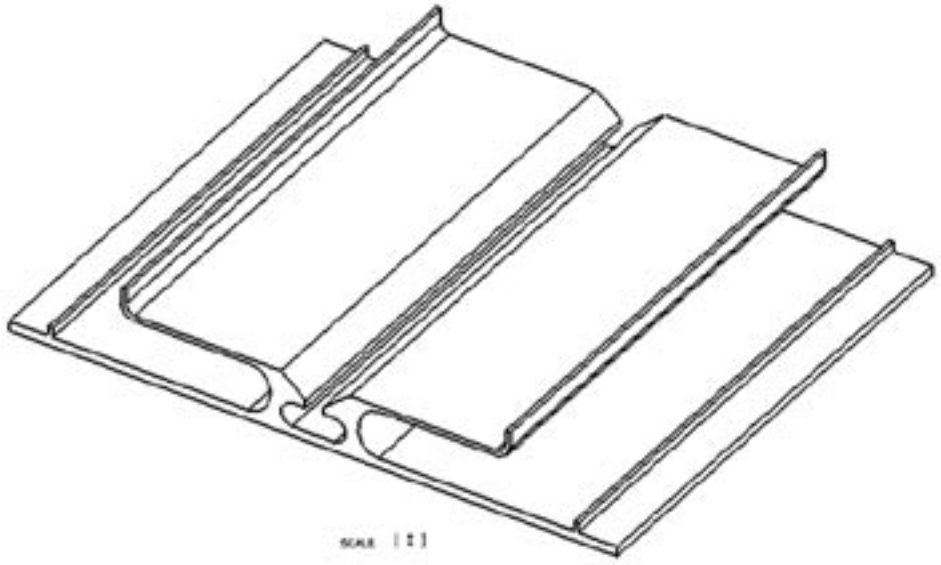
SCALE 2:1

SCALE 1:1

Bottom Extrusion Engineering Drawings



SCALE 2:1

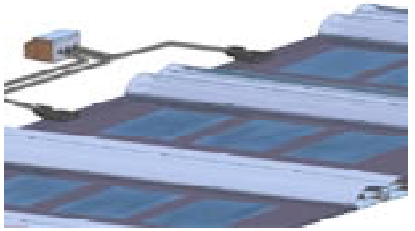


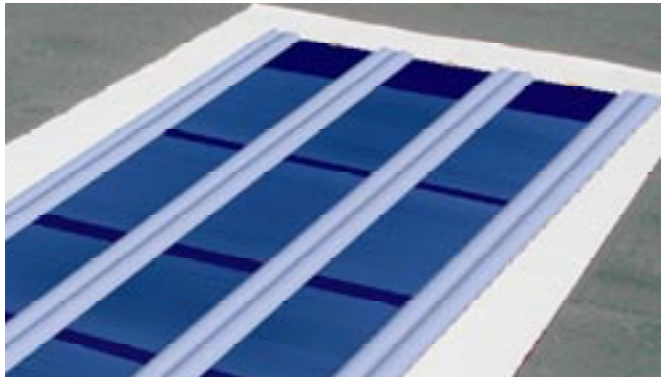
SCALE 1:1

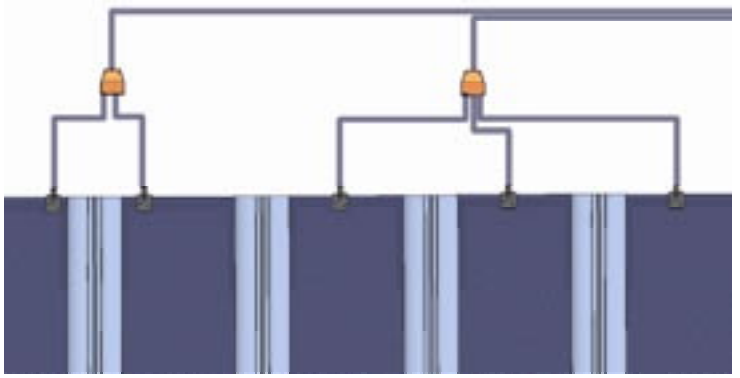
Overall System

The picture of the roof models the system on a low-sloped roof with and Acrylife membrane. Below is one four feet wide roll of Acrylife membrane with three panels in place.

The renderings on the left show a typical wire layout for the system, with the panels feeding to the junction boxes, and the boxes feeding to the main system.







Conclusion

Summary

The report summarizes the work conducted over the course of a semester into the integration of United Solar photovoltaic panels, and an Acrylife polyvinyl roof membrane. For the solution presented several assumptions were made. Further investigation will require relaxing, or changing some assumptions as the process continues.

Areas of Future Research

Electrical Connection
Wind Uplift
Long Term Weather Affects
Prototype Site Test

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Appendix A