DIY SOLAR PANELS

YOU CAN BUILD THEM!

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SOLAR TECH DIY, INC

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You CAN Build Them!

By Patrick J. Minns MBA

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Patrick J. Minns

Index Sheet – VQR Bar Codes in Chronological Order

*5:*36 How-To maintain solder tips

0.29 How-To recognize damaged solder tip

11:43 How-To establish length of tabbing wire strip

5:33How-To determine tension bend location

16:30How-To create a “Pair” of solar cells

3:28 How-To test solar pair indoors

16:21 How-To Connect “PAIRS” to create STRINGS

8:53 How-To add the 9^{th} solar cell to a string

0.27 How-To move a STRING onto substrate

8:13 How-To connect STRINGS by the end-runs

1:03 how to properly open caulking tube and gun”

10:19 “how to apply clear silicone caulking to tabbing wire

8:21 How-to build the 1st leg of POSITIVE outbound lead

2:30 How-To set up outgoing NEGATIVE lead to battery

5:14 How-To de-air solar panel encapsulant via vacuum

14:14 How to pour Solar-Tite 384 encapsulant

11:55 How-To remove trapped air under STRINGS

1:29 How to install Tedlar Backsheet

10:01 How to seal Tedlar Backsheet

10:11 How-to repair solar cells, BUS BARS that won’t adhere

1:18 How to test solar cells repaired with conductive paint

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Table of Contents

A special work of thanks must go out to my wife and children who supported me through all of the work required to produce this book. Further, this work would not have been possible without the support of Nitza and Izhar Shy Ph.D., for whom a brief mention herein is hardly sufficient to convey my heartfelt and sincere thanks.

Introduction

Have you ever seen solar panels in use somewhere and thought, “That’s a great idea. I am going to do that”? However, after pricing the solar panels, did you give up on your idea because of the high cost of those solar panels? Perhaps you have recognized the usefulness of smaller solar chargers for things like charging cell phones, powering security cameras, or security lighting, but you discover the smaller solar panels are nearly as expensive as the larger ones?

My experience was with an RV owned by a close friend who had paid a small fortune to have his RV outfitted with solar panels and deep cycle batteries that gave him unlimited dry camping range. While he could camp virtually anywhere in the open desert, I was tethered to the KOA campground, dependent on access to the electric utilities at the campground to enjoy all the amenities and appliances in my own RV.

I have always been a DIY (Do-it-Yourself) enthusiast, and I viewed my friend’s RV through those “DIY” eyes. After examining his solar panels I thought, “These solar panels were built by some process that I am going to learn.” I researched solar panel construction techniques, and I discovered a methodology that could be done at home using tools I already owned. I began handcrafting solar panels, and while the earlier versions were primitive, they performed reliably for several years before being taken out of service, replaced by units benefitting from my improving skillset.

In my quest to find the knowledge I needed to handcraft solar panels, I read every book available on the topic and watched every YouTube video as well. What I found was a patchwork of information that often left me confused in the face of differing opinions, and widely varying methods for handcrafting DIY solar panels. A frequent and most common cause of frustration was the obstacle of technical jargon. Demonstrators of what appeared to be highly effective methods were catering to an audience already well versed in photovoltaics.

In order to make sense of the various sources of information, I conducted experiments, and through trial and error was able to eliminate methods that did not work while adopting those that did. I attended electrician school in order to learn basic electrical theory so I could evaluate information through a trained eye, so to speak.

I discovered that people were very interested in my solar panel building activities. Neighbors would come watch me work while I was handcrafting solar panels; most being intrigued by the possibility of them participating in the activity. In 2011 a power outage struck Southern California, large swaths of Arizona, and into Mexico. At the time I had an array (collection of solar panels working in concert to generate electricity) containing a dozen DIY solar panels. I also had a large bank of deep cycle batteries; as a result, our house had lights, Internet, and hot water.

The effect of one house having light when all around my neighbors did not, lent for a very dramatic visual statement. I had the entire cul-de-sac at my house examining my solar panels, and it occurred to me that I am onto something. I was onto the notion that I could pass on the knowledge I have gained in a language that is straight forward, but still teaches the principles necessary for successful handcrafting of solar panels. I would do away with the technical jargon that confused me; as well as, the assumption of technical proficiency. I would present the material in a straight forward manner gradually exposing and introducing terms and concepts. The reader will come away with a deeper understanding without needing to Google search terms encountered while reading this eBook.

The only readers who may have an issue are those with more advanced knowledge on the subject. They will notice that I wrote to readers that have never built anything, certainly never soldered before, and the descriptions of actions are in minute detail. This is intentional. Readers who truly have no previous experience will be able to digest what I have written, and actually understand the instructions. More importantly, the instructions are supported by illustrations, and the major tasks are demonstrated on video.

Square bar codes known as “VQR” (Visual Quick Response) bar codes have been provided to link the reader directly to my YouTube channel. Each VQR bar code is linked to a unique and exclusive how-to video that pertains to a specific task necessary to handcraft a solar panel. Each video is narrated, and recorded from the perspective of a person completing the task. In order to watch the videos you must download a free App from the App Store on your smart phone, the specific App I am using is “Visualead”, a free App that I used to create the bar codes.

I am confident that upon completion of this eBook you will be ready to handcraft your own solar panel even if this is a totally new competency to you! Moreover, this book applies to a broad age range. With parental oversight there is ample reason to believe youngsters around the age of twelve are capable, and the upper age limit is bound only by the physical limitations of the participant. The information contained herein will lay the foundation upon which you may start on the road to energy independence. With this eBook, you have knowledge, and as they say, knowledge is power. So whether you are looking to handcraft small solar panels to charge cell phones, or build large solar panels for an off-grid cabin, this is the ideal source of information to kick off your entry into the world of photovoltaics. Good luck!

Section #1 Choosing a Workspace, Securing “WIP”, and Patience

The first step must be to find a reasonably secure work area because it can mean the difference between satisfaction when working on a solar panel, or ghastly frustration when someone or something breaks your work-in-progress. I speak from experience. I learned the hard way that delicate solar cells break about as easily as Pringles. As you progress in the steps required to complete your solar panel, you will gradually and temporarily need to enlarge your “secure” workspace to encompass an area at least as long, and wide as the project you are currently working. What does “secure” mean? I will answer that question below, but I want to touch on a vocabulary matter you may encounter very quickly. I refer to the construction of your solar panel as “handcrafted” because you are indeed building a useful survival tool with your wits, hands, and tools. There is tremendous satisfaction connected to this activity because every aspect of what you are doing is positive. It is healthy for you, your wallet, the environment, and as a positive example for family, friends, neighbors, and co-workers. You are displaying a sense of stewardship for this planet on which we depend for our own lives, yet are depleting at alarming rates. I also refer to this activity as a “trade”, because in a sense, you are learning a skillset which may become a source of income for you at some point in the future. At the very least you are employing the skills to SAVE money if directed towards offsetting your grid-supplied electricity. Every watt you generate for free is a watt the electric utility provider won’t charge you for.

Secure means a work space that can provide protection for your WIP (work in progress) from accidental damage of all types throughout the life of the project. I cannot stress enough how frustrating it is to discover that a careless incident has shattered a string of solar cells nearing completion, or worse, the entire solar panel. The waste of time and money notwithstanding, it is demoralizing to see the results of your loving attention destroyed by random carelessness. It is the type of thing that makes one want to throw in the towel, so don’t let it happen to you. The vulnerability increases once you walk away from your work area because your WIP will be laying out, unprotected, for all to see and, well, drop things on. It is a phenomenon experienced by many in the trade, the physics-defying ability of sensitive and fragile solar cells to attract foreign objects to fall on them almost as if they are magnetic! I joke of course, but the point is that the statistical probability of damage by foreign object is directly proportional to the frailty of the objects in danger. I made that up even though it sure does sound scientific, but oddly, it seems to hold significant validity. I have a whole picture worth of proof on the next page to support my theory on the matter that solar cells break easily when impacted by anything more solid than say, a few grains of sand dropped from about 2 mm.

One of the most important considerations when selecting a work area will be to provide physical protection for the WIP from the moment the solar cells get exposed; to the day you transition the finished product to use generating clean, free electricity. The initial work area will require a small footprint, approximately the size of two solar cells wide (whichever type solar cell you are using) for soldering pairs, the first component needed to start putting STRINGS together. Since any sizeable solar panel will contain multiple STRINGS of solar cells soldered together in order to form the complete unit, building the requisite number of STRINGS takes a few days. The completed STRINGS will require a very safe place to sit while the remaining STRINGS are hand-crafted, somewhere safe from accidental contact with foreign objects, dust, or liquid. I suggest using those plastic storage tubs that are designed to hold wrapping paper and narrow enough to fit under a bed. They are long, flat, and can indeed be used to shield the waiting solar panel components until being mated with a substrate and protective cover. There are so many options that you are limited only by the boundaries of imagination.

I warn you in the most urgent terms avoid the foolish notion that because you live alone, or only with other adults, or with fellow hobby enthusiasts, that nothing could happen to your WIP. Please, don’t tempt fate, your siblings, your rivals, your children, in-laws; I think you get the idea. I once watched in seemingly slow-motion as my son absentmindedly tossed a hard cover book onto a desk where I had left my project unprotected. The book landed squarely on top of a newly soldered 4-cell mini-STRING shattering them all and while angry, I had only myself to blame. From the moment you open the protective wrapping around the bundle of solar cells until they rest under the protection of their final covering they are vulnerable. Breakage is the first threat because as I hinted earlier, they are indeed very fragile and they do break easily if handled roughly or if impacted by falling objects. I have many examples as you can see below.

FIGURE 1.1 This is a collection of broken cells from a decade of handcrafting solar panels, and while it may seem daunting, it is just part of the territory when practicing this trade. The goal here is to learn from my mistakes so you don’t end up with a collection such as this. If you DO happen to break solar cells, it is not a problem, you will get the feel for how to handle them in short order, but it will save you lots of grief by paying heed to my warnings about securing your work areas.

Patience: I would be remiss if I failed to touch on the issue of patience. There is a learning curve associated with any new activity, no matter if it is learning to play soccer, or learning this fine trade of handcrafting solar panels. There is no such thing as an established timeline to gaining total proficiency in all aspects related to handcrafting solar panels because every person has a unique learning ability. I recall vividly the first time I had solar cells laid out to solder for the first time, never even having soldered wire before, hands shaking; confident I had gathered as much information about doing it as humanly possible. All that was left was to dive in, and to be honest, it wasn't pretty in the beginning. I broke many solar cells as you see above, but as I honed my skills, the occurrence of broken cells became less frequent. You will also achieve proficiency in your own time, so keep the occurrence of broken solar cells in perspective and remember, it is part of the learning curve.

The project is NOT a foot race; you are not in a contest measuring your speed against anyone else. Take your time, focus on the task at hand, and recognize that there is nothing gained by working too quickly, perhaps outstripping your skill level. I like to refer to the old adage, "measure twice, cut once" taking extra time to verify my measurements, wire lengths, cell positioning, etc., before committing permanently via solder, bolting, or encapsulating. Hurrying a project will only increase the likelihood that a mistake will be made, a solar cell or two broken, and the possibility that your solar panel will not generate electricity. If you have made an error due to impatience, it is not likely that you will catch the error until the point at which you are testing it in the sun, at which time it is too late to make adjustments to the project, and you will be frustrated beyond words. Of course it is far better to avoid the mistake in the first place, but mistakes do happen, I make them, as will you, the trick is to learn from them and move on. Generally, if you are able to recognize an error early on, there is nothing that cannot be repaired or redone, but ONLY if you catch the error before encapsulating the solar panel. After that, the chances for repair are slim at best; such is the nature of encapsulants, since they provide permanent protection against the elements as well as human fingers attempting repairs. If you cover the solar cell with Plexiglas instead of using encapsulants, there might be a chance of repair but do you really want to be tearing apart a solar panel at the point where you would otherwise be putting it to work? Let me answer that for you, No! Time is better spent doing it correctly the first time around.

Frustration: On occasion you will run into situations that find your patience stretched to the limit. If you are learning this trade from the ground floor, you may encounter situations that you are unfamiliar and perhaps uncertain how to proceed. That is normal in any learning situation, it is how you react to sticking points that will determine whether you can move forward and overcome the obstacle. Getting mad and letting your anger get the best of you will only set you back and possibly thwart further development. Unfortunately when we get frustrated and angry, the things our bodies do to prepare us for either fight, or flight, are counterproductive to the task at hand. Adrenalin coursing through our veins does nothing for hand stability, something absolutely necessary for soldering and keeping the solar cells in-tact. Nor does it lead to rational problem solving, again another critical ingredient for success. It happens, it is natural, and it can be a destructive force if it gets away from you. Once that point is reached whereby vile curses are rolling off your normally mild mannered tongue and you are looking around wild-eyed for some lesser creature to go take out frustration on (don't do that!!), all is lost for the moment. Once to that point of broiling frustration it is time to push away from the project and go take a break.

Related directly to this point is a set of instructions I once read in a manual about the use of lock picking tools. The manual stated that the reader will encounter locks that defy initial attempts to defeat during the learning process, and then goes on to reassure the reader that frustration was normal, and that it is perfectly fine to take a five-minute break. What caught my interest was the next line which I now paraphrase and offer to you as advice, and that is **to return to the project after cooling off!** Very important that you return to the project and get a positive success for the session to maintain your enthusiasm. Like anything else in life worth doing, it takes time to learn proficiency. If we gave up on new things simply over frustration, life would be a very narrow tunnel indeed. Like the saying about riding bicycles or bucking Bronco's, if you fall off, take a deep breath, steady yourself and get right back on. They say that if you don't, it will be a long time if ever before you screw up the courage again. Besides, you have an advantage over the hapless bicycle or Bronco riders in our example because unlike them, you aren't thrown from the abruptly stopped or violently bucking Bronco and hence, don't have to suck wind back into your impact-deflated lungs or pick pebbles and sticks out of your bicycle road-rash. The WIP is there waiting for you once the calm has returned and you are ready to face the obstacle and win the day. Once calm, I have always found the resolution laughably simple and nothing I should have become excited about in the first place. I trust you will find the same condition to be true and I will take it farther and state with confidence that when you look back after completing the project, the sense of accomplishment will far outweigh any frustration along the way. The ensuing solar panel projects will be smoother, quicker, and you will not likely be held up by the same type obstacles because you will be developing proficiency.

Timing: I find this to be a very relaxing activity, the process of soldering and creating something with my hands. I enjoy soldering solar cell pairs while listening to talk radio or podcast, and you may find other ways to make the experience not just enjoyable, but therapeutic. Try to make a daily routine you spend perhaps just thirty minutes soldering pairs of solar cells together, working steadily towards the completion of another solar panel. It should not be a chore to handcraft a solar panel because if you see it as such, you will avoid doing it. Always return to the core reasons you chose to get involved whether founded in environmental concerns, or purely economic reasons; then slowly and steadily work towards your personal goals.

Section #2

A) Hand-Crafted Solar Panel, Just Before You Go "WIP"

Just some background so I am not humming the Star Spangled Banner while you hum My Country Tis of Thee. I am trying to fill in every blank that left me scratching my head when I first started because I couldn't find answers anywhere.

Tools of the Trade: There are a few tools one must have in order to handcraft solar panels. The good news is that the cost associated with "gearing-up" is not extreme; in fact, I would have to say it is very inexpensive to enter this trade.

Soldering gun or iron - minimum of 45-watt, with the wide tip. A word to the wise on equipment such as this, stick with brand names with proven reliability. My preference is the Weller Soldering Gun 8100-B, 100-watt but there are several models available from this trusted brand.

Spare soldering tips - at least one pair on hand at all times. You should also have a collection of tools needed to keep the soldering tools clean to include a sponge, wire mesh dipping tray, and a stand to rest the soldering gun/iron on during use.

Rosin core solder - iron-free-99.3% Tin, .07% Copper. It doesn't need to be this exact mix, but melting points should be approximately 350° F.

Flux Pen - Kester brand, #186-needed to bond the rosin core solder to the surfaces being joined. Any brand pen will suffice.

Probes and Pokers – (Pictured on the next page) tools with which to hold down delicate tabbing wire or to move parts without having to use potentially oily fingers (which might compromise the solder). Also, when using the solder gun the temperatures can exceed 400° F, capable of inflicting serious burns to flesh, so the use of probes help keep flesh off the hot parts.

Weights - to aid in positioning of solar cells and tabbing wire prior to soldering because things tend to move when contacted by the solder tip. Sockets from a tool kit work well but virtually any dense, heavy and appropriately sized object. It is a good idea to apply a soft non-slip coating to the bottom of the metal sockets, preferably something that will provide protection against scratching of the solar cells like a rubber plumbing gasket material. Simply cut out a piece of rubber and attach with two-sided tape (so you can tear it off if you need to use the socket). Always use great care when setting the weights down onto a solar cell! Gently lower the weight onto the target and set it down ever so lightly.

Safety Glasses – to protect eyes against foreign objects.

Wire Cutting - you can use small scissors or small wire cutting tools.

Magnifying Glass - for close inspection of solder joints, inspecting solar cells for cracks, or if you have questionable eyesight, a hat-like device with a magnification lens that can be rotated down for hands-free magnification.

Measuring Tape - or ruler, yardstick, or flexible-soft measuring tape. A three foot yardstick is useful.

Yardstick - a thick wood model is preferable because you will use it to draw straight lines on the substrate (the surface that you mount the strings of solar cells in the final stages of assembly). Straight lines are essential in solar panel construction whether physically drawing out the solar cell pair placement on your work surface, or tracing the outline prior to cutting your Plexiglas covers.

T-Square - typically a tool used in the drafting trade, this is a valuable tool for ensuring with 100% certainty your lines are at true angles such as when tracing your substrate cutout pattern. Throughout your design and construction phases accuracy is absolutely critical! Corners have to be 90° or things simply will not fit making it look amateurish and difficult to weather seal. I can live with amateurish but unfortunately the life of the solar panel depends on a moisture free environment. I use the same T-square I bought in 1982 for a high school drafting class in virtually every project I have ever done as an adult.

Combination Square - because it is such an accurate tool for giving you the PERFECTLY sized template for the tabbing wire strips you will be cutting, or for drawing outlines on a smaller scale. An excellent all-around measuring tool with leveling capabilities which you will need later.

We are DIY people, otherwise you wouldn't be reading this, nor would I be writing it. There is just something about that feeling of pride, of fist-pumping, back-slapping, you just pried your dog from the jaws of an alligator type primal feeling of victory when the _ _ _ _ _ _ (fill in the blanks) actually works!!! Like that feeling you get when you plug your own flat tire after you had priced it at the local tire retailer at $120 installed, with a patch kit that cost under $5. The examples go on and on, and I bet each of you has a great success story to share. I am confident you know the feelings of joy I describe.

The funny thing is that in all that back-slapping we tend to gloss over the more unpleasant obstacles we overcame to finally achieve success. The best way to avoid a negative outcome while handcrafting a solar panel is to maintain a clean, organized, and clutter-free work area. No, I didn't just land on this planet from Mars. I live here as well, and have the same space restrictions as most. Unless you are fabulously wealthy, and have a few extra hobby rooms or a seven-car garage, you will have to carve out space perhaps using mining equipment and explosives. I will give you the bullet points, and you find what works for you. The following is a list of what is involved in the identification of a suitable area to ply your trade. You will need…

Sturdy Surface - you won't be pounding horseshoes on an anvil but you need a surface that will be level, and steady. You will be performing delicate work requiring a steady hand, so a wobbly table won't work. It can be a plank of wood laid across a dozen cinder blocks if that is all you have, just make it steady enough to lean on without resulting in vibration.

Project Surface - the surface that you will be soldering on, staging your pre-cut tabbing wire, recently soldered single and paired solar cells, soldering support sponge, and poking/holding tools for the duration of your project. It should be sturdy enough to be carried as you transition from active work, to securing your WIP between sessions. Glass is ideal for soldering on because it dissipates heat efficiently thus reducing the occurrence of heat related solar cell fractures. Ceramic is also good such as the type used in decorative tile walkways or industrial walls, the trick is to find a single piece large enough to work on while joining solar cell pairs.

Light - has to be sufficient to clearly illuminate the project surface mentioned above. If you are in a fixed area where you will regularly work, LED lighting is excellent for producing high lumens output as well as brightness. LED fixtures are currently very expensive; a typical four foot LED style fixture is $100 at big box home improvement stores. A more economical way of getting LED light from an existing 48" fluorescent light fixture is to purchase special 48" LED bulbs that fit exactly into the existing two-prong slots. You must do some simple rewiring of the fixture, basically bypassing the ballast, and for $40 you get the full benefit of LED lighting. One could also simply install an LED light bulb into a standard clamp-on work light and have very strong light for under $20. Enough about light, you simply need quality illumination.

Air Circulation - because toxic fumes are created during the soldering process, there needs to be a source of fresh air to evacuate any lingering smoke or fumes.

Organization - is a very important trait to have in this trade. Keeping your work surface clear of trash, clutter, wire clippings, anything that is foreign to the project should be put away immediately after use. Things tend to get broken when too much clutter starts to encroach on the work area. You control the space so there needs to be tight discipline regarding the sanitation and organization of the work area. If you maintain strict standards over the organization of your work area, getting cooperation from people with whom you cohabitate will be easier. If they see a pile of goo, they won't feel overly hesitant about tossing on a few more trinkets or trash, and in doing so being totally unaware they just smashed your newly completed string of cells. Conversely if the work area is clean, orderly, and free from clutter, others will be less likely to deposit foreign matter because it will be slightly more obvious who started the trash pile?

Secure Storage for the WIP - as I touched on at some length earlier, nothing is more disheartening than to shut down working on your solar panel for the night only to discover that someone in the family missed the memo about randomly tossing sporting gear into the garage upon opening the door, or some similar mishap. I suggested plastic storage totes earlier, the type that slides under a bed as an option but there are plenty of choices available in the storage category of products. You simply need to find what fits into your budget and your environment. If you are industrious, shelves built along the wall in the garage, or high up along the perimeter of some least-used room in your dwelling; just anything to get them up and out of the hands of curious siblings, children, and/or guests.

Dust - won't be found anywhere on the production floor in factories producing solar panels. In such environments the air is purified, filtered, and air curtains help to keep new particulate from being introduced into the production areas. Most of us will be working in our garages, bedrooms, living rooms, and weather permitting, even outdoors. It is unrealistic to expect to create dust-free work space when handcrafting your solar panel in any of these environments but you need to take reasonable steps to keep the solar cells as clean as possible. The nature of this type project means it will take possibly a couple days to complete a solar panel. During this time, some of the completed solar cell pairs, and completed strings will have to sit idle while you complete the remainder of the components. Dust will accumulate on the surfaces of the solar cells, the longer they sit, the heavier the coating. This is why it is so important to have a sealable container in which to store the WIP during these periods. Even covered and inside a container, some dust will accumulate over the upward facing surfaces. Not to worry, a layer of dust at this point can be dealt with successfully, you simply do NOT want to encapsulate or install the final covering until the dust has been removed. How you ask? Gently brush the dusty surfaces with a soft paint brush; I use artist brushes made by Plaid, soft nylon and natural fiber bristles that gently push away the dust without the risk of scratching the delicate surfaces. They say you should avoid using canned air for fear of static electricity, not something we are concerned about it this application. You may also use a Shop-Vac in conjunction with the hobby nozzles (pictured on the next page) to give you pin-point precision when cleaning the WIP. Why is dust a concern at all? It is well known in the field of electronics that dust acts like an insulating blanket because it traps heat underneath the layers. Heat is a universal enemy to electronic equipment to the extent I am willing to bet at least one of us has lost a desktop computer to the ill-effects from dust. Heat causes computers to slow down as their internal self-defense protocols react to heat by shutting down in a process known as "Throttling". This process acts on a computer CPU (central processing unit) like "shock" does to the human body when facing some significant injury to include those resulting from excessive heat. Shock preserves blood for use exclusively by vital organs like the brain, cutting off the blood supply to other organs because the body sees them with lesser priority in terms of the developing crisis. Throttling helps reduce heat in the computer by shutting down functions that are contributing to the heat which is manifest by slow performance and at worst, a completely blue screen while the computer tries to cool itself. Dust should be eliminated especially in the final stages where the long "strings" are being installed onto the substrate, and certainly just before adding encapsulants. Dust may reduce the curing effectiveness of encapsulants, compounds, silicone sealants, so as you see, there is nothing positive about dust making it onto your final product. The dust removal should be done each time you pull a new solar cell out to solder the tabbing wire strips, dusting with a brush both sides of the solar cell prior to soldering as well as the glass soldering surface.

Gloves, or Not - if you have watched a few YouTube videos on the subject of DIY solar panels, you will have seen every possible combination of work environments, work surfaces, and of course, some glove supporters. Gloves are tools used to help prevent certain contaminants from being introduced onto the solar cell surfaces. Human hands transmit grease, sweat, and oils from our bodies onto the surfaces we subsequently touch as we proceed through daily life. Surfaces we touch collect all manner of contaminants that go beyond the scope of this book, but the issue is of great importance to the task at hand. Suffice it to say that we touch a wide variety of objects in our travels to include our own bodies. Even if we washed our hands before commencing work, human nature will have us touching our faces, hair, clothing, and each time our fingers come away with detritus of several descriptions. I can universally guarantee that nothing on those fingers I just mentioned will have any positive effect on your solar panel. In fact, the contrary is true when you consider that bodily fluids are sometimes very oily or greasy in composition. Dare I suggest an experiment dear reader? Could I request that you wipe one finger across your cheek and forehead and then take note of any sheen on the finger? I am sure there is a study somewhere on the number of times we touch our face, head, etc. throughout the day because we all scratch, wipe, or swipe at ourselves all the time, probably absentmindedly. Either way, formerly clean hands have a way of picking up foreign matter as do hands covered in a glove. Gloves can give a false sense of security because the wearer knows that the solar cells are now safe from oily human skin, but they perhaps don't realize how often those gloved fingers are touching faces, beards, hair, and the like. After the glove itself becomes contaminated the point of wearing them is lost, so I feel it is best to be educated about the need to have clean hands, clean work area, and if you work clean, your final product will be clean.

So You Spilled Soda on…or some other mishap whereby something splashes onto a solar cell or a string already completed. You can clean the liquids off with a very gentle dabbing motion using a soft, absorbent cloth, or tissue. Once the offending liquid is removed, the residue can be cleaned from the solar cell by saturating a small portion of a very soft rag, or Q-tip and gently dabbing the areas in need of attention with rubbing alcohol (isopropyl alcohol).

Residue - The reason for using isopropyl alcohol is that it dissolves most oils, alkaloids, gums, and other things I cannot pronounce, but best of all, it evaporates without leaving behind oily residue. The occasional finger print will come right off with this method. I cannot resist the urge to reiterate the warning about leaving your WIP out in the open when you are not actively working on it. It is one thing for you, the craftsperson to slop a glob of chili onto your solar cell, but quite another to come out and discover some unrecognizable, formerly liquid, silver dollar-sized glob of something on your WIP.

Safety Is A Primary Concern At Every Stage

I do not know the skill level each of you has with regard to working safely around electrical components. There is no question that electricity can be deadly, for example, a review of the U.S. Department of Labor website revealed that in 2013, 71 people were killed by electrocution while working in construction jobs. This is an OSHA report and thus we can extrapolate that these were job sites filled with hazards. Homeowners fare little better according to the Florida law firm Leesfield Leighton Rubio Mahfood, who advertise that over a quarter million Americans are hospitalized annually after an electrical shock of which as many as 14% will die from their injuries. When you put these two sets of statistics into the perspective of our lifelong pursuit of Doing-it-Ourselves, we straddle the fence on the issue of injury statistics. I don’t mean we are confused about which side of the fence to fall; we are exposed instead to both categories of hazard, construction trade and that of the homeowner.

Handcrafting solar panels represents risks you need to know about especially if you are a parent who will be supervising a younger person performing this activity. Once the solar panel is completed you will undoubtedly want to put it to work, and why wouldn’t you? It is an exciting day to look forward to! The solar panel itself is live, electricity generating unit the moment sunlight strikes it at the appropriate angle whether you are ready or not. Connecting the solar panel to a deep cycle battery represents a new set of risks and dangers, if mishandled because of a battery’s high discharge current capacity, and the presence of caustic compounds. Inadvertently connecting cables to the wrong polarity or accidental contact with battery terminals by tools or jewelry can cause an arc, a sudden release of energy capable of melting steel wrenches upon contact. Battery charging generates hydrogen which is combustible at 4% concentration, especially hazardous without ventilation. If you intend to mount your solar array on a roof, the risk now includes falls from the roof or the ladder used to get there. The ladder in question must NOT be made from aluminum since that material conducts electricity if a live wire comes into contact with it. Once your array (multiple solar panels or modules joined together) is up and providing power, if not grounded properly (or not at all), there is a shock risk which also might escalate into a fire if conditions are right.

Hopefully I haven’t shocked or frightened anyone away! I mention the things above so that you are aware of the risk inherent in working with electricity. Things do happen on occasion that are unusual and that defy logic, like when you have done everything right, yet you are hit by another driver who was doing everything wrong. Outside of your control is, well, outside of your control, which is why you need to be in control of those things that you can. The idea is to prevent accidents that result from carelessness, working too fast, a sloppy work environment, taking shortcuts, or any of the other behaviors that are fairly certain to have been responsible for previous accidents somewhere. There is a reason for the absurd warnings we see on everyday products such as those on firearms instruction manuals that specify not to point a weapon at oneself. Seems pretty self-explanatory and awfully big on common sense yet, if you search on YouTube I promise you that you will find footage of people who not only shot themselves while looking into a gun barrel, but then posted the film! Therefore I must place graphic warnings of what could happen to you should you take shortcuts, or act on impulse when you really don't know what to do next. If you run into a situation where you absolutely do not know what the next step is, STOP, get your instructions out, double-check, go online, email me, but do not simply guess. If you do, there is an even chance that whatever the step is will come out incorrectly and the resulting error could be costly in terms of wasted time and effort, not to mention cost.

Extension/Power Cords - must always have all prongs present; never use one that has any visible damage to the plug or surroundings. Never use a cord that is crimped, torn, cut, or has wires showing through the outer cover. Inspect the power cord for the solder gun, lights; as well as anything that you plug in to an outlet to complete your project. Don't overload a wall outlet, extension cord, or surge suppressor by "piggybacking" in order to plug in your soldering iron or soldering gun. Piggybacking is when you increase the number of outlets available by adding outlet extensions on top of outlet extension (see photo example on the next page). The cumulative draw on such a mass of clustered outlets results in concentrated heat sufficient to start a fire. You need to be able to extract electricity safely, with a fresh surge suppressor that is plugged directly into a wall outlet or receptacle. That will ensure a steady supply of consistent power without placing the entire structure in mortal jeopardy. If you are a parent with very small children, perhaps toddlers, you are aware that chewing on extension or power cords is a common behavior. According to Lynda Liu with Parents Magazine, in 1997 (I know, a tad dated) more than 6,000 children were treated in hospital emergency rooms for electricity related injuries. Seventy percent of them were under the age of five and had either chewed through a power cord, or stuck a foreign object into a wall receptacle. Just be aware that when you plug in the soldering iron it would be a good idea to triple-check that you have devised some method for keeping that cord out of harm's way. Lastly, when changing solder tips on either the iron or gun models, unplug them while performing the change-out. You can imagine why…

Heat - is a factor with soldering equipment since the tip must achieve a temperature sufficient to liquefy solder. For example, the specific solder I use has a melting temperature of 350°. At such temperatures skin is no match and serious burns can occur if contact is measured in fractions of a second. No rational person would intentionally expose themselves to such intense heat but if perhaps an unsecured soldering iron (the round cylindrical type), not sitting in a rack becomes airborne and lands in your lap because a passerby tripped over the power cord. The human brain is going to respond to this with respectable elasticity but it has to rely on our clumsy limbs to affect our rescue. Reacting with lightning speed we would snatch the offending soldering iron from our lap but in those few seconds a very serious burn will have occurred, one requiring immediate medical attention. **ALWAYS USE A STAND** in conjunction with a soldering iron because they are hot all the while they are plugged in, even when not in your hand. That makes them a very wily risk which demands your respect!

I like to use the soldering gun because I control the heat. When actively soldering, not only does the area directly under the solder tip get extremely hot, pretty much the entire solar cell becomes too hot to touch. You will not be able to hold down tabbing wire against the solar cell for alignment prior to soldering because your fingers would receive third-degree burns. Thus, the reason for the “Probes and Pokers” on the equipment list. They are the instruments used to hold tabbing wire down while soldering. So important is this tool that I strongly recommend this tool in every enthusiast’ toolkit. They will safely allow you to manipulate the tabbing wire and hold it gently in position while soldering. The surface you are soldering on will also become very hot for a brief time as you solder. That means you cannot solder on a surface that will combust, or melt from the soldering iron. So any table that is plastic MUST have your glass work surface between the solder activity, and the table.

Fumes - are present when the solder reaches the temperature necessary to liquefy it. The need for ventilation is paramount as the resulting smoke from solder should NOT be inhaled directly. A fan may be used to push the offending smoke away, perhaps a desktop model that is battery powered (rechargeable batteries of course) or an actual smoke extractor which pulls the smoke away from the work area and filters it in case there are impurities. If you have sensitivities to the odors or fumes, such a device might make your soldering activities worry-free and worth the expense. We will be using lead-free solder which spares us from exposure to the toxins most notorious for causing illness namely lead. You can take comfort in the fact that the MSDS (Material Data Safety Sheet) information for the encapsulating materials we offer for sale is NOT hazardous material and this fact is confirmed by the U.S. Department of Transportation.

D) Know When to Ask for Help

I had an instructor who used to tell the class, "The only foolish question is the one you don't ask".

Here is where the males of our species, yours truly included, invite all sorts of grief to come crashing down on our heads because sometimes we are just too proud to admit when we don't really know what to do next. I know, some of you are chuckling while others may want to punch me in the teeth for putting something so sacrilegious into this book. I admit that in the far distant past, there was a time when I would charge ahead on a project, and if I encountered obstacles (translates into the fact that I didn't really know what to do next) I would do what I thought was common sense or fit with what I thought I knew in general. Those are the type of projects that may have had to be done over, but done properly the SECOND time. You will not encounter many obstacles after reading this eBook if any at all because I tried to anticipate your obstacles based upon those I experienced early on. Between the written instruction, still photographs in the margins of this document, and the exclusive How-To video library there will not be a question unanswered regarding this handcrafting process.

I have covered some of the hazards one might encounter while handcrafting a solar panel but my list is not all-inclusive. There are many situations and combinations of factors that could lead to injuries or accidents and thus, an all-encompassing list would require multiple volumes. We take risks every day, some we are aware of while others catch us completely by surprise. If you are new to the exciting field of photovoltaics, you will probably not stop with one solar panel, you will go on to build your custom array. Your participation in photovoltaics places you in contact with electricity generating equipment, power storage devices, grounding, and some basic wiring tasks. It would be extremely wise to explore methods for learning basic electrical theory in a systematic and comprehensive approach. There is so much information online however, I fear that sometimes we learn just enough about a topic to pose a threat to ourselves if we base our research ONLY through Internet sources. Book titles on residential electrical systems, solar power, photovoltaics, and virtually every aspect of the electrical trade can be researched, but you have to do the reading. What I strongly recommend is to enroll in a formal training course, something you take at your own pace, perhaps an online course, of the caliber such that upon completion you could pass the relevant state contractor test portion. I am referring to Mike Holt Enterprises where you can find a full line of courses ranging from topic-specific to complete electrical contractor test preparation. They are good people who will help you achieve your education goals and don't hard-sell you for anything you don't want. They can be found online at www.MIKEHOLT.com or by phone at 888-632-2633. (Unsolicited endorsement)

Section # 3

Now to Create Your "WIP"

What are the Components?

Solar Cells- are the core element of a solar panel and these instructions apply to polycrystalline, monocrystalline, or multicrystaline solar cells universally as each are mechanically similar. **The only difference of any kind** you will experience during assembly, whether you are working with mono, poly, or multi-crystalline solar cells is the length of tabbing wire used to connect a pair of the solar cells. In order to connect two cells together, tabbing wire is used not only to physically bond them, it also conducts the excited electrons (or current) on their path through the solar panel.

What electrons you ask? A brief refresher or introductions as it were, to explain how a solar cell generates electricity when exposed to sunlight is in order. It all begins about 93-million miles away on the Sun which has a surface temperature of over 5,000°C and a core temperature some 2,700 times the surface temperature. The core is intensely radioactive and produces light-energy known as **photons** that have no mass, only huge amounts of energy and momentum. It may take a million years for a single photon to travel from the Sun's core, to the surface where it is propelled into outer space with an approximate speed of 670,000 miles per-hour[2]. In about eight minutes the photons cover the nearly 93-million miles of space to reach Earth but some photons will be deflected in outer-space, the remainder make contact with the atmosphere and on to the planet's surface. When the sun warms your skin on a sunny day you are feeling the photons strike your exposed skin creating the warmth that is the source for much of the life here on Earth. When photons strike a solar cell as illustrated in the graphic on the previous page, they can glance off, pass through, or make a perpendicular, head-on impact. It is the perpendicular impact, or anything reasonably close to it that creates the excited electrons leading eventually to electricity generation. How can the photons generate electricity? This is a complicated scientific principle known as the "photovoltaic effect" which I will briefly describe, only for familiarity. I do suggest further reading from other sources for greater detail.

Refer to the cross section of a solar cell on page 31, and note the blue surface of the solar cell being struck by the photons as indicated by the red arrows. Photons will do one of three things when striking a solar cell; they can bounce off, a glancing shot so to speak, they can penetrate completely, passing through the solar cell and striking the ground or whatever is behind the solar module, or lastly, can pass into the solar cell causing the desired chain reaction that the solar cells are poised to perform. A solar cell is really a sandwich made from two layers of silicon serving as the bread, and a hollow area in the middle where the electricity is created. The layers of silicon on their own will simply allow the photons to pass through and so, each of the layers is treated with a chemical, or "doped" as it is called in reference material. In essence the silicon wafers must be treated in order to provide them with "semiconducting" properties. According to Whatis.techtarget.com a semiconductor is any material usually a solid chemical or compound that can conduct electricity under some conditions but not others. As you will see, the two halves of our silicon sandwich will each be "doped" with a different agent to achieve a specific result. As you probably guessed, many doping agents are used to achieve different results giving silicon a broad applicability in electronics. Let's get into how the silicon is "doped" in order to work as they do…

The side of the solar cell facing the sun is the "**negative**" side of the cell and is called, "n-layer", or "n-type" in our graphic. This negative side of the solar cell is "doped" with phosphorus because at the atomic level, phosphorus has the unique trait of containing an extra electron in its atomic structure. This extra electron sits at rest in the atoms structure inside the "doped" solar cell until sunshine-propelled photons collide with the "n-layer" at the proper angle. Photons are comprised of energy and momentum from the sun's radiation and thus, upon colliding with the "n-layer", they release the stored energy and momentum of which they are made. In response to being bombarded with these balls of energy, the atoms become excited from the sudden and vibrant radiation energy and the extra negatively charged electrons get bounced free from the phosphorus-doped N-layer of silicon. The chain reaction starts on the sun-facing side of the solar cell but once the electrons contained within this section become excited, broken free from the valence that previously held them, they then perform the next required step which is passing through the P/N Junction. This junction is the area in the center of our sandwich example and it is depicted in our graphic as simply a white line. However, it is a one-way street for the electrons because once free, the flow of electrons around the circuit begins and represents the formation of "current", or electricity. The importance of the P-layer should not be understated because without the vacant electrons in the boron-doped silicon molecules, there would be no flow of electrons, hence, no electrical generation. Once the flow of electrons is started, a path is made for them to travel from cell to cell by way of the tabbing wire which we will discuss next. I did not want to make this an overly technical discussion because once we start talking about atomic structures; I suspect some readers may have skipped a few pages in hopes of bypassing a science lecture. I think we covered the most pressing science behind the photovoltaic effect which you are probably interested in if you have this in your line of sight either printed or electronic versions. Technology is advancing in photovoltaics on a quest to achieve greater efficiency, the highest possible rate of conversion of sunlight into electricity. Experimental doping agents have shown interesting promise and thus, in order to follow the developments, my Solar Tech DIY Facebook blog will include discussions about emerging technologies in the field of Photovoltaics.

Upon close visual inspection you will notice that solar cells look different, seemingly all of them have some different variation on color and line patterns, irregular shapes visible on the surface although, some don't, and some are solid in color. We touched on the reason for the color differences earlier when discussing the origins of the monocrystalline verses polycrystalline solar cells. If you recall, monocrystalline solar cells are cut from a single monocrystalline silicon ingot as seen in the page margin to the left. The ingots are grown through the Czochralski process, a method of creating large single crystal ingots for use in semiconducting. The silicon required for this process is very clean and pure and so the resulting solar cells cut as wafers from these ingots will have a consistent coloring shade and appearance.

Contrast the consistent appearance of monocrystalline solar cells with the haphazard and random patterns discernable on polycrystalline solar cells, the difference is obvious in the photo above.

In light of the visual difference, it is easy to distinguish between the two types. The random patterns of the polycrystalline come from the molten origins that mixed several smaller crystals or even crystallites which upon cooling retained some of their individuality in appearance anyhow. While the resulting polycrystalline ingot can be as much as 99.9% pure, the solar cells cut from these ingots are slightly less capable than their monocrystalline cousins. One visual cue consistent with all types of solar cells is the presence of tiny wires running horizontally across the sun-facing side as well as a pair, or even a trio of white bands running perpendicular to the tiny wires. As seen in the photo above and to the left, those white bands are known as **"bus bars"** onto which you would solder the tabbing wire that not only connects the solar cells together, but also serves as the conduit for the flowing electrons. The **bus bars** are also on the back, or positive side of the solar cells, in certain versions the "**bar**" is replaced by small "**tabs**". Whether **bus bar** or **bus tab**, they function the same and are joined to the solar cell in the same way. The tiny wires that appear as thin white lines running horizontally across the negative, sun-facing side of the solar cell are called "fingers", and are added to the silicon wafer during the manufacturing process. They are necessary for the efficient movement of electrons through the entire surface the solar cell once the sun is out and spewing photons for the solar cells to absorb. To end the conversation about solar cells, I want to touch on the common blue color present in a great many versions and types of solar cells. The technical details are beyond the scope of this eBook but suffice it to say that a silicon nitride antireflective coating produces that blue tint common in solar cells. The silicon nitride antireflective coating is present to optimize specific wavelengths on the color spectrum, which helps capture as much light-energy as possible.

Tabbing Wire - is also known as Interconnect Wire and it provides two functions. First, it serves to physically join the solar cells together thus providing structure and sturdiness. Second, it provides the path and conveyance for the electrons set in motion once photons begin knocking them into motion within the solar cell. Different sized tabbing wire is available and for this type of project, I recommend (.15 x 2mm) which is an ideal width for most of the solar cell types we will be working with.

Tabbing wire is made out of flat copper wire that is then coated with tin, or a tin alloy that when heated becomes liquid and helps the wire bond to the **bus bar**. Some tabbing wire suppliers may suggest that use of rosin core solder is unnecessary due to the presence of the tin coating over the tabbing wire. Disregard such advice since the solder gun tip <u>needs</u> rosin core solder on it simply to convey heat, it doesn't matter if the tabbing wire is pre-tinned. When the heated solder tip (that is lightly coated with rosin core solder) touches the tabbing wire, the tin coating liquefies. Heat, liquid tin, and a clean **bus bar** make a great mating surface for tabbing wire to bond onto a solar cell. When preparing to solder tabbing wire, pre-heat the solder gun and apply just a small dab of rosin core solder with each application of a tabbing wire. This will ensure consistent heat for each tabbing wire portion, the result being a uniform performance throughout the entire string of solar cells.

Heat discussion again - the temperature inside a solar panel during summer months can easily exceed 175° as I have personally measured. You will experience how quickly solar cells not only collect, but retain heat as you gingerly handle newly completed solar cell "pairs" while testing them in full sun. It takes but a few moments to thoroughly test a "pair" because you are only measuring volts, and amps, requiring one switch turn and simultaneous cable swap. When successful (which will be increasingly more consistent as you practice, but hopefully right off the bat) there is the obligatory self-celebration, a couple fist-pumps, an appreciative look towards the heavens, followed by curses when you burn all of the flesh making contact with the solar cells you were just fist-pumping about. Now multiply the heat by whatever number of little cousin-solar cells that will be encapsulated along with the two that just charred your flesh in a solar panel, under glass, perpendicular to the sun, all day while you are hunkered down in the root cellar hoping there isn’t anything else down there similarly escaping the heat. Unfortunately the heat has a dampening effect on solar panel performance because of some complicated phenomenon that exceeds the scope of this manual. While complicated, I can provide an overview in generic terms on the next couple pages.

Solar panels generate electricity basically by reacting to stimuli from an external source, the sun. Specifically, photons from the sun that collide with our phosphorus-doped N-layer of silicon wafer, the top half of our silicon sandwich example. Photons are comprised of energy and thus, when they collide with atoms inside the solar cell that have excess electrons, they knock the electrons lose. The dislodged electron conducts a frantic search for a new atom to call home, one that is in need of an electron. This process is repeated many millions of times over within the confines of a solar cell. Freed electrons bounce and dance down through the P/N Junction inside a solar cell and in doing so are create the electricity attributed to solar cells.

Vibration is created when photons strike atoms inside a solar cell, but there is another source of vibration, heat. Most of us have seen water boil; we have seen evidence of heat making molecules move so fast that the resulting collisions are visible to the naked eye in the form of churning water. Solar panels need to be perpendicular to the sun for the best efficiency which translates to a significant exposure to high internal temperatures. Think of your sun glasses sitting on the dashboard while you shopped, even for thirty minutes, those glasses are going to be too hot to immediately put on if the sun was shining directly on them. A solar panel that is mounted perpendicular to the sun and is filled with dark colored solar cells will generate high internal temperatures. The byproduct of this intense heat is vibration at the molecular level, not visible like the boiling water molecules, but present nonetheless.

Add to the equation triple-digit ambient air temperatures and the resulting temperature inside the solar panel becomes a problem. Excessive vibration within the solar cell environment causes a slowdown of electron movement as they must now struggle against more movement than normal. The cumulative effect of this added vibration from the various sources is that the electrons get bogged down and have difficulty moving freely within the P/N Junction. If movement is restricted to the point whereby the electrons cannot join the flow, or current, they die out having expended energy uselessly while attempting to join the flow of electricity. The heat may not stop the flow entirely but the decline in power output will be noticeable.

Stated another way, prior to the sun rays striking a solar cell it is in a state of rest to include the electrons contained within the layers of silicon that comprise our solar cell. The electrons at rest represent a low-energy existence at the time and the sun's photons represent high-energy. Without oversimplifying the process, the difference between energy levels while the electrons are at rest, and the energy contained within the inbound photons, represent the electrical potential within a given solar cell. It seems unnatural that a hot, desert environment with a lot of sunshine may not produce as much energy as a clear, cold, but sunny day in an environment other than a desert but as described it is true. This brings up the ideal time to segue into a brief conversation about how solar panels are rated for performance or output. There must be a uniform standard for establishing the wattage performance on solar modules (another name for solar panels) and so, for uniformity, all solar modules are tested by the manufacturers at a consistent air temperature of 25°C/77°F to simulate exterior conditions. Then the module or solar cell is exposed to lamps powerful enough to mimic the 1,000 Watts per meter squared (1,000 W/m^2) typical of noon time sun and output is measured. Manufactured solar modules have ratings called ***"temperature coefficient of power"*** that tells the reader how each 1°C temperature increase will negatively affect the performance of a given solar module, for example, the number might be 0.5%. The first step in this process is to establish the difference between ideal laboratory test conditions verses real world conditions where the solar module is deployed. For example, if a solar module was being observed for temperature related performance issues at 85°C/185°F, it would represent 60°C OVER the baseline <u>**Celsius**</u> testing figure of 25°C. To quantify the decline in output we need only multiply 60°C by the ***temperature coefficient of power rating*** of 0.5% to arrive at 0.3 (60 x 0.5 = 0.3). The next step is to multiply 0.3 by the Designer Wattage provided by the manufacturer (100 Watts for this example) to arrive at the number of Watts that will NOT be generated because of excessive heat.

The potential loss of generating capacity at an internal temperature of 185°F is 30 Watts, or 30% of total generating capacity.

If we are looking for a number value that reflects a percentage we must convert our answer into the proper format. Remember from math lessons that in order to multiply any number by a percentage, you must first reduce the percentage into a whole number, one that can be multiplied. Simply moving the decimal point to the left by two spaces is the equivalent of having multiplied the percentage number by 1/100, the required step in mathematics to convert a percentage into a whole number. Our new mathematically acceptable number for this calculation is 0.3 (zero doesn't need to be there, just a visual place holder so attention is drawn to the decimal point).

If you are good at performing match calculations in your head, the 100-Watt solar panel is ideal to work with for this example since we need to find a numeric value for the 30% performance decline we have identified due to excess heat. If we multiply 30% by the "designer wattage" of 100 Watts, we will reveal at the quantity of watts that will NOT be generated due to the heat. When we multiply the 100-Watt solar panel by the ***temperature coefficient power rating*** number of 0.3, it equals 30-Watts, so the excessive heat will deprive the solar panel of 30-Watts of generating capacity.

The last thing I want you to walk away thinking is that solar modules (solar panels) up on your roof will simply get too hot to work at all. This is NOT the case but knowledge is power, and being aware that heat has an effect on solar panel power output can assist you in taking the appropriate steps to mitigate surprise heat waves. Simply knowing heat reduces the amount of electricity your solar array can gather should prepare you for this eventuality because there are a few steps to take. First and foremost is to conserve the existing battery power when days are exceptionally hot. This might prove difficult in light of the comfort electric fans bring to a hot room, but if not conserving fan use, look elsewhere for devices that can afford to be shut down until the next day in order to conserve power. Adding solar panels to compensate is one option especially if heat is a regular presence where panels are deployed.

Bus Wire - is very similar to tabbing wire with the same structure and function; it is simply much heavier gauge. Bus wire carries the current generated by the solar cell STRINGS and delivers it to the junction box. There will always be two bus wire leads coming out of a solar panel, one positive, the other negative, which then connect to the corresponding output leads within the junction box. In addition to carrying current the bus wire provides infrastructure for the STRINGS within a given solar panel until such time as encapsulation permanently secures the internal components. The typical solar panel or solar module upon close inspection has four rows of solar cells running from the bottom of the solar module, to the top. If you look at the ends of the four rows, you will see how the rows are connected to each other at both ends of the solar panel, I have attached a photo to the left. The photo depicts only two rows while a typical solar module would have four but the photo serves an excellent example of what is known as an "end run" since you guessed right, and it is the end of a run of solar cells.

When you get to the step where bus wire is being used, the solar module is nearly completed. You will have utilized tabbing wire to connect the individual solar cells, and now the bus wire is used to connect the rows, or STRINGS of solar cells physically together, but also to provide a conduit through which the electrons (current) can flow not between solar cells as the tabbing wire provides, but between ROWS of solar cells. The flow of current follows a path around the rows, very orderly, and the bus ribbon is the path the current flows through as it makes its way into the battery bank. We will cover more on the specifics of soldering with bus wire but you will find it one of the easiest elements to work with due to its size, sturdiness, and rigidity. In addition to connecting the rows of solar cells inside the structure of the solar module, one bus ribbon for each, the positive and negative leads that must be accessible on the back of the solar module. It is these leads made from bus ribbon that physically connect each solar module to the photovoltaic cables that allow for quick connecting to other solar modules, or the leads are tied into "project boxes" or junction boxes where other types of cabling may be connected if not utilizing special photovoltaic connectors.

Rosin Flux - in a pen, like a magic marker, used to coat the silver BUS BARS on both sides of the solar cell prior to soldering the tabbing wire to the solar cell. You may use other forms of flux such as the gel that can be brushed on, but the pen variant is so efficient that it is hard to justify NOT using a Rosin Flux Pen as depicted on the "tools" chapter. According to Wikipedia, the word "flux" is derived from the Latin word, "fluxus" and translates into the word "flow" in the English language, and indeed that is one of the functions the flux performs after it is applied to the BUS BAR. In fact, the flux cleans off any impurities that might otherwise have a negative effect on the bond between the solar cell and the tabbing BUS BAR. Additionally, the flux aids in the process of heat transference from the soldering gun tip, to the tabbing wire you are soldering. It is non-negotiable, you MUST use a flux of some type or you will have a very difficult time achieving a solder that is mechanically sound and will conduct electricity.

Section # 4

The Hand-Crafting Process:

Now for the hands-on, and if this is your first project, take your time, this is not a race against the clock. The tasks that seem unfamiliar now will be routine and simple after a few repetitions.

STEP 1-Creating the "Pairs"

Most of you have heard the question, "How do you eat and Elephant?", and hopefully you recall the answer because it applies to the method for handcrafting a solar module. The answer to the riddle is, "One fork-full at a time", and in solar panel terminology, one **"pair"** at a time. The starting point is creating the first **"pair"** of solar cells, which leads to more **"pairs"**, until you have paired the number of solar cells that match the desired wattage for the particular solar panel you are handcrafting. If you have decided on building a 72 Watt solar panel for example, it will require 36-solar cells that will require **"pairing"** (based upon 36 polycrystalline 3"x6" solar cells). Dividing the number of solar cells in our 36-cell project by 2 (since we are going to be making **"pairs"**), we know that we will need to make 18 **"pairs"** of solar cells in order to arrive at the 36-solar cell solar module.

1. **Preparing the first solar cell** - The starting point for pairing solar cells is to prepare the first solar cell to be joined by soldering tabbing wire onto the front, or "**negative**" side (the side that faces the sun) of the solar cell.

2. **Application of Rosin Flux** - Before soldering, open the Flux Pen and perform the "wetting" of the pen tip by pushing the tip down onto a piece of cardboard. This will push the pen tip back up into the pen casing which allows it to become saturated with the liquid flux material. Once moist, simply draw lightly over the **bus bar** on the side of the solar cell that will be soldered first. The flux material does not need to be flowing over the boundaries of the **bus bar**, you are only placing a small amount, enough to coat the surface, anything more and you will have a mess on your hands. Use just enough to lightly cover the white portion of the **bus bar**, a small amount of over-application is acceptable, but it needs to be a very small amount.

3. **Determine the length of the tabbing wire (see the demonstration video by scanning the bar code on the previous page)** that will accomplish the task of completely covering the white **bus bar** on the front, **negative** side of the solar cell. The **bus bar** will run from the top of the cell, all the way to the bottom and will be equal in measurement to that of the solar cell. If you are using a 3" inch by 6" inch polycrystalline solar cell as featured in the margin photo, the tabbing wire will simply need to be twice as long as the **bus bar** . Why twice as long? Remember, the way we solder the tabbing wire is from the front, **negative** side of the first solar cell, underneath the next solar cell in the pair. In addition to being double the length, an additional amount needs to be present to accommodate a stress relief point which will give slack to the solar cells to expand or contract commensurate with the internal temperature. The YouTube "How-To" video demonstrates how to determine the length of tabbing wire

needed. Therefore, the first solar cell of every pair will have an overhanging pair of tabbing wires once you complete the initial soldering onto the sun-facing side of the solar cell. Note the last photo on the previous page; it depicts the overhang needed to connect with the next cell in line.

NOTE: *Some YouTube video tutorials that depict solar cells being prepared for soldering by scuffing the bus bar surfaces with sand paper or a pencil eraser. DON'T do this UNLESS there was an initial failure of a specific portion of the* ***bus bar*** *to grip the tabbing wire. Failure means you have attempted to solder tabbing wire onto some portion or all of a* ***bus bar*** *but it will NOT stay affixed to the* ***bus bar****. Occasionally you will experience this and it isn't because the* ***bus bar*** *is defective, you may have omitted the step of applying the Rosin Flux and so the two surfaces are having difficulty bonding. Therefore, BEFORE doing anything else when encountering an obstacle, verify that you have applied the Rosin Flux to the* ***bus bar.*** *If you do resort to attempting a repair, any scuffing or erasing on the* ***bus bar*** *must be done with a very delicate touch and with gentle pressure. You are merely trying to remove impurities before reapplying a thin coat of Rosin Flux, then attempting to complete the solder. Typically this would be the end of the line for this cell in question because without all pre-designated* ***bus bar*** *making excellent contact, the cell would be compromised. Remember, a solar module (solar panel) is only as potent as its weakest individual solar cell. For example, if using the polycrystalline solar cells pictured on the previous page, typical output for such cells is 0.5 Volts and 3.75 Amps. A solar module containing 36-solar cells of this rating would then produce 18-Volts, multiplied by the amperage (average of 3.75 Amps) gives us the "designer watts" for such a panel. Based on the math we would have a solar panel capable of producing 67.5 Watts under ideal conditions. However, if one individual solar cell is compromised by a contact point (****bus bar****) not contributing to electron flow, the performance of the cell will be severely compromised. For the sake of example, let us say that one out of the six* ***bus tabs*** *on the back or POSITIVE side of a solar cell is defective and you are unable to achieve a solder. You are almost done with this very last STRING of your first solar panel, and you ask yourself, how bad can once little defect have on the WHOLE solar panel? A LOT is the answer. Like a chain that is only as strong as its weakest link, the ENTIRE solar panel will perform at the level of your one defective solar cell. So if we do the math, one contact point out of six means that each point could carry 16.6% of the electron flow (current) and if missing, that much of the flow would be idle because the "bridge" is washed out. If we multiply the average current, or amperage expected from our example solar cells of 3.75 Amps, times the 16.6% output deficit resulting from said missing bridge, we drop the ENTIRE solar panel to a reduced number of 3.15 Amps. Again doing the math, multiplying our revised solar panel amperage to the new figure, assuming the voltage will remain the same for our defective solar cell (it wouldn't in real life) and so we will use the established solar panel total of 18-Volts. Because of a single shoddy contact point, a previously acceptable performance level of 67.5 designer watts is reduced to 56.7, and while it is only 10-Watts, it is the principle of the thing because that loss is the result of poor decision making in a moment of haste that you will be paying on for a very long time. It is much better to just swap out the solar cell because it does happen from time-to-time, not perhaps from being defective as I labeled the example, but there are many* *factors that contribute to a solder obstacle. Temperature fluctuations, impurities on solder tip, solder surfaces, moisture present, and on, so it is not automatically going to be a faulty cell.*

4. **Lay out a solar cell on your work surface** that we discussed early on. Weigh it down on the outer edges as in the photo to the left after GENTLY brushing away any dust particles from the solar cell surface.
5. **Prepare the solder gun/iron** by cleaning the tip using a sponge soaked in distilled water. If you have an electronics specialty store, sponges are sold specifically for this purpose with groves for cleaning around the tips. Many solder stands have sponges built-in for convenience. Cleaning the tip requires the soldering gun to be plugged in, and the trigger being pulled on the gun models because they need to be hot during the cleaning process. It will steam and sizzle, which is normal, and your purpose is to remove the old solder and any oxidation since last used. Finally, you need to perform a step known as "tinning" of the solder tip which is simply applying a thin coating of the rosin core solder around the tip while the tip is clean, and hot. It is a VERY good idea to repeat this process frequently, perhaps as often as after each pair of cells that you mate to keep the solder clean and smooth. Good solder tip maintenance practices WILL result in cleaner, smoother, and electrically conducive contacts. If you don't practice consistent maintenance habits you will notice an increasing level of difficulty achieving

clean tabbing wire across the solar cell tops that are visibly obvious, evident by lumpy uneven tabbing wire. The soldering gun is probably having difficulty maintaining the temperature connectivity needed to bond the liquefied tin surrounding the tabbing wire to the bus bar. It then leaves behind an uneven trail of half melted clumps of solder which leaves a big question mark over the quality of the solder joint. Before you begin to solder, ensure a stand is available for the soldering iron if this is your tool of choice and have the exhaust or desktop fans turned on and pointed such that any fumes would be swept away from your face.

6. **Lighting** - needs to be on and sufficient in brightness to see your work clearly. This would be the time to put your vision enhancement device on such as was described very early on.

7. **Tabbing Wire Preparation and Placement** - I explained how to establish the length of strip needed for any size solar cell earlier but recall that the strip needs to double the length of the bus bar on the face of the first cell to be soldered plus a small expansion fold in the center. You can pre-cut enough strips for the entire project or just do a few at a time, it is your choice, but either way a template is a great tool to ensure consistent tabbing strip size every time. It can be a piece of wire, coat hanger, even cardboard, first measured and then cut to the exact size you need. This rigid, durable item then serves as a reliable yardstick against which to measure and cut the total number of strips needed. If using solar cells that have two bus bars, and if the panel will be comprised of 36-cells, then you know in advance that 72-strips will be required.

Heat conversation-again! As we have discussed already, heat is a major factor inside the confines of the solar module. Solar cells sit behind glass or Plexiglas, in the prime solar radiation hours of the day, sort of like you sitting inside your car in a parking lot with the windows rolled up somewhere hot, like Death Valley. We know for a fact that heat causes materials to expand, for example, look at any concrete driveway or sidewalk and note the expansion joints. You have been stepping on them your entire life perhaps not knowing why sidewalks all seem to have uniformly spaced perpendicular grooves, well now you know they are expansion joints. Failure to allow for some minor movement would lead to cracking of the concrete slab and similarly, we need to make some accommodation to the tabbing wire. The extreme heat during the day is countered by extreme cold in some places and not only at night. The temperature differences are likely to cause movement of the solar cells inside your solar panel, perhaps only a millimeter or less, but enough that if no slack has been made available on the tabbing wire the solar cell may fracture. The way we accommodate the tabbing wire for these variations is to create a bend in the tabbing wire at the mid-point so there is spare material that can expand during extreme heat without placing stress on any particular tabbing wire section. The photo on the previous page depicts a method I utilize for providing the expansion slack required for tabbing wire, not the only method but one I have used many hundreds of times successfully. It involves creating a bend in the tabbing wire just past the edge of the negative or sun-facing side of the solar cell to allow for expansion should the solar cells expand or contract in reaction to temperature fluctuations. **The following steps will achieve the proper bend location on your tabbing wire for the expansion relief:**

7a) Establish the exact length of the bus bar on the solar cell. That combination square I suggested you add to the tool kit is ideal for this task. You can use this tool to safely and precisely measure the **bus bar** setting the solar cell as pictured to the left. You can then slide the ruler portion of the tool out until it is just slightly over of the solar cell edge. Tighten the adjustment nut once you have the ruler set in the right place so the combination square can now be used as an exact template for where the bend needs to be made in the tabbing wire strip. Take a strip of tabbing wire, lay it onto the ruler surface and push it as far forward as the stopper will allow. Don’t apply force; you are only trying to align the tabbing wire strip against the edge of the ruler where it meets the combination square handle. Remember, you are measuring where to make the bend, so now to make that bend, you simply push downward on the portion of the tabbing wire strip that is hanging over the edge of the ruler. You will have created the "crease" needed to make a clean bend, which you will now do, all the way in half. You will notice that the sides are uneven in length, with good reason. You see, if one were to simply fold a tabbing wire strip in half, the resulting strip of tabbing wire would NOT fit across the face of the solar cell that is sun-facing, or the **NEGATIVE** side. What they would end up with is the bend sitting on TOP of the solar cell instead of between two solar cells that are joined together. The crease would need to be pressed down by the hot solder tip in order for the tabbing wire strip to rest smoothly onto the **bus bar**. Failure to get it to lay flat on the solar cell would likely render the cell useless and the pressure needed to flatten the crease with the hot solder tip would certainly fracture the fragile solar cell. Even if it was possible to smooth out the crease formerly marking the midpoint of the tabbing wire strip, in doing so the expansion relief now there is no expansion relief for the solar cells which may form micro-fractures from the resulting stresses should temperatures extremes of either type appear. It is best to follow what my grandfather used to tell me over and over which I did not understand until my mid-twenties, "measure twice so you only have to cut once". You could "eyeball" it, but you will be wasting an awful amount of time and money on broken cells because you will miss more than hit.

You may have a different method for establishing such measurements and if so, please feel free to continue what works best for you. The important point to take away from all of this is to find a template so you can create consistent tabbing wire strips for the whole project. It is an important issue because the habits formed early will become the foundation for all of your future handcrafting projects of this sort. When the measurement is taken for the TOTAL length of the tabbing wire strip, we start at the tip of the **bus bar** on the top sun-facing side, to the underside of the next solar cell in the pair we are creating. Therefore when determining the length of strips, the length of the **bus bars** on the tops and bottoms of the solar cell need to be considered. If the **bus bar** runs the full length of both the front AND back sides of the solar cell, doubling the bus bar measurement and adding ¼ inch for the bend and cell pair gap will suffice. Some **bus bars** do not extend the full length of the back side; rather they appear as small squares. These **bus tabs** perform the same function; they are simply smaller and as such require less time and effort to work with. The mid-point where we would naturally want to make our crease is of little relevance in this case even though it makes sense to simply make a fold in the middle. The **bus tabs** fall well-short of the edge of the cell and thus, all of the tabbing wire protruding after the final solder has been made is serving to throw off the mid-point of the strip. Your bend will be the one we mentioned that ends up on the top of the cell putting your cell at risk.

7b) Now that the bend-point is marked, simply bend the strip of tabbing wire at the spot until the two halves are touching. This is a good opportunity to straighten the wire as much as you can use a ruler as a guide perhaps.

7c) Pull the two tabbing wire strip halves apart gently until the wires are reasonably straight and level. Place the strip on your work surface and gently pull the two halves apart which will cause the crease to shrink. Refer to the picture on the next page. Once the strip is straight and you have pulled taut enough to drop the crease to about 3mm off the work surface. This will leave a small arch of tabbing wire to give-way should expansion occur in extreme heat. Likewise, should freezing weather occur, the arch will allow for the cells to move closer together as the arch is ideal for accordion type movement.

8. **Apply Rosin Flux to the bus bar pending** application of tabbing wire. Perform the "wetting" process with the pen by removing the cap and then pushing the felt-tip down

onto a clean cardboard surface. This saturates the tip and ensures plenty of liquid is present to deposit onto the **bus bar**. Lightly apply a coating to each **bus bar**, thick enough to reflect a sheen that would be obvious to the naked eye, but not enough for liquid to run outside the boundaries of the **bus bar.** You definitely do NOT want to apply the same downward pressure on the Rosin Flux pen during application to the bus bar; in fact the tip should not be making enough downward pressure on the bus bar to move the tip upwards into the pen cylinder as the wetting process calls for. Just a nice, soft, swiping motion that leaves a smooth, neat trail of liquid material. It is fine if the material appears to dry out in the time it takes you to align the tabbing wire strip, as long as you solder within the hour, it will maintain the integrity.

9. **Place cushioned weights over two corners** of the solar cell to be soldered to prevent sliding of the cell while being soldered. The weights should be placed such that they are half on the cell, half on the work surface, so the rubber gasket material serving as a cushion will provide the grip needed to prevent sliding. Refer to the photo on the next page.

10. **Apply the tabbing wire strip over the bus bar**, only one at a time, and get it aligned with the **bus bar** so that there is none of the white **bus bar** material showing around the sides of the tabbing wire. Tabbing wire is apt to squirm and twist everywhere except where you need it to stay. It is malleable and so you can very effectively straighten it to eliminate any curvature that is causing the difficulty. Once you have it reasonably straight and aligned with the bus bar, you may use small weights to hold the tabbing wire down just prior to soldering. Ideally the tabbing wire will be resting neatly on the **bus bar** prior to applying the heated soldering tip because there is no time for making placement adjustments while the solder tip is hot and making contact. You need that tabbing wire strip to sit still while the solder tip moves across its surface. While you are not applying downward pressure, there is still enough friction from the soldering tip to cause movement of the tabbing wire, a very frustrating occurrence to react to while holding a dangerously hot soldering tip, which can be made more frustrating if the solder has bonded the tabbing wire to the **bus bar** crookedly. This would require the tabbing wire strip to be removed and repositioned, all the while placing the cell in jeopardy of damage from the repeated exposure to handling and to high heat. Therefore, it is important to have the tabbing wire strip positioned properly before applying heat. The result will be a smooth soldering experience and good electrical contact. It is also advisable to place a weight on the tabbing wire portion that hangs over the cell, the part that will be soldered to the underside of the next solar cell. This will aid in the continued alignment while soldering.

11. **Prepare the solder tip by performing the "tinning"** process by cleaning the hot solder tip on the distilled water soaked sponge and then applying a coating of solder to the still-hot solder tip. Remember, this will allow for proper heat transfer from the solder tip and into the metals being joined, in our case, tabbing wire to **bus bar**. If using a soldering iron, plugging it is will result in it heating, and staying hot, so a stand MUST be used to keep that dangerous tip out of harm's way. If using a soldering gun, you must activate it by depressing the trigger which will heat the tip very quickly.

12. **Keep the trigger depressed throughout the task at hand**. Once the tabbing wire is attached the trigger of the soldering gun may be released and the solder tip will quickly cool.

    12a) With the trigger depressed (solder gun), briefly touch the hot solder tip against a strand of rosin core solder, just enough to lightly coat the soldering iron or gun tip.

    12b) Trigger held down, start at the left side of the **bus bar** and position the solder gun or iron tip over the tabbing wire about half an inch before the edge of the solar cell. Allow the solder gun or iron tip to make contact with the tabbing wire to start the soldering, not pushing downward, but instead, allowing the weight of the soldering gun to do the work. Your job is to make the micro-adjustments in contact pressure as the solder gun or iron's tip glides across the tabbing wire surface. You have the task of preventing too much downward pressure from pushing the tabbing wire off the **bus bar** which can be mitigated by cushioned weights being used as place holders. The first indication that the soldering process is underway will be a change in the appearance of the tabbing wire on the solar cell. Prior to soldering it will look exactly as it does on the roll, or laying there on the solar cell. The soldering tip will cause the tin coating that surrounds the tabbing wire to liquefy and allow the two surfaces to bond which will give the tabbing wire a flat, shiny, and smooth appearance. There can be minor rough texture visible, but there should be no bulges, bumps, or obvious sections that are lifted away from the **bus bar**. It is ideal to make just one pass over the tabbing wire being soldered to keep the fragile solar cell from shattering from the high heat. Repeated passes over the already bonded surface will only increase the risk of damage, there will be no benefit, no added continuity, one good pass, perhaps two to smooth out any solder piles should be the maximum. I suggest watching my video on the task for a demonstration on this task especially if this is your first time soldering. In terms of difficulty across the spectrum of required steps, soldering is probably at the head of this short list. Having said that however, soldering is an easy task to master and proficiency does not take long to achieve considering how often you will be practicing while joining solar cell "pairs". Don't fret the process though, you CAN do this successfully even if you have trouble in the beginning, just don't get frustrated and give up if the tabbing wire is not adhering or it is moving around on you. Take a break, re-read the portion of this book covering the step you are hung up on, or watch the video at www.aaroncake.net/electronics for a tutorial, but RID your mind of any negative thought about not being able to solder. It doesn't matter if you are 85 or 15; this is indeed a skill YOU can master!

Once the first tabbing wire strip is soldered you simply repeat the same process for the remaining **bus bar** or two as some solar cells have three **bus bars** for added electron (current) flow.

13) Continue soldering the two (or three) tabbing wire strips to the negative, sun-facing **bus bars** until all of the cells intended for the specific project have two (or three if required) tabbing wires protruding and ready to accept the second solar cell needed to create the pairs. For example, if hand-crafting a solar module containing 36-solar cells, you will need to have 36-solar cells with the tabbing wire extending from the **NEGATIVE**, sun-facing side, hanging over into emptiness until we connect the **"pairs".** You may just perform the same procedure 36-times, or you may decide to create pairs along the way so as to mix things up. Either way, you will come to the next step which is to make **"pairs"** out of the single solar cells that currently have tabbing wire overhanging their respective edges and are ready to be mated with another solar cell.

14) Pairing the solar cells is next and is done for a specific reason. It is a terrible waste of time to assemble a solar module only to discover a bad solar cell somewhere in the mix. Identifying a weak solar cell AFTER completing assembly with all the required soldering makes it a complex process to replace a solar cell so late in the process. It is far better to test cell "pairs" BEFORE connecting them into a **STRING** with other solar cells for permanent encapsulation because by then, repair is nearly impossible. Testing to ensure the solar cells are viable is easier to accomplish after solar cells have been "paired", and it is the best time to catch any sub-par solar cells before committing them to a STRING. It is just irresponsible to put so many hours into something only to have it simply not work when placed in the sunshine! You should never be surprised by a solar module not performing at all when exposed to the sun for the first time. It is far more efficient to test each "PAIR" of solar cells prior to inserting them into a **STRING,** so we handcraft the cells into **"pairs"** first, and then later connect the **"pairs"** for assembly once we confirm the performance.

In order to connect a second solar cell to the first, we will make use of the tabbing wire that extends off the side of the first solar cells we prepared. Those first tabbing wire strips are soldered to the **negative,** or sun-facing side of the first half of our future pair. The overhanging tabbing wire strip must be soldered to the back, or positive side of the second solar cell in the pair. In order to accomplish this, the solar cells will either have full-length **bus bars** or small square **bus tabs** which are identical in physical structure and purpose as the **bus bars** on the top of the solar cell. The order of steps is as follows:

14a) Turn the first solar cell in the pair over so that the negative, sun-facing side is facing down, towards the table thus exposing the back side of this solar cell. The result will be an upside down solar cell that has tabbing wires protruding from underneath it meaning they are coming from the NEGATIVE sun-facing side. There should be as many strips protruding from under this inverted solar cell as there are BUS BARS on the now downward facing solar cell which will be used to join the next solar cell.

14b) Place cushioned weights on the first solar cell on the rearmost portion of the solar cell. It is very important to keep this cell as stable as possible and the weights need to be heavy enough to prevent movement, but not so heavy that the weight damages the solar cell. Gently place the weight into position without any scraping of the weight against the solar cell and taking care not to crack the cell by the sudden application of the weight.

14c) Place a new solar cell upside down, to the right of the cell it will be connected to.

You don't need to weight it down just yet; you need to apply Rosin Flux (pen) to the bus tabs on the now upside-down solar cell in preparation for pairing.

14d) Move the second solar cell into position so that it can receive the tabbing wire from the first solar cell in such a manner that the tabbing wire rests across the **bus tabs** for general positioning. Just as the first solder tasks with tabbing wire strips, these will be just as wiry and perhaps will not be resting directly on top of the bus tabs. This is where the "probes and poker" tools come in to play that I mentioned in the earlier section on the subject. My affectionately labeled "sausage fingers" make manipulation of small wires difficult but therein lays the usefulness of various fine manipulation tools designed for such purpose. Using a flat bladed poker to move the tabbing wire into the correct alignment over the **bus tab**, you can then apply small weights to hold the tabbing wire in position for soldering. The soldering process is slightly different for the positive side **bus tabs** which are smaller than the **bus bars** on the front side of solar cells. You still add the Rosin Flux, but the application of solder is different, and requires a soft touch. This is true soldering where the hot solder tip must rest on the tabbing wire, directly on top of the **bus tab**, with barely any weight behind it (that means YOU need to be sensitive to the weight you are allowing the solder tip to place on the solar cell).

The heat from the solder tip passes into the tin-coated tabbing wire, **bus tab**, and solar cell allowing rosin core solder to melt upon coming into contact with the tabbing wire. Leaving the solder tip too long on the spot will certainly break the solar cell so you need to be as brief as possible, but long enough to have the rosin core solder wire melt upon contact with the tabbing wire and NOT from contact with the solder tip. If the rosin core solder wire makes contact with the hot tip it will indeed melt and flow down onto the top of the tabbing wire, BUT, there will be poor electrical conductivity. In order for the solder to conduct the flow of electrons, the rosin core solder wire needs to receive the full heat of the surrounding environment so that the collective heat allows the liquefied solder to flow between the surfaces needing to be bonded. I strongly recommend going to YouTube and watch an excellent tutorial on the subject of soldering because this person has captured the essence of how to successfully achieve good conductivity solders. The tutorial location is given on the next page.

14e) With the trigger depressed on your solder gun (assuming your soldering iron is plugged in), clean the solder tip by wiping it several times across the sponge soaked in distilled water. Next apply a thin coat of rosin core solder to the hot solder tip otherwise known as "tinning". With the tabbing wire resting in place above the **bus bar** or **bus tab**, gently lower the heated solder tip onto the tabbing wire and gently press down so that it adheres to the **bus bar** or **tab**. As it sits ever so lightly on the tabbing wire it is transferring heat into the tabbing wire, the Rosin Flux, the solar cell, and the work surface. This heat is what causes the solder to melt (on the solder gun tip) and then mix with the tin to form the electrically conductive bond between the two surfaces. The tin coating on tabbing wire should start melting upon making contact with the solder gun tip. I strongly urge you to watch the YouTube video OR one of mine depicting the process I am describing here.

You won't use rosin core solder wire directly onto tabbing wire, for this procedure only the solder gun or iron tip require "tinning". However, when connecting end-runs you will be required to place the rosin core solder wire directly onto the bus wire where it should melt as result of contact with the super-heated bus wire. It is a mistake to believe *that the solder gun tip itself is how to melt the rosin core solder. If you DO touch the solder wire against the hot solder tip, rosin core solder wire will indeed melt and run quite freely over the bus wire and* ***bus tab****. Problem is that when it cools and solidifies; chances are it is not bonded to the surfaces requiring such a bond. It will look reasonable to the untrained eye, but there will be obvious visual cues that are too in depth to cover here, but suffice it to say the solder is not going to achieve good electric conductivity. It may work when tested initially but the long-term outlook is not good. So, never rely on simply touching the hot solder tip to deploy rosin core solder over the joint! Take your time, use magnifying glasses as I have pictured in the tools list, make sure you have adequate light to see your target, and have a steady hand. It will work as you need it to, just be patient, you will be bonding these like a pro in no time! The reason the joint may fail down the road is the temperature related expansion and contraction I have mentioned previously. If the solder joint is solid, done properly, it will have the strength to withstand the internal movement albeit tiny in measurement, but lacking this strength, the outcome might very well be different even considering how tiny the movement is.*

15) Testing the pair you have just joined is the next step as I have previously indicated; this is the time to catch a problem as opposed to when the solar module is completed. In order to conduct a test on the "PAIR" of solar cells you will need your multi-meter which will be used to measure the volts and amperes produced by the pair. Both monocrystalline and polycrystalline solar cells produce a minimum of half of one volt, so a "PAIR" of either type should slightly exceed 1-volt or there is a defect somewhere. Likewise, the amps (short for amperes) will be measured with simple adjustments to the multi-meter cabling and tool settings. The voltage performance is generally consistent across the full spectrum of solar cells genres including the mono, multi, and monocrystalline solar cells contained within our kits. What WILL be different is the ampere generating capabilities between the various solar cell types. Polycrystalline solar cells produce the same voltage as monocrystalline solar cells (0.5 Volts) but the purity inherited from the single-ingot origin allows monocrystalline solar cells to achieve double the ampere output. Monocrystalline cells measuring 5" square are my favorite to work with and produce over 4-amps, so a "PAIR" being tested can achieve 4.5-watts and above. The low ampere performance of polycrystalline solar cells might be seen as a drawback to some, I find them to be durable, consistent in performance, and achieve 18-volts in a smaller footprint than most other types of solar cells. **FYI: calculate WATTS by multiplying the VOLTS x AMPS.**

Calculate WATTS by multiplying the VOLTS x AMPS

NOTE: *this is when you really get hands-on with your fragile project. I made reference to the fragile nature of solar cells earlier, but once you start the process of creating "PAIRS", the level of care when handling your components needs to increase. A pair of solar cells joined by way of tabbing wire is reasonably secure when laid flat and undisturbed. Moving a solder-joined "PAIR" of solar cells requires two hands, one for each of the cells in the "PAIR". When moving the "PAIR", it is best to slide the pair to the edge of the work surface where the "PAIR" may then be slid over the edge and gripped by thumb and forefinger. Once in such a pincer-type hold you may either transition the "PAIR" onto the test surface, or transport the "PAIR" by holding them such that the solar cells hang down naturally while still being gripped in the pincer type grip with both hands. When moving between test surface and storage, take great care that the wind does not sweep the "PAIR" off the test surface or get broken. It has happened to me, and not only was it the gust of wind; it was my instinctive grab at what had been suddenly lifted out of my hands. My hand collided with that which I was trying to save and in the contest between bones and flesh verses wafer-thin silicon, you can guess what entity won. When joining "PAIRS" of cells into STRINGS of cells containing anywhere from 4, to as many as 18, the resulting "STRING" can be 20" inches all the way up to 7.5' feet long (comparing a 16-cell 32-watt solar module to a 72-cell 150-watt solar module). I endorse the smaller solar modules of 100-watt range because we can safely produce these but more importantly, I can mount them without needing assistance. When you start moving larger, twice as heavy solar modules up onto second story eves or roof-tops, having a second person present is mandatory because of the safety topics we covered early on in this manual. The risks are increased across every activity starting from the ladder work, to the lifting of the module, to working high-up with an object that exceeds the weight threshold you can safely maneuver, to the risk of exceeding weight capacity of DIY frames to name a few concerns.*

16a) The best method for testing solar cell "PAIRS" is in the actual sunshine, as close to noon as possible, but you can safely test up until about 3 pm which would be the tail end of the usable solar irradiation for measurement purposes. You will need an electrical measuring device known as a Multi-meter that comes in a wide variety of capabilities and price ranges. There are models available that provide digital readouts as well as analog versions that have meters with the traditional moving wand to read results, any one of these will suffice. Having an LED screen is an easier way to interpret the results especially if your eyes have difficulty seeing small figures on a dial. This is a tool that can be purchased for $5, up to several hundred but the price is irrelevant because you can have perfect success with the $5 unit. There are two measurements taken during testing, one for voltage and another for amperage and to transition between tests requires the switching of one cable and one change of a dial position as depicted in the photographs on page 52 (two pages back).

16b) Move the "PAIR" of solar cells to be tested onto a flat piece of material large enough to support the joined "PAIR" of solar cells. It can be glass, cardboard, wood, just so long as it is sturdy enough to support the weight without bending in a slight breeze. Once the "PAIR" is on the surface and you are ready to walk to the test area, place a finger or two over the tabbing wires to hold the solar cell pair onto the surface. You can experience a gust of wind picking those cells right off your test surface so this step is important.

16c) Once into the sun lit area for testing, place the surface containing the test "PAIR" on the ground or table top where unobstructed sun is striking the solar cells. For testing as well as final deployment, orient the test subject to the South if you reside in the Northern Hemisphere, facing north if you reside in the Southern Hemisphere.

16d) Connect the black NEGATIVE lead coming from the multi-meter to either one of the tabbing wires protruding from the top, sun-facing side of the test pair which is the NEGATIVE polarity of a solar cell. This NEGATIVE test lead should ideally have an alligator clip with which to grip the tabbing wire protruding from the sun-facing side of the solar cell. The second probe coming from the multi-meter is the red POSITIVE lead which must be placed against the bottom of the test pair at a point farthest away from the alligator clipped negative lead. This POSITIVE test lead should be the metal probe which is ideal for positioning against the underside of the solar cell being tested; it can even achieve a good reading while touching the target cell at an extreme angle. The easiest method to give good access to the test spot on the underside of the lower solar cell is to slide the "PAIR" backwards on the test surface until an inch of the target solar cell is exposed, overhanging the testing block. Once overhanging you gently hold the test lead against the underside of the overhanging solar cell, towards the back of the cell nearest to where it hangs over. Apply enough pressure with the POSITIVE test lead to maintain contact but not enough to lift the solar cell off of the test platform. Contact with the POSITIVE test lead is only required for a second as the multi-meter interprets data instantly. The data will be depicted on the LED screen and you will have instant measurements for the desired test parameters. Don't be concerned if the numbers change a lot on the meter during the test process since your hand holding the probe to the underside of the cell is the weakest link in the testing process. As you navigate the test procedure, balancing the pair at the end of the test platform, keeping everything in order, you will have the proclivity to slip with the hand holding the probe to the underside of your test pair. This will cause the multi-meter to provide a wide range of numeric results most of which will be outside the acceptable performance window. If you encounter wildly fluctuating data, simply stabilize the hand holding the positive probe and the numbers will also stabilize.

16e) Interpreting the results are a matter of determining whether the performance falls within the expectable parameters. In general, a polycrystalline solar cell **'PAIR'** comprised of 3"inch by 6" inch cells must produce a minimum of 1-volt since each cell will contribute a minimum of 0.5-volts. The amperage will range from 1.7 to 3.5 with everything in-between. If using the 5" inch square monocrystalline the volts will be the same, a minimum of 0.5-watts per cell, but the amperage will be nearly double that of the polycrystalline solar cells.

16f) If within the acceptable performance parameters set the "PAIR" aside for later inclusion into a "STRING" that will comprise the heart of the solar module. This is the time to really secure the tested "PAIRS" in a safe location while other "PAIRS" are either constructed, or tested until the requisite number of "PAIRS" is made to support the project.

16g) If the performance is <u>not</u> within the guidelines, check the following:

a) **Look for any tabbing wire issues** by closely examining the entire surface of the **bus bars** and **bus tabs**. You are searching for any failure of the tabbing wire to adhere, perhaps a solder failure due to the handling as you transported the pair to the test site.

b) **Examine the solar cells individually**, and closely, perhaps with a magnifying glass or a jeweler's loupe because the magnification will allow you to see cracks in the solar cell that had previously eluded your initial inspection or occurred during the soldering process.

c) **If all of the tabbing wire appears secure** and there are no visible cracks in either solar cell, it may be the multi-meter providing invalid data due to some fault with the device. Ensure the battery is fresh and that the fuse is in-tact and has not been blown. You will know a fuse in blown when it is unable to give you a reading on the amperage you are testing for. Without the fuse, most multi-meters simply will NOT provide any measurement of amperes and the data you receive will only be the number "1", or an error code. In order to replace the fuse you will need to remove four screws visible from the front of the device or on the back, under the battery cover. It requires a very small set of screwdrivers, the type that comes with eye glass repair kits that are sold at most hardware and convenience stores. You can purchase the fuses from any auto parts store since vehicles all require fuses of various sizes and types. Once the fuse is replaced it is a good time to check the battery health since the unit is open and will not work properly with a drained battery. After replacing the fuse and battery, inspect the cables used to connect to the solar cell being tested. Push them into the "input jack" firmly to ensure solid contact with the device and also check the cables for frayed spots or lacerations. If you have reviewed all of the steps outlined above and there is no change upon final re-testing, consider the cells to be defective and set them aside being careful to somehow mark them so as not to accidentally have them appear in a project. Consider yourself very wise for preventing your project from ending in disappointment.

STEP 2 - Combining "pairs" into "STRINGS"

Keeping true to our example of eating an elephant, we have been taking the equivalent of many small bites by producing the solar cell "PAIRS". Now we are gaining ground on the monumental task before us with the completion of enough **"PAIRS"** to represent a complete solar module. In terms of the hypothetical elephant carcass, we will have made a sizeable dent but now we are going to be taking bites the size equivalent that of a Killer Whale (now what pray-tell would an elephant be doing anywhere near the habitat of a Killer Whale?). Connecting "PAIRS" in order to build STRING is a benchmark in the handcrafting process that moves swiftly since it only requires four "PAIRS" to equal a STRING, four STRINGS to comprise a solar panel. I need to remind you now that four "PAIR" of solar cells equates to a STRING containing eight (8) solar cells but we need STRINGS containing nine (9). We need to add one solar cell to either end of the four STRINGS. Each newly added solar cell should have tabbing wire strips protruding from the end that is not going to be connected with another solar cell. For example, you will add a solar cell to either the right, or left side of the STRING. You will then need to establish the polarity since this last solar cell being added will serve as an end-run to be connected with bus wire to the adjoining STRING or the outbound lead connecting with project or junction box. To physically establish the polarity for the final cell of the STRING, the tabbing strips on the new solar cell should be connected with the **bus bar** or **bus tabs** on the OPPOSITE side of the solar cell at the other end of the STRING you are working on. Alignment is important here and should be a focal point each time you lie a "pair" down to add onto a STRING that is under construction. It is extremely distressing to reach the stage at which you are able to place the STRINGS inside a solar panel frame but cannot fit them because you built crooked rows. Making repairs after the fact is tedious, difficult, and might just discourage you from proceeding to the next step, or even dropping the skill completely. But you can avoid this by using something as simple as a straight line drawn on your work surface to use as a guide. As you solder tabbing wire onto the top, NEGATIVE or the bottom, POSITIVE side of a solar cell it is common to require multiple minor adjustments to positioning of cells in order to maintain the straight line orientation. Minor movement is incidental to the contact of the soldering tip, your hands, your tools, and the solar cells simply reacting to the ever so slight pressure from the soldering tip which is completely normal. Simply set the solder tool down and realign the pieces in need of adjustment and continue. As the STRINGS grown in length, the same process applies for each "PAIR" added to the STRING.

17) Joining the tested solar cell "PAIRS" in order to build a STRING is the next step in the building process. Most all solar modules will be comprised of four STRINGS; the difference between the various solar modules will be the size, the type, and the number of solar cells. However, differences notwithstanding, the larger modules (70-watts and larger) all have four rows or STRINGS of solar cells connected by bus wire inside their respective casings. You may build custom solar panels to meet any need you might have, certainly smaller solar modules may be only two STRINGS of cells like those made specifically to recharge small household batteries, but I am referring to solar panels seventy watts and above. I prefer to handcraft these larger modules because I feel they have the most applicability to RV, out-of-doors activities, off-grid living, and are light weight enough to mount where larger panels could not possibly fit. However, having admitted my preference for the larger solar modules does not diminish my bedrock conviction that every owner of a cell phone should have a solar module of sufficient size to charge their cell phone at the very least, a project that is within the grasp of the most novice of solar panel handcrafters. The main reason I am fond of the 70-100 watt range solar module is that I can mount this size module anywhere I need to without requiring physical assistance. This can be a major safety factor if working on a roof, alone, or hanging the modules from the eves which have lower weight tolerance. This is the tremendous advantage you have in that you are not bound by module sizes offered by the big manufacturers; you can customize modules to fit specific opportunity locations or to fit a specific electronic device. Once you are at the point of creating the STRINGS, you have gained some valuable experience soldering. The remainder of the assembly is soldering the **“PAIRS”** together basically, a task you will become much more proficient as you complete more STRINGS. Any difficulties you are having now will be a mere hiccup the next time until the following unit when you will be a confident handcrafting genius.

17a) The first “PAIR” in a STRING will start off with the NEGATIVE or sun-facing side down and the two strips of tabbing wire pointing towards an open area large enough to accommodate the second “PAIR” of solar cells to lie next to the first. Gently set cushioned weights strategically around the first set or “anchor” in order to prevent movement as you set the second “PAIR” in place. At this time, apply the Rosin Flux pen to the **bus tab** or **bus bar** on the second “PAIR” that you set down next to the first (you may go either way, right or left, whichever you are comfortable with) in order to prepare it for soldering. Remember, some solar cell types will have **bus tabs**; some will have **bus bars** running the full length of the cell on the back or POSITIVE side of the cell.

NOTE: *aligning the STRING so that the finished product will sit straight up and down inside the solar panel is important. All four STRINGS of solar cells must fit within the confines of your substrate (solar panel backing material that the strings of solar cells are mounted to) and there is not much room for error. For example, if your solar panel substrate is 25" inches wide and you are working with 6" inch wide polycrystalline solar cells, four rows will consume 24" inches leaving ¼" inch between the STRINGS. There are many ways to achieve straight "PAIRS" ranging from drawing a straight line, to utilizing small rubber spacers originally designed for laying ceramic tile in perfect square patterns. Rubber tile guides provide a mechanism for laying solar cells or "PAIRS" of cells into perfectly aligned rows. I caution you if you decide to use this method because the tile guides sometimes catch the corners of solar cells as you attempt to lift your completed solar cell "PAIR", or STRING off the work surface. Sometimes the simplest method is going to work the best instead of the fancy tile spacers, something as simple as drawing two lines on the work surface to use as the guidelines for building STRINGS of solar cells. In my demonstration videos I use an 8" inch wide pine board that I affixed a wooden yardstick along the edge on which I connect the "PAIRS". Whichever method you use, the ultimate goal is to arrive at a STRING that sits in a very straight line. I like to use the edge of my work surface, half of a hallway dressing mirror which provides an excellent straight-edged guide as I built my STRING. You may find other methods that suit you as an individual and I encourage you to find methods that fit your needs. There is no hard and fast concrete method, this is where you get to experiment and find what works for you.*

17b) With the first “PAIR” of solar cells weighted down, slide the “PAIR” to be connected so that it rests underneath the loose tabbing wires that we are going to solder to the **bus bar** or **bus tab** on this new “PAIR” we are joining with the first**.** Position this second “PAIR” so that it is aligned and straight using a method of your choice to achieve straight lines. The ideal distance between the two pairs will be only approximately 1/8 to 1/4 inches. As a rule of thumb, you generally only need enough space between the two pairs of solar cells to allow room for expansion and contraction, enough space for the expansion bend you made with the tabbing wire connecting solar cells in a given “PAIR”. Take a moment now to go back through this manual and examine the photos that include pairs of solar cells or actual strings and note how far apart the solar cells are from one another. You’ll start to notice consistency in the distance between cells in the examples I have provided in the photographs throughout this book. The photographs in question contain polycrystalline solar cell pairs that utilize 3” x 6” cells, and you can see the spacing is minimal because you really don’t need that much space between them once they are inside the protective housing of the solar module. The presence of the crease in the tabbing wire will allow for the minute movements related to temperature variations, and the spacing only needs to be sufficient to prevent contact between cells throughout the working life of the solar module. Once you have the second solar cell “PAIR” in the proper position, you now must set cushioned weights to prevent this “PAIR” from moving during the soldering process. When setting your weights down, take great care not to impede your soldering on **bus tabs** or **bus bars** as obviously you cannot place the tabbing wire over a blocked **bus tab** or **bar**. You also do not want the cushioned weights to interfere with the movement of the solder tip as you are working over a particular cell. Once into position, align the tabbing wires that are now hanging over the back or positive side of the solar cell in need of being soldered and positioned directly over the **bus tab/bar**. Use cushioned weights to keep the tabbing wire in place so you can move right in with the solder tip.

17c) Now that it is aligned and the tabbing wire in position and ready to solder, it is now time to join the two “PAIRS” of solar cells. Before starting remember to clean the solder tip and perform the “tinning” step as we discussed earlier. Just as with the method used previously on the back, or positive side of the solar cell, carefully place the hot solder tip on to the first **bus bar** to be soldered, remembering to allow just enough weight to rest on that tip to transfer heat into the tabbing wire to melt the tin coating around the tabbing wire but no more. After a few seconds of allowing the solder gun tip to heat the surrounding material, touch the solder wire to the tabbing wire and it will melt fairly quickly. Release the trigger on the solder gun, reapply a dab of solder and move on to the next **bus wire/tab** until they are all completed on the “PAIR” being connected. Once the tabbing wires have been soldered and the “PAIRS” joined, it is time to add the next “PAIR”, until you have joined a sufficient number of “PAIRS” to comprise your string. In the “How-To” videos filmed for this book, we like to focus on the 36-solar cell panels for reasons stated earlier that revolve around safety, ease of mounting, and the wide range of applicability.

17d) Volt/Amp check upon completion of each string- you may perform the same voltage and amperage testing as done for a “PAIR”. You should not find any faulty solar cells since each “PAIR” has been tested prior to being added to a **STRING**. You can estimate the outcome by performing some basic calculations using data from the voltage and amperage testing completed on each “PAIR” before adding them to the string. For example, if the string you just completed contains nine (9) monocrystalline solar cells, each producing 0.5-volts, and each “PAIR” averaging 4.4-amps, we can expect our string to test on the multi-meter under noon-time sunshine to provide 4.5-volts at 4.4-Amps. Remember, VOLTS are additive because we are soldering our tabbing wire in series, starting on the **NEGATIVE** or top of the solar cell and soldering it to the underside or POSITIVE side of the next solar cell. I do not anticipate you to have any surprises here since you have been testing as you go, right? That is the reason we test as we go, so there are no unpleasant surprises when it comes time to test the larger units such as STRINGS and ultimately, the completed solar module.

17e) Apply a protective coating of silicone - to the tabbing wire along the full length of the STRING that you have just completed. To accomplish this task, ensure that the sun-facing or **NEGATIVE** side is facing down exposing the full length of the tabbing wire that is soldered to the solar cells. The purpose of this application is to provide protection against the elements, namely oxygen which serves as an accelerant to oxidation. The thin layer of silicone also provides additional support for the connected solar cells by distributing the weight evenly across the entire surface of the solar cell. This becomes increasingly important as the STRING occasionally will need to be lifted by the overhanging tabbing wires at both ends of the STRING. Lifting a STRING of solar cells in this fashion might be necessary when inserting the STRINGS into the framework of the solar module. Without the silicone calking you risk tearing the soldered tabbing wire free from **bus bars** or **tabs** even if you are as gentle as humanly possible. The added strength and weight distribution qualities give the STRINGS added durability and survivability during the final stages of assembly. Place cushioned weights at 4 locations on the STRING including two at either end, and two somewhere near the center of the STRING. The weights are to prevent movement of the STRING as you gently brush the silicone caulking over the tabbing wire. Take great care when placing the cushioned weights so there are no fractures or other damage to the STRING.

18a) Cut the tip off a tube of silicone caulking, not the whole tip, just about an inch below the tip of the lid. Keep in mind that the cut you are making will directly control the size of the silicone caulk bead that is emitted by the caulking application tool. Therefore once you make the cut, you are committed to that size bead for the life of that particular tube of silicone. It is better to cut a smaller hole because you can later adjust the size by making another angled cut and your bead size will increase. Too large an initial hole and you will have a messy WIP (work-in-progress). If you are using a traditional caulking application tool, after snipping the applicator tip off at an angle, you must then puncture the inner seal at the end of the caulking tube. This can be accomplished by using the small metal rod affixed to most caulking application tools, on the underside of the applicator tool that is there for this specific purpose. Simply rotate this rod so that it is pointing straight ahead of the caulking application gun and then use this rod to puncture the seal inside the caulking tube. If the caulking gun you are using does not have a built-in seal piercing rod you may use any long, slender object of sufficient length and rigidity The silicone caulking tube is now ready for use and may be inserted into the appropriate chamber in the caulking application tool. The tool will then need to be adjusted by pressing the trigger in order to move the ram forward to make contact with the base of the silicone caulking tube. Once the ram makes contact, continue to squeeze the trigger a couple times with your goal of being able to see the initial flow of the silicone caulking material enter the applicator tip that you previously had cut open at a slight angle. It is HUGELY important that you use CLEAR caulking! Now, to prevent a panic attack let me warn you in advance that when you watch in abstract horror as a WHITE bead of caulking escapes the tube clearly labeled as, well, CLEAR. As it cures it becomes transparent, I suspect as a mechanism to make it easier to work with during application so take it in stride. For this application you will not be applying silicone caulking directly onto the tabbing wire with the caulking gun. Instead, use the gun to apply a healthy glob (scientific term for about a plastic water bottle cap full) onto a scrap piece of cardboard from which you will apply it by hand.

The coating of tabbing wire on the back, or POSITIVE side of the solar cells is done upon completion of each STRING of cell "PAIRS". Apply this coating as each STRING is completed, you want to get protection in place as soon as possible because the corrosive forces are at work on exposed surfaces fairly quickly. The STRINGS are fully protected by an encapsulating material when the panel is completed, but until then, it is best to protect them any way you can. This process also helps protect long-term inside the solar module as well.

18b) Gently paint a thin coat of the silicone caulking over the tabbing wire surfaces ONLY. To be absolutely clear, DO NOT apply caulking over the tabbing wire surfaces running in-between the solar cells nor the backs of the solar cells. You do not want to add any resistance to that portion of the tabbing wire since it is the shock absorber allowing for temperature related expansion or contraction. If you paint a particular section and upon completion can see only the white silicon caulking on top of tabbing wire, and no actual tabbing wire, then you have successfully coated the surfaces in need of assistance. When brushing the silicone caulking onto the tabbing wire surface, remember you are still working with very delicate surfaces. It is not unheard of for a stray paint brush bristle to catch a junction between tabbing wire and solar cell with enough force to dislodge the tabbing wire or fracture the solar cell. This is the type of task where one should be wearing the magnifying goggles and painting with very small brush heads.

18d) Store the silicone caulking coated STRING safely as we have discussed previously until that time when you incorporate it into the solar module assembly. A place where it is safe from jostling, objects falling on it, or undue exposure to the elements. As suggested earlier, this is the ideal time to place the STRING into a storage container that can be slid under a bed or out of harm’s way. Once secured, move on to the assembly of the next STRING by repeated the steps taken to prepare this one you have just secured.

NOTE: ***When a STRING is completed, the last solar cell on either end of the STRING must be of opposite polarity in order for the STRINGS to be connected together in series. In three pages you will encounter the definition of series wiring, but in short it is achieved by connecting the solar cells from the sun-facing NEGATIVE side, to the bottom of the next solar cell which is the POSITIVE side. When connecting STRINGS together the same principles apply as when connecting individual solar cells to create the "PAIRS". Just as we connect the solar cells together by soldering tabbing wire from the sun-facing side, to the POSITIVE underside of the next solar cell, we want to continue making connections in series; we will simply be connecting STRINGS together by joining the NEGATIVE tabbing wires protruding off one STRING to the POSITIVE, or back side of the STRING next to it. Connecting STRINGS occurs as they lay side-by-side on a substrate with the last solar cell at either end trailing tabbing wire strips that will be used to make the series connections. The tabbing wires from the respective STRINGS are connected together by way of bus wire as depicted in the photo on page 66. The photo depicts the series connection, as you examine the photo take note of the tabbing wires trailing off the solar cell on the right-most STRING. It is coming off the top, sun-facing side of the solar cell which we know to be the NEGATIVE polarity. The solar cell it is connected to at the end of the next STRING has tabbing wires protruding from the underside or POSITIVE polarity and also take note of the bus wire that connects the two STRINGS. The picture almost appears to depict two STRINGS connected by tabbing wire coming from the tops of both STRINGS but upon closer inspection you will indeed see that the left-most tabbing wire strips do come from under the left STRING.***

STEP 3- Connecting the STRINGS via "End Runs"

AFTER THIS BRIEF INTRODUCTION TO THE "END RUN" I AM GOING TO TALK ABOUT SUBSTRATES BEFORE LISTING THE STEPS TO CONNECT THE END RUNS. SUBSTRATES ARE THE SURFACES YOU WILL MOUNT THE STRINGS TO IN ORDER TO CONNECT THEM AND CREATE THE FLOW OF CURRENT (OR EXCITED ELECTRONS)

You are already familiar with an "end-run" because you have read about it several times thus far and I simply hadn't yet provided the terminology until we were at this stage of assembly. An end-run is simply those tabbing wire strips that overhang from both ends of a STRING, one end-run comprised of the NEGATIVE leads, the other end being the POSITIVE leads. You cannot use a STRING that has the same polarity on both end-runs; it just is not going to allow the flow of electrons or current to become part of a circuit, the most essential function of the STRING. The purpose for the way tabbing wire runs from the top of one cell, to the bottom of the next is to facilitate the movement of electrons; we are basically providing a roadway by soldering the tabbing wire onto the cells. As photons strike the solar cells and the electrons start to get excited and ultimately break free, if they have a path to take that allows them to fulfil their new mission (to find atoms in need of electrons, just somewhere else), they will indeed move swiftly. Once in motion, providing they have a path free from obstruction (see the end-run description on the next page) and continued radiant energy from the sun, the electrons will travel the roadways we lay for them.

The path taken by the electrons becomes a flow as more gather, and with their collective, frantic, single-minded purpose, they become the source of electrical current. The path must be similar to an extremely bumpy roller coaster ride with a few very sharp corners thrown in for the faint hearted electrons. They must rapidly follow the over-under contours of solar cells which are virtually pumping electrons out and into the flow which makes several sharp, 90° turns right back in to another STRING of solar cells at the speed of light or something close to it. The tabbing and bus wire highway you will have provided becomes like a one-way subway system moving electrons at incredible speeds. Take another example of a highway, the type we drive our cars on, which serve a similar purpose, getting moving objects from one point, to another, in a one-way flow of traffic (at least it works that way most of the time) in appropriately marked lanes. To illustrate the concept of obstacles that cause inefficiency, an automobile traveling on a freeway is a fairly universal concept for those living in developed countries because we rely on freeways regularly and the idea of blockages are very similar with similar results. Just as electrons move rapidly through the tabbing wire, cars move swiftly in lanes alongside other vehicles and barring collisions, move with steady and rapid speed. However, throw in that collision on the freeway, and we all know what that means right? Bumper-to-bumper traffic with near walking speed if you are lucky, and that is one BIG “IF” because you are just as likely to be sitting idle. Similarly, sloppy soldering, the absence of Rosin Flux, cold solders, and extreme heat have the same effect on electrons as a car accident has on a freeway. The car accident based traffic jam is the equivalent of what is known as **“resistance”** in electrical terms. Resistance describes conditions whereby electrons have difficulty flowing freely through the solar cells and STRINGS due to factors such as cold solders, an absence of rosin flux, or cracked solar cells to name a few factors. Cars held up on a clogged freeway would be the equivalent of electrons running into the backs of others in the current that have reached an obstacle, thus resistance, and like a traffic accident the resistance stops the free flow of energy or at the very least, slows it considerably. I am not saying there can be no errors at all and that it must be machine-like in perfection (your performance I mean), rather, you should be aware of the concept because it can manifest itself through poor performance or outright non-functionality of the solar cell or STRING.

Substrates - We Need To Slip This In Now…

THIS IS A NECESSARY INSERTION POINT FOR A CONVERSATION ABOUT SUBSTRATES BUT ONCE DONE WITH THE INTRODUCTION INTO THE TOPIC WE WILL REVERT TO THE STEPS NEEDED TO CONNECT THE STRINGS.

Merriam Webster isn't much help in figuring out why the word substrate is used conjunction with solar panels. "The base on which an organism lives" is what I saw when I was trying to handcraft my first solar panel after reading an instruction manual that was awfully shy on critical details. By now you have caught on that my mission is to over-state every detail which can become tedious to the veteran handcrafter of solar panels so I beg pardon, and please understand it is for a reason. For the newer members of this elite club, these might be new concepts and terms, and no assumptions can be made about familiarity other than that there is zero familiarity. I vividly recall the obstacle of trying to figure out what the @%$& is a substrate the first time I set out to construct a solar panel? Naturally I figured it out and have tried a variety of them and by perusing the YouTube channels offering instructions on this process I see that there is indeed a wide variety in use.

A substrate is the object that your solar cell strings rest under, or upon as they perform their work of collecting photons in a completed solar panel. Substrates that serve as a base, where the solar cell STRINGS are set atop the substrate with the sun-facing side up, are typically made from materials such as wood, aluminum, tempered glass, or thicker synthetic plastics. Regardless of the material you select, it must be 100% water repellant, and if it is not so naturally then you must treat it in order to make it so. If wood is the substrate of choice, painting it with water-based paint alone will not suffice because wood is porous and moisture will find a way to soak through from the outside. The result will be condensation on the inside of the solar module even though for all practical purposes, the seal is in-tact. Once the water starts condensing on the interior, time is short for that particular module because the elements will erode the performance and frankly make it a dangerous fire hazard. Therefore, it requires something like silicone caulking to be painted on to the plywood OVER the paint, a very light coat, but thick enough to ensure that a water tight barrier is present. There may be other water proofing products used that I am not familiar with that will suffice, just make certain the product produces no fumes and has a guaranteed lifespan of at least three decades. Even if silicone caulking is used, it must be allowed to cure completely before being enclosed by tempered glass or synthetic coverings like Plexiglas. As silicon caulking cures it emits fumes that must be allowed to escape prior to sealing the solar module.

Substrates generally come in three types, the “box” type, “sandwich”, and “single-sheet tempered glass” and the names imply directly what each looks like.

<u>Box type substrates</u> - are so named because the substrate serves as the base on which the solar STRINGS are sitting, sun-facing (negative) side upwards, and the bottom, positive side of the solar cells facing down and actually resting on the substrate. The substrate perimeter is lined with thin square wooden rails that will then support a cover made from tempered glass, polycarbonate, or acrylic. The cover provides the physical protection for the solar cells against rain, hail, birds, dirt, or foreign objects from any source. Typically these type substrates would not be used in conjunction with encapsulating material because the weather protection is provided by the cover. In addition to the cover, recall that the inside of the substrate is painted with silicone caulking to prevent moisture from seeping through the porous wood substrate. Recall also that we paint silicone caulking on the back, POSITIVE solar cell tabbing wires that are exposed as a protection against moisture. We may take an additional step of coating the front, sun-facing solar cells with a thin coat of GE RTV 615 Optically Clear Silicone mixed with Xylene solvent to thin it for paintable consistency. This very thin coating of silicone would protect the solar cells and tabbing wires without compromising the performance of the solar cells. Taking this step is very expensive but would give this type of substrate the serious protection needed to give it a credible lifespan. As of this writing, GE RTV 615 can be purchased on eBay for just over $350 for a 1-lb, two-part kit. One would need to fairly fond of this type substrate to invest that much to ensure longevity and might be better served looking to a different design to achieve the desired durability. Barring the use of GE RTV 615, this would be the least expensive method to mount the solar STRINGS to create a working solar module (panel). Many times the material you will use to construct the box will already be on-hand somewhere in your garage and therefore, not much need be purchased in addition to waterproofing and the cover. These boxes can be tricky to seal completely and so the lifespan of this type substrate is less than other designs but cannot be equaled for an affordable, functional solar module. My first handcrafted solar modules are of this design and they served me well for a number of years.

Sandwich type substrates - are named as such because frankly the solar cell STRINGS are literally sitting between two pieces of tempered glass, polycarbonate, or acrylic. This makes for a visually interesting solar module because you will have a clear view of both NEGATIVE and POSITIVE sides so it is a great conversation piece. The drawback is heat retention within the confines of the sandwich interior. These might be best suited for climates rich in sunshine but light on the temperatures. Don't misunderstand, if you do experience unseasonably hot weather for a short spell, your solar modules won't self-destruct, they just won't perform as well as they would in milder temperatures. I would not recommend these types if you live where triple digit temperatures are the norm. Typically the solar STRINGS are affixed to the polycarbonate, acrylic, or tempered glass that comes into contact with the bottom or POSITIVE side of the solar cells. After securing the STRINGS and then connecting them via bus wire and running the POSITIVE and NEGATIVE leads out, the sandwich is completed by adding encapsulant followed by the second piece of substrate over the top. Heat will cause expansion of the glass, acrylic, or polycarbonate as well as the STRINGS. If delicate objects are sandwiched between expanding and contracting solid objects, said delicate objects are going to get shattered! The STRINGS can be protected against this by placing small plastic craft rings called Pony Beads that are glued into place between STRINGS to act as support pillars for the upper and lower substrates. If temperature related expansion or contraction occurs, the Pony Beads prevent the two substrate pieces from coming into contact which of course would shatter the solar cells resting between them. A drawback to using two pieces of tempered glass would be the cost, double that of simply using a single piece in conjunction with an encapsulating material. But if that is where your mind is set, then go for it! Just be aware that weight will be a factor, perhaps not so much with Plexiglas, but there will be no hand holds with which to grab purchase when handling unless you add something for safety when mounting.

Single-Sheet Tempered Glass Substrate - This is my personal choice after experimenting with other methods. A single piece of tempered glass is very strong when married with a frame made from 1.5" angled aluminum. When you examine commercially manufactured solar modules, most all have tempered glass substrates supported by an aluminum frame. This combination provides excellent protection from the elements, light falling objects, and provides outstanding heat dissipation. It is also comparatively light meaning it is safer to hang, requires less framing material because the solar array will be lighter than those with wood substrates. Why tempered glass as opposed to a normal piece of glass like those sold at Home Depot? Generally the glass sold at home improvement stores are for replacement purposes when windows or picture frames break, things that are fairly common in our homes. As we have learned, some the hard way, when those type glass surfaces break, the resulting shards can be extremely dangerous and it takes but a tap to shatter such glass. In fact, according to Mark Ford, fabrication department manager at AFG Industries, normal glass breaks at 6,000 PSI but tempered glass at a significantly higher 24,000 PSI. With this comparison in mind, imagine one of your works of art is resting strategically on its rack generating a happy throng of excited electrons when a crow flies overhead and chooses to drop an acorn from 200 feet in the air onto your solar module. The resulting CRACK! And the familiar sound of tinkling glass is your solar module wreckage, because that is what you will be left with if anything but tempered glass is used.

The cost difference is notable, but when you consider that the money saved buying the cheaper glass is negated by the loss of an entire solar panel if that cheap glass is broken! The time invested on the project is lost, the cost of the solar cells, and the fact that you really lost TWO solar panels. What? I have one broken by a bird, how do you come up with TWO? Well, if you are reading this and are intending to handcraft a solar panel, your intentions will change upon completion of the first of your solar panels. The full benefit of a solar power generating system is that the energy must be gathered by several solar panels working collectively to fill the battery bank. Once the first panel is complete, most people (yours truly included) will continue handcrafting solar panels until the array is built, and yet there are so many applications for solar panels, we tend to keep building them because you can never have

enough to fulfill all the uses. However, since you are merely reading this book, I will attempt to explain that feeling of liberation, of pride in your accomplishment, the pure joy watching the battery meter rising because of that solar panel you JUST BUILT! One is not enough to make the kind of difference any of us want to see and so the natural inclination is to continue producing them and as you do, each time becomes quicker, easier, and of higher caliber until you are filling your first array, or filling the roof of the RV. So the crow took not just the solar panel you recently finished and deployed, but also the next one on deck is also a casualty because it is NOT fulfilling an additive role. Rather it is serving as a replacement, a premature one at that, the final tally being one broken solar panel and one a “lost opportunity”.
The definition of an “opportunity cost” is when energy or resources are expended one way, and by doing so you are prevented from doing something else, perhaps somewhere else that would have been more profitable. The outcome or results from whatever that other thing is that you COULD have expended energy and resources on will never be known because you chose to focus elsewhere. It sounds like a bunch of smoke and mirrors but when you really break it down into a cost/benefit decision, it just makes sense to protect your hard work so you can keep replicating what works instead of wasting your time and money by saving a few dollars up front by using inferior glass.

One contributing factor in the cost of tempered glass is that it must be cut to the final size prior to being converted because after the process is complete, alterations are not possible. Once cut, we learned from Mark that the glass is then sanded, washed, inspected, and then heated to over 600°C/1,112°F, after which it is rapidly cooled. The cooling process is known as “quenching”, whereby there is rapid cooling of the outer layers causing the inner layers to try to pull free as cools at a more natural pace. The inner layers eventually cool down but the tension created by the uneven cooling between layers is the source of strength attributed to tempered glass.

Tempered Glass, Polycarbonate or Acrylic Covers, How to Choose?

Two primary drivers in a decision between tempered glass verses synthetic covers will be your budget, and the desired lifespan of the solar panel. In an ideal situation there would be a substrate that is both inexpensive and just happens to be impervious to the ravages of long-term exposure to UV radiation. Unfortunately the best long-term UV protection for a solar panel substrate is tempered glass; the unfortunate part is the expense. In spite of the expense, commercially manufactured solar modules include tempered glass almost exclusively for good reason, topmost is safety. Tempered glass will shatter if struck with sufficient force but unlike typical household glass it does not break into potentially lethal shards. Instead, it shatters into very small pieces that stay confined within the synthetic layers embedded during manufacturing process for that very purpose. Tempered glass does have excellent thermal properties, and low iron for better light spectrum penetration. Since tempered glass is not in jeopardy of discoloration from extended UV exposure there is no need for filtering agents as there are in synthetic covers. Yellowing is an indication that the acrylic or polycarbonate is breaking down at the molecular level and is visually obvious by the trademark yellowing. This yellowing reduces the amount of photons able to access the solar cells and places the solar module at risk of shattering because the synthetic material becomes brittle as it breaks down. Modern synthetic products have advanced in UV filtration technology giving them longer service life, but that same filtration blocks some of the sun rays useful for generating electricity. The cost of tempered glass is higher due to the specialized nature of the product and the inability to alter the size once the piece has been cut and then exposed to the tempering process. Shipping costs are expensive whether purchased online or at a local glass shop since the shop will likely have the tempered glass made elsewhere. Packaging to ensure the greatest possible protection requires an irregularly shaped, bulky box that requires fragile handling. The combined cost is going to be more than a drive to the local hardware store for a sheet of acrylic or polycarbonate but the investment in tempered glass will pay dividends for decades to come because the solar panel will be in service for many years after synthetics have succumbed to the effects of UV radiation.

I do not suggest in any way that synthetic materials are inferior as a choice for substrates; in fact, the product developments continue to improve service life. In fact, some of the top-tier manufacturers are now offering a warranty against yellowing for a decade. There are additional benefits to polycarbonate and acrylic such as the superior impact resistance compared to glass. When hefting your solar module up onto a rooftop solar array you will appreciate the 50% reduction in weight compared to tempered glass. I have used both acrylic and polycarbonate for the covers on solar panels of various sizes and my rule of thumb is that for rack-destined solar panels, tempered glass is used. Smaller battery charging type solar panels have synthetic covers because they can be cut to size economically by me at home. I am not concerned about yellowing because the smaller solar modules used for battery charging typically do not stay out in the direct sunlight longer than it takes to charge an individual set of batteries. They are stored inside between uses which can help extend the service life indefinitely since they are also sheltered from temperature extremes when stored indoors. Acrylic is more rigid than polycarbonate which makes it less likely to sag after prolonged exposure to the effects of weathering. Irrespective of which synthetic cover type is used, it is still a good practice to use spacers like the Pony Beads discussed earlier. If the sagging is severe there is a chance it could actually sag low enough to make contact with the solar cells which would not be tolerant of such contact. Minor sag is expected as the synthetic materials get softer when in direct, hot sunlight. Even the more rigid acrylic covers will sag eventually and therefore, a bracing system whether Pony Beads or something similar should be used to help protect the solar cells. Whatever you use should be done sparingly, and with objects that will NOT cast shadows onto the solar cells.

Optics comes in to play when discussing substrates that serve as a covering over the solar cell strings whether tempered glass, acrylic, or polycarbonate. You want the least amount of resistance between the inbound photons from the sun, and the hungrily waiting STRINGS of solar cells. The science of it is beyond the scope of this writing but a brief overview is in order. The general idea is that photons originating on the sun are comprised of energy and momentum since they have no mass of their own. In fact, we see some of the energy in the form of visible light, but there are also bands of energy we cannot see with the naked eye because they are emitted in the ultraviolet and infrared light spectrums. Now it gets technical as we get into which wavelengths are absorbed and which are allowed to pass through, but the underlying principle is that some UV light gets through, some does not. Ultraviolet light exposure causes acrylic and polycarbonate sheets damage over long periods of time. Some of this damage is visible in the form of yellowing while some is not such as the loss of elasticity, or in other words, they become brittle. In order to stave off damage from prolonged UV radiation, some acrylic and polycarbonate sheeting is treated with a coating of UV repellant. The chemical nature of the repellant is a trade secret but the top manufacturer's warranty against yellowing for a decade, a significant improvement over previous technology. However, there has to be a balance between the UV protections offered by the repellant while simultaneously allowing a maximum number of photons through to make contact with the solar cells. I have researched this topic in depth and my understanding is that from our perspective (the DIY solar panel handcrafters), the UV protection that is added to acrylic or polycarbonate sheets is not sufficient to negatively affect the solar panel output. One author suggested that keeping the solar panels clean, regularly wiping dust from the collection surfaces is sufficient to offset any hindrance to performance resulting from UV coatings.

By now it should be obvious to you that substrates either sit under the solar cells so that the POSITIVE, or back of the solar cells rest on it, **or** the solar cells are affixed to the underside of the substrate and the sun-facing NEGATIVE side gathers sunshine through it. When the substrate serves as a **base** that the solar cells rest on, we are not concerned as much with optic qualities rather, we are most interested in water proofing. However, when the sunshine must pass through the substrate made from tempered glass, acrylic, or polycarbonate, we are concerned about three categories of properties: 1) Optical, 2) Thermal, and 3) Chemical properties. I am covering this information for familiarization purposes, NOT to suggest you need to use any particular cover type, instead, you will have enough information to make an informed decision when it comes time to purchase the substrate or a cover for the solar panel. Indeed, there are several other properties such as mechanical, and electrical to name two, however, since it is a discipline all unto itself, I am focusing on the properties most pertinent to us. The properties are as follows:

Thermal Properties:

Coefficient of Thermal Expansion - has to do with how much the product (glass, polycarbonate, or acrylic) will expand in extreme heat, or contract in extreme cold. For example, acrylic sheets expand up to 8-times more than a piece of glass would. This needs to be kept in mind when using acrylic or polycarbonate because they will definitely be moving on a daily basis as the solar panel heats up in the direct sunlight. The methods used to secure the cover to the substrate base needs to allow for minor movement as the cover will want to expand and over time, will start sagging. The Pony Beads or other support objects will prevent sagging from causing damage to the solar cells if the sagging becomes extreme. This is also why we place the crimps in the tabbing wires connecting individual solar cells in a string, so they too can expand.

Optical Properties:

Refractive Index - has to do with how much the incoming sunlight is "bent" when entering the glass or synthetic surfaces. For example, polycarbonate has a refractive index of 1.49 which means it filters UV light at wavelengths below 300 mm, almost the same as standard glass.

Dispersion - is a measure of the separation of sunlight into its component colors in the light spectrum.

Transmission - is a measurement of the light passing through the material.

Reflectivity - measures the amount of light returned off the surface.

Absorption - measures the amount of light energy that is converted into heat that is not transmitted nor reflected.

Chemical Properties:

Glass contains sodium or alkali metal ions that migrate to the surface of glass after exposure to liquids or water vapor. This causes salt or Alkali leaching which manifest itself by a cloudy or hazy appearance to the glass. Tempered glass made specifically for photovoltaics (solar panels) is usually coated with silicon dioxide to serve as a barrier against this sort of decay. This mechanism for decay is absent in the synthetic covering materials but they have their own vulnerabilities related to UV exposure as well as protections. I would surmise that the leaching process takes a very long time measured in decades as all of us have observed glass that has been exposed to direct sunlight for many decades that hasn't started leaching irrespective of the climate. By extension, I think it very prudent to use tempered glass and I am equally confident that if leaching did occur, it would be so far in the future as to be inconsequential to us in this application.

In Conclusion, it is really a matter of personal preference based upon cost and expected lifespan of your solar module. If you need to get a solar panel up and providing electricity quickly, like yesterday, the synthetic covers are readily available, comparatively inexpensive, and the best part is that they can be cut to custom sizes. When selecting synthetic covers or substrates, they need to be thick enough to provide the support needed by the solar cells, but not thick enough to block inbound photons. Shop the products before purchasing because you want at the very least, to examine the product for the properties we discussed above and compare your decision finalists to find the best match. Using tempered glass is my personal choice for providing the highest level of longevity, yet I do employ both acrylic and polycarbonate for custom or battery recharging solar panels.

NOW TO CONNECT THE STRINGS AS PROMISED….

19a) there are two possible scenes facing you right now.

1. You are laying the STRINGS onto a substrate, sun-facing or NEGATIVE sides of the solar cells facing upwards, which then will be covered by tempered glass, Plexiglas, or acrylic sheeting. No encapsulating material used.

   Or…

2. You are using a single piece of tempered glass, acrylic, or polycarbonate and that single piece IS the substrate. In this case you must lay the strings down so that the front, sun-facing side of the solar cells is facing downward and you are looking down at the back side, or POSITIVE side of the solar cell STRINGS. Remember, when you are done with the connecting and encapsulating, the solar panel will be flipped over and the side that is currently facing downward towards the floor will be the side facing the sun.

19b) sizing the Substrate- no matter the material, the substrate must provide a platform sufficient in size to hold however many STRINGS you are installing into the substrate. You can pre-measure the substrate width by multiplying the width of a single solar cell on one of the STRINGS, by the number of STRINGS being placed side-by-side on the substrate. For example, if you created four STRINGS using 3"inch x 6"inch polycrystalline solar cells, your calculations would look like this: 6"inch width x 4-STRINGS= 24"inches wide. Add some room for slightly imperfectly aligned STRINGS and temperature related expansion; two inches on all sides should suffice. This would give you a substrate width of 24" inches + 2" inches for expansion= 26" inch-wide substrate. The calculation for the length is the same although now that you have STRINGS ready to mount, you can basically take the length of any STRING, add three inches on the top, same for the bottom, and you now have a substrate outline that can be cut out of the substrate sheet (if using synthetic). Examine the photos at the page bottom; the middle photo depicts the placement of the bus wires in relation to tabbing wires and the end of the solar panel. The picture to the left depicts a substrate which has had the STRINGS installed and is simply waiting for a cover to be installed. Remember, we are NOT using encapsulating material so the waterproofing of that bottom substrate is very important, so follow the steps I outlined earlier involving painting a coat of silicon caulking all around the substrate even if it is primed and painted. Note also in that left photo, the sides of the substrate have rails of wood on which we secure the cover. The side rails must be wide enough to provide a good purchase for the cover you select since you will be both gluing AND screwing the cover down. The rails cannot be too tall or they will cast a shadow over the STRINGS as they sit inside the substrate collecting photons later in the day. The rails need only provide enough clearance so that IF a cover should sag, it won't make contact with your solar cells as they would fracture for certain. Placing the spacers such as the Pony Beads is absolutely critical in these type boxes because the synthetic covers will sag to some degree after a certain amount of time. This is normal so don't panic one day when you notice the formerly flat sheet of acrylic covering your panel now looks more like a wavy water surface, it is fine so long as you have the spacers in place.

Sizing Tempered Glass Substrates - must be done at the manufacturing facility producing the glass. Unlike acrylic or polycarbonate sheets which can be custom cut easily, tempered glass cannot be cut after undergoing the tempering process. This is where planning is important; you must know exactly the type and number of solar cells that will be used in the construction of the solar panel needing a substrate. Most people selling tempered glass for use in solar panel construction will know exactly what you need if you provide the two items, number of cells and the measurement of the specific type of solar cell you are using. Your request whether in person or online will be met with familiarity and they will recommend the size commensurate with your solar panel so you won’t have to measure. If you did need to measure you would follow the same process as for non-glass substrates to derive the measurements.

19c) ***FOR SCENERIO “A” - <u>First</u> STRING ONTO SUBSTRATE***

*** This applies to the box type substrates where the sun-facing negative side is towards you as you install the STRINGS onto the substrate.*

Set the substrate onto a stable, well illuminated surface that is tall enough for you to sit comfortably while soldering without needing to bend uncomfortably. Retrieve the first STRING from where you have been safely storing it away from danger. Set the STRING onto a flat surface OTHER than the substrate because you are going to clean the STRING. Using the quality brushes you purchased, gently brush the sun-facing side of the solar cells with a side-to-side motion and remove any dust that has settled during storage. Once dusted, pick up the STRING and set it gently onto the substrate on either the left or right side of the substrate. You can pick up a STRING by the tabbing wires at either end if you have large enough hands. If not, it might be easier to move the STRING much like moving a row of cookies off a cookie sheet. You can gingerly slide the entire STRING onto a long, thin piece of cardboard so that you are moving the STRING on a solid surface. When you deposit the STRING onto the substrate, simply line up the cardboard with the substrate and tilt the cardboard at a gentle angle. While tilting, gently vibrate the cardboard to assist gravity in getting the STRING to slide down onto the substrate. You can take comfort in the durability of your STRING because you took the time to paint silicon caulking over the tabbing wire connections giving the STRING much greater survivability. Once the STRING is on the substrate, position it by half lifting, half pulling the STRING in whichever direction needed to align it to one side or another.

NOTE: ***Take notice of the “end runs”, on either end of the STRING you just set in place. One side will have tabbing wire strips coming from <u>underneath</u> the last solar cell in the STRING which are the POSITIVE leads. The other side will have two tabbing wire strips hanging over, but these originate on the top, sun-facing side of the last solar cell on that end of the STRING and are the NEGATIVE leads. Every STRING must have opposite polarities at each end and if not, something was done wrong when creating the STRING. This first STRING on the substrate sets the pattern for the next STRING placed on the substrate as they will alternate polarity. For example, if the first STRING has placed POSITIVE leads at the top of the substrate, the STRING placed right next to the first one would have NEGATIVE leads at the top. Think of it in terms of bunks in a military barracks, for us veterans who attended that friendly college-like environment known as Boot Camp. Recall that the barracks were absurdly wide, long single rooms that housed several rows of lockers and bunks. If you also recall that the bunks were arranged in a head-to-foot pattern down each row, and for a good reason. Unfortunately for our example, not for the same reason, it was for prevention of airborne illnesses and by staggering the heads of the men, there is less chance of spreading sickness. In a solar panel we need that POSITIVE to NEGATIVE flow of current or electrons because it allows the volts to***

combine and collect as it flows in that "series" configuration.

19c) *FOR SCENERIO "B" __First__ STRING ONTO SUBSTRATE*

If using a single sheet of tempered glass, acrylic, or polycarbonate, the frame must be firmly secured in place with clear silicon caulking between the glass edges that rest on the aluminum frame. The most notable difference between laying STRINGS down onto glass surfaces compared to wood is the ease of movement on the comparatively slippery surface of the glass. While this makes for easy positioning of the STRING, plenty of headaches follow because after making very minor positioning adjustments, you don't WANT those STRINGS moving around AT ALL! There is a remedy, we **just cannot employ it until the last STRING has been laid in place and no further** adjustments need to be made. The fix is a dab of clear silicon caulking on the corners of alternating solar cells down each STRING to prevent slippage while encapsulating. That notwithstanding, a second difference is that we lay these STRINGS with the sun-facing, or **NEGATIVE** side DOWN and directly onto the tempered glass surface. So now pick up the first STRING to be installed either by the tabbing wire strips on the ends or by other means, and gently set the STRING onto the substrate. You will be able to easily slide the STRING into position once safely down onto the surface, and being the first of four STRINGS, you will need to position it to the farthest left, or right on the substrate. Note the polarity, which side the tabbing wire strips are protruding, from under or on top of the last solar cell in the STRING. This will help when placing the next STRING because the "end-runs" must be of opposite polarity.

19d) FOR SCENERIO "A" - __Second__ STRING ONTO SUBSTRATE

You now have before you a substrate containing a single STRING that is sun-facing or NEGATIVE side is facing upwards and you are now adding a second STRING immediately next to it. Examine the polarity as written at the top of the substrate above the first STRING, note it and place the opposite polarity next to it as you insert this second STRING. The end result should be a POSITIVE pair of tabbing wires next to a NEGATIVE pair coming from under the last cell in the STRING. Once down, carefully half-lift, half-pull the STRING into position paralleling the first STRING and about ¼ inch apart, the width of a #2 pencil eraser. Now that you have two STRINGS in place, you have a good idea of how the spacing will be when the remaining two, or even possibly a single STRING is added. You will need a little space in which to work while securing the STRINGS in place with clear silicon caulking. With a pencil or fine point ball pen, trace a faint outline on the substrate at the corners of the solar cells in the first and second STRINGS as the sit on the substrate. Writing directly on the substrate is perfectly fine, just make your lines lighter, just enough to make out the outline for guiding your placement of silicon caulking dabs that will be used to affix the STRINGS to the substrate. Use the open space on the substrate where the remaining two STRINGS will be going, to temporarily hold the two STRINGS you just traced the edges around. Gently move them aside by the same method used to transport them into position and go grab your caulking application gun and make certain it is loaded with a tube of fresh, **clear** silicone caulking. Use the caulking applicator gun to apply pencil eraser sized dabs on four places on each solar cell position, keeping in mind that the dabs will be serving as an adhesive and do not need to be very large. Remember, these are delicate wafers and will not tolerate heavy downward pressure applied in an effort to "mash" down an overly generous caulking dab. When gently setting the STRING in place over the caulking dabs, the weight of the STRING plus a VERY gentle massaging motion is all the pressure required to bond the caulking with the STRING. So, after placing the appropriate quantity of properly sized "dabs" of caulking directly onto the substrate, pick up the first STRING and gently set it into position in either the left, or right-most side of the frame corresponding to where you have deposited the caulking dabs. As indicated, there can be only the softest of pressure applied to the individual solar cells in the STRING that you just set in place, so if there needs to be some minor manipulation of the cells it should be done with a soft paint brush. If you go to the exclusive How-To video library, watch the video related to working the encapsulant into the substrate entitled, "How-To Remove Air Bubbles from Encapsulants". This demonstration video will teach you a method for using a standard 2" inch paint brush to apply downward pressure directly onto solar cells without exposing the STRING or solar cells contained therein to risk of destruction. It will require very gentle massaging with the paint brush to flatten out the caulking dabs under the STRING, but just enough to give the caulking a reasonable grasp to the POSITIVE side of the STRING.

19d) FOR SCENERIO "B"-<u>Second</u> STRING ONTO SUBSTRATE

It is time to place the second STRING next to the first, taking note of the polarity at the top of the first STRING. Place the end containing the opposite polarity next to the first STRING such that the order is POSITIVE, then NEGATIVE, or in reverse order, you simply **CANNOT** have like-polarities next to each other. Once down onto the surface, gently slide it into position about ¼ inch apart, visually uniform, and verifying the polarities are opposite as they sit side-by-side. This is a good time to use a couple of your cushioned weights to steady these two STRINGS as you continue to work. I am going to save you time reading further steps that mirror these two.

In order to complete the placement of the remaining two STRINGS, simply repeat the alternation of polarity at the end runs as you install the STRINGS. Try to align the STRINGS as close to perfect as you can before the next step.

19e) FOR SCENERIO "A" – Third & Fourth STRINGS ONTO SUBSTRATE

With two STRINGS already secured in place, you are now ready to place the third by following the alternating polarity process. Since you have two STRINGS firmly in place, it doesn't take a massive stretch of the imagination to estimate where the next STRING will be setting to include the fairly precise position of individual solar cells. If not, you can use a pencil to draw out feint lines to use as guides because you are going to be dropping the dabs of silicon caulking. The dabs should be placed as before, in several random places on each solar cell's position, about the size of a #2 pencil eraser. Verify the polarity of the existing end runs, place the new STRING over the silicon dabs and massage it into position. You will be eyeballing this STRING unless you had previously drawn guidelines, but once you are confident it is securely in the proper position, repeat the process and install the final STRING. With this final STRING, make certain the polarity is correct before placing it onto the silicon dabs. When done, you should have four STRINGS laid in straight, parallel lines in relation to one another, and eight (8) tabbing wire strips protruding from the each end of the solar module.

20) Now we will connect the "end-runs"- and at this stage the substrate type does matter as the connection process is the same regardless. This is the time to discuss the way electricity flows in a circuit because you need to understand the one-way travel of electron flow to appreciate why we route the tabbing wires the way we do. After reviewing the information on the next page about electric circuits, consider the way you placed the strings onto the substrate, alternating polarity with each string. You laid the POSITIVE polarity of the first string next to the NEGATIVE polarity of the next in line, and so on. Now think about the way you place "AA" batteries into any electronic item requiring more than one battery. You lay them into the device in the same fashion as the STRINGS were laid on to the substrate. Examine the photo on the next page depicting a universal battery compartment and specifically take note of the alternating polarity of the slots the batteries rest in. Just like our STRINGS, these batteries lay side-by-side with polarities needing to be opposite where they rest in the compartment. This can also be supported by the alternating location of the springs in the battery charging compartment (next page); because the spring can always be correlated with the NEGATIVE polarity on a battery. It is a universal truth that the spring will always push the batteries upward from the NEGATIVE, or bottom of the battery. When looking at the battery compartment photo, try to imagine with the minds' eye, the image of a battery superimposed over the solar cell STRING with the polarities aligned. Whether batteries or solar cell STRINGS, they follow the exact same principles for the flow of electrons, from the NEGATIVE terminal on the first battery into the POSITIVE terminal of the battery next to it, through the battery, and out through the bottom, or NEGATIVE terminal.

In fact, we could use computer trickery, if I was super-slick, I could use graphics to depict the strings floating up off the glass substrate and down into the battery compartment. It works exactly like that, so when you are joining the strings at the end-run, you can picture batteries sitting in a compartment either waiting for a charge, or to perform work in the form of releasing their stored energy.

Just as you worked first with individual solar cells to create “PAIRS”, you will again be creating “pairs”, **this time you are joining two STRINGS by connecting their tabbing wire “end-runs”. The method for** joining two STRINGS is to connect the tabbing wire strips protruding off the ends of the first and second STRINGS which MUST be of opposite polarity. As the steps to assembly go, this is one of the simpler steps because the process involves soldering a large **bus wire** to the tabbing wire strips. Your single greatest chance for error on this step is unplanned movement of the STRINGS as you solder the end-run tabbing wire strips to the **bus wire** that will connect them to each other. This is less of an issue with the STRINGS that are held in place by the dabs of silicon caulking, and definitely a factor when the substrate is tempered glass or synthetic material. Therefore, you may use cushioned weights to secure the STRINGS while working on end-runs, or you may use clear silicon caulking to secure the STRINGS to the glass or synthetic covers**.** Remember, the solar cells will be face down on a glass substrate so you can be more liberal with the clear silicon caulking since there is little chance of it becoming introduced into path of sunshine and negatively affecting the solar module’s output. **Simply apply a dab of clear silicon caulking to the sides or corners of each solar cell in a STRING, perhaps one small #2 pencil eraser** sized on at the top of each solar cell and a similar dab on the bottom of each cell. You then use a small craft paint brush to spread the clear silicon caulking over the edge of the solar cell so that it is partially on the solar cell, and partially on the glass or synthetic surface. Allow it to dry for a few hours so that it is cured with sufficient strength to grip the STRING by the combined effort of all the tiny dabs. A direct benefit of using the caulking dabs to hold the STRINGS in place is that the caulking prevents the solar cells from being lifted up and away from the substrate once the encapsulant is poured over and around the STRINGS. If the STRINGS float to the top layer of encapsulant, they won’t completely lift out of the still-liquid encapsulant but the resulting layer over the POSITIVE strings will be extremely thin once the encapsulant cures. The lopsided thickness of layers between sides of the STRINGS will result in an uneven level of protection between sides of the STRINGS. Too much encapsulant between the glass and the STRINGS provides no added benefit since the back side of the STRINGS will be more vulnerable to the hazards that encapsulants are supposed to protect against. Rust will more easily form on any exposed tabbing wires thus compromising the health and longevity of the solar module. Similarly the solar cells will not be fully protected against incidental contact to the vulnerable back side of the solar panel while being installed, or while mounting, perhaps during extreme wind conditions where debris is being thrown around. Conversely, the dabs of clear silicon caulking will prevent floating and allow the encapsulating material to envelope the STRINGS completely which is absolutely critical for the lifespan of the solar module. There will be a more effective moisture and impact barrier if the solar cells can rest in a cushion equally distributed between the top and bottom sides of the collective STRINGS within the solar panel frame. Now let us get to the heart of the matter and show you how to connect these strings.

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21) **Visually confirm that end-runs are of opposite polarity** - on the two STRINGS you are about to join together. You will connect them by using a strip of BUS WIRE that is long enough to lay OVER both sets of tabbing wire strips that are known as end-runs. When connecting two STRINGS there will be two (2) end-runs needing to be joined, one from each of the STRINGS being mated. Remember, we are “series” wiring, from one NEGATIVE end-run to the adjoining POSITIVE end-run at the end of the respective STRINGS. A piece of BUS WIRE approximately 9.5” inches long will make the physical connection between the two end-runs. The BUS WIRE is the thicker metal wire that parallels the ruler and is sitting on top of the tabbing wire strips that will ultimately wrap around the BUS WIRE. Also note the presence of cushioned weights on the last solar cell in the STRINGS. These help keep the STRINGS in place while I manipulate the tabbing wires in order to make the connections and soldering immediately thereafter.
22) **Use your pointed tools to assist your fingers** - in securing the BUS WIRE into position where it will be soldered to the tabbing wire strips. Start with the tabbing wire closest to the edge of the solar panel and while pressing the tabbing wire down to prevent it from fracturing the solar cell, bend the tabbing wire so that it wraps around the BUS WIRE at least once, and then allow the remnants to fold neatly back over on

itself, or snip it with wire cutters. This step is demonstrated, simply scan the VQR barcode in the lower right corner to watch our “How-To” video to gain familiarity because it is difficult to describe in written form but easy to visually convey by video demonstration. After wrapping the tabbing wire around the BUS WIRE, feel free to move on to the next tabbing wire in line for the same connection steps of wrapping the thinner tabbing wire around the much wider BUS WIRE. The folding process of wrapping tabbing wire around the BUS WIRE provides strength and grip, the soldering provides the electric conductivity so important in photovoltaics.

23) **Draw a light coat of Rosin Flux Pen over the four spots -** on the BUS WIRE that is to be soldered remembering to “wet” the Rosin Flux pen first. Remove the cap and push the Rosin Flux pen tip down into a piece of cardboard to get the tip soaked with the flux material. Then lightly apply a coat of the Rosin Flux over the four places you are about to solder in order to join the strings. This means pressing the tip against the BUS WIRE where it will be making contact with the tabbing wire. You want a slightly visible sheen from the Rosin Flux pen, taking great care to ensure it does not flow outside the immediate area where the soldering will take place. Rosin Flux is sticky and makes a mess if it flows all over and around a tabbing wire, something that is less likely to

happen if the tip has been first “wet” prior to application.

24) **Prepare the solder gun or iron by “tinning” the solder tip -** by touching the rosin core solder wire against the heated tip of the soldering tool. The small amount of solder that cools on the tip helps to convey heat from the solder tip, into the surface in need of bonding. Once tinned, it is now ready to solder the BUS WIRE to the tabbing wire.

25) **With the solder tip hot, and freshly “tinned” -** hold the tip lightly on top of the first section of wrapped tabbing wire that has been coated with Rosin Flux. You will see the tin coating around the tabbing wire melt, where you then lightly touch the tabbing wire with a strand of rosin core solder wire which will liquefy and flow around the bus wire/tabbing wire combination.

26) **Turn now to the bottom of the STRINGS that have just been joined.** You DO NOT connect these two at the bottom exactly as you just did with the top. Instead, you are now going to connect the bottom of the second STRING, to the bottom of the third STRING which should be opposite polarity of each other. This is accomplished by repeating the step from step #25 where you joined the two STRINGS at the top of the solar module. A strip of BUS WIRE approximately 9.5”inches long laid over the two sets of overhanging tabbing wire strips followed by wrapping the tabbing wire over the BUS WIRE as you just completed in step #25.

27) **Moving on to the TOP of the third STRING -** where you will connect the third STRING, to the top of the fourth STRING. Again, verifying the polarity is opposite for these two final connections, measure the final strip of BUS WIRE needed to connect these two final strips. Repeat the steps previously taken to solder the BUS WIRE to the tabbing wire and upon completion, you have succeeded in connecting all of the STRINGS.

28) **After connecting the STRINGS on the entire solar panel -** you will be left with two

STRINGS that will each have an end-run not attached, just two tabbing strips overhanging. Typically these two STRINGS that become the anchor for the outbound lead are the left and right outer-most STRINGS. If you have three STRINGS (it is possible if you make three STRINGS of 12-solar cells each) these two un-occupied end-runs will be at opposite ends of the solar panel, it just comes out that way because you are working with an odd number of connections. It will merely require you to run a wire (also called a conduit) along the inside of the solar panel, along the inside wall of the substrate. Because of the limited distance the wire must transport the electrical current; the wire size can be smaller than that used to transport the energy from the solar array to the battery bank. I use a 12-guage stranded copper wire which is perfect for the purpose, small enough to fit easily and effective for bringing the POSITIVE and NEGATIVE leads into close enough proximity to fit into a single project box enclosure which we will talk about later.

29) POSITIVE Outbound Lead Construction - connect **bus wire** to the POSITIVE STRING just mentioned in the previous step. This BUS WIRE strip will be soldered perpendicular across the POSITIVE end-run, covering the two tabbing wire strips protruding from the last solar cell of the STRING. The bus wire strip should be pointed towards the inside of the solar panel since your goal is to have the **bus wire** strips from the **NEGATIVE**, and POSITIVE leads meet in the center, top of the solar panel. This is because you will be connecting these BUS WIRE strips to a junction or project box. Heavier insulated wire will deliver the current to where the work needs to be done, primarily destined for deep-cycle batteries. The first outbound lead, the POSITIVE, requires two pieces of bus wire each being four (4) inches. The first piece will lay across the end-run coming off the POSITIVE string (with tabbing wire coming from the non-sun facing side of the STRING). You will position the small bus wire strip, hold it in place with cushioned weights, and then solder this bus wire to the POSITIVE end-run. The blocking diode is installed at the end of the newly soldered POSITIVE outbound lead, towards the mid-point of the solar panel frame. After the diode is soldered to the first part of the POSITIVE bus wire, a second piece needs to be added in order to meet the **NEGATIVE** outbound lead at the solar panels' mid-point.

30) Connect a BLOCKING DIODE to the POSITIVE bus wire strip installed to the POSITIVE end run in the previous step. A blocking diode is a device (pictured immediately above) that prevents the electricity stored in the battery bank from leaking out through the same solar panel that generated the electricity in the first place. Some junction boxes contain factory installed blocking diodes so be sure to check if you are not certain before committing to this step.

NOTE: ***shade is the universal enemy of solar panels as it robs a solar panel of consistent performance. In fact, shade can essentially neutralize an array that is only partially shaded because it creates a weak link so to speak in our chain of solar cells. The solar panel(s) that are either partially, or totally blocked from direct sunshine stop producing current because without the energy filled photons from the Sun, there is simply not enough excitement going on within to knock electrons from their respective valence layers. However, those shaded solar cells act like a magnet for those electrons that <u>have</u> been broken free within solar cells that ARE in the sunlight thus disrupting the current flow for the whole solar array. Just as our solar panel benefits from the additive value of all those solar cells working together, when one fails to generate current due to shade, they ALL fail. Once a solar cell, STRING, or even a single solar panel contained within an array becomes shaded, the electrons lacking sunshine become unmoving and act as a sponge that absorbs electrons that are inbound from other solar panels in the same circuit. Michael Boxwell describes explicitly the mechanism in his book entitled "Solar Electricity Handbook" where he points out that by absorbing all the inbound current, hot spots are created that can lead to fire in the solar panel.***

At the bottom of the page I include an example of clever ingenuity by a homeowner who deals with shade by hanging his handcrafted solar panels from the eves of the house. He was able to achieve the proper orientation (south) and the tilt angle (his is set to an optimum fixed year-round angle arrived at by the formula, "90°- his latitude (33°) = a tilt angle of 57°) by using PVC pipes to provide the desired tilt angle. He is able to avoid the shading issues and still employ solar panels without having to mount them on his roof. One solution to shading might include using less shade sensitive types of solar panel namely those made with amorphous cell technology.

31) **Connect a length of BUS WIRE from the unoccupied end of the blocking diode -** that has the grey color band facing the direction of the battery bank or charge controller. This particular strip of BUS WIRE need not be the same length as the NEGATIVE **bus wire** lead because the blocking diode takes up some of the space formerly needing to be covered by the BUS WIRE. This BUS WIRE strip will run from where it is soldered to the blocking diode, to the mid-point on the solar panel frame. It then makes the 90° turn to position the POSITIVE lead to connect with the junction or project box.

32) **Create the NEGATIVE outbound lead that originates at the END-RUN -** (the only END-RUN that does NOT have anything connected to the tabbing wire strips protruding from the top of the last solar cell in that STRING). The length of this particular BUS WIRE should be the full distance between the END-RUN, and the mid-point of the solar panel frame (as marked in the How-To video). It must then also make the 90° turn upwards to be able to connect inside the project or junction box. **Bus wire** is used for joining STRINGS as well as for the outbound leads, and they can never come into contact with each other at any time inside the solar module. There is the very slight possibility of creating such contact if we are not careful when creating the outbound leads. The path these specific bus wires take puts them in close proximity to the STRING connections along the top of the frame on the inside. Notice in the photo below how the BUS WIRE strips do not touch each other irrespective of the function. The outbound leads run above the bus wire segments joining STRINGS but are as far away from the aluminum frame as possible. The frame is made from aluminum and will short-circuit the solar panel if any contact was made between BUS WIRES of opposite polarity.

In order to ensure that contact between BUS WIRES cannot occur as result of temperature related expansion or contraction inside the solar panel, all of the BUS WIRES can be coated with clear silicon caulking. A light coating of the caulking will provide protection against moisture and serve to anchor the BUS WIRE to the substrate at key points where movement would be problematic. Just a dab under a half dozen points on each lead should suffice. Note in the photo below how the yellow coated **NEGATIVE** outgoing lead is rather lanky, clearly in need of an anchor to prevent any incidental contact.

33) **Yellow coloring is not a part of the actual NEGATIVE** outbound lead; I merely placed it there for ease of visual comparison to its surroundings. It was removed after the photography was completed. Once the **NEGATIVE** lead is soldered to the

respective END-RUN, you will need to extend this **bus wire** nearly to the end of its 14" inch length so that it meets the POSITIVE outbound lead where you have marked the mid-point of the frame. Once in the center of the frame, both the POSITIVE and **NEGATIVE** leads should be bent upwards at a 90°. After making the sharp turn with the bus wire to point both leads straight up into the air, there needs to be at least one inch of wire remaining that is pointed upwards so the connection can be made with the project or junction box. You have two choices on how to put your solar panel into service, **1)** Connect with other solar panels on an array (multiple solar panels on a racking system) or **2)** Connect the solar panel to a charge controller for use charging batteries either deep cycle, or rechargeable battery configurations like battery operated cordless tools, laptops or other devices that operate off direct current electricity. The more solar panels you build the more power you will be able to generate.

Step 4

Encapsulating your "WIP" for the Ultimate Long-Term Protection

Not every "WIP" will be encapsulated as this is a personal choice; it just happens to be the most effective method for replicating the type of protection afforded solar panels manufactured in automated factories. It is not possible to identically replicate the processes because it is carried out with equipment outside the financial realm of the typical homeowner or DIY enthusiast. Having said this, it is still possible to achieve the same level of protection in our DIY handcrafted solar panel projects, providing the same level of insulation against moisture, dirt, insects, rodents, birds, or other external threats to the integrity of the solar panel. The primary goal of this stage of solar panel assembly is to provide the best protection against moisture possible. Encapsulants do an excellent job of encasing the STRINGS in a soft, gel-like silicone elastomer coating that provides outstanding long-term protection against the elements. Encapsulants provide a soft, flexible cushion for the solar cells that allows for temperature related expansion and contraction and it provides a physical barrier between the solar cells and the outside environment. There are a variety of encapsulating agents on the market, some better than others, and based on my experience, there are only a couple that I would use regularly and those are the only brands I use for my DIY panels, QSIL, Solar-Tite, and Dow Sylgard.

During the video demonstration available in our Solar Tech DIY "How-To" library I used Solar-Tite 384 at a mix ratio of 2- ounces of Solar-Tite curing agent to 16-ounces of the Solar-Tite Elastomer Base. I am also fond of QSIL 214, 216, and 219 which have very similar properties as Solar-Tite products but they cure in a fraction of the time. In fact, I have poured the QSIL encapsulating compound over my "WIP" in the early morning hours and was able to install the solar panel that very same evening onto a rooftop array. Deployment of a new solar module quickly is a difficult ambition to find fault with, who isn't excited to put the fruits of their labor out into the sunshine? I have handcrafted a great many solar panels yet each completed panel elicits the same level of excitement as I felt with the first one I ever finished. The use of quick-curing encapsulating products definitely will give you quicker deployment, but you need to have everything ready and complete all of the procedures within a very tight window of time. When the manufacture states the cure time will be 28-minutes, they are not off by more than a few seconds so you really must have proficiency to avoid the consequences of encapsulants hardening before you are ready for that to happen. The slower curing encapsulating agents will allow you much more time to work with air bubbles (extracting them) and to install a Tedlar Backsheet well within the extended cure time window. It is a matter of preference and proficiency, two criterions you will personally be in a position to make after just a little experience.

34) **Plumbers Putty** - is used in my demonstration video around the perimeter of the substrate. This is done for the express purpose of denying open space for encapsulant to flow where it serves no purpose and is therefore a waste of the valuable material. Note in the photo below how the putty is used like a dam, rolled into round sections generally the diameter of a pencil but rolled smaller or larger depending on the specific area you are working. Once the sections of putty are laid into position, use your fingers to gently push down on the putty rolls to make a more seamless bond between the putty-roll and the tempered glass. This will help prevent encapsulant from flowing under the putty rolls and going to waste. Take care not to crush the putty rolls when pushing down, you don't want to alter their shape such that the encapsulant might flow OVER the putty sections. There is another risk in the form of leakage from the corners of the aluminum frame onto which the tempered glass substrate is affixed. If silicon caulking is not used to seal the corners, AND if putty is not used to stop the flow of encapsulant, it will literally leak out from all four corners of the frame long before it has the chance to cure. Typically the main body of the frame will not leak because silicon caulking is used to bond the aluminum frame to the substrate thus, preventing leakage along the body. Corner leaking can be prevented by continuing the caulking bead all the way UP the corners when laying the initial caulking bead when installing the substrate onto the frame. Once the encapsulating material is cured, gently pull up the plumbers putty out of the solar panel by either extracting the putty rolls in-tact or gently digging out the crumbled remnants. I have never quantified the fiscal savings from using the putty to close off the areas it does but I know one thing for certain, it allows more of each encapsulant batch to build up where it is most needed, surrounding the solar cells.

35) **Removing air bubbles or "de-airing" encapsulants after mixing** compounds, and how this process impacts your curing timetable.

Having said all that earlier about the sense of pride and speedy access to your functioning solar panel, there are some things you need to know about the super-quick curing encapsulating products. When the manufacturer supplied Technical Data Sheet indicates that curing commences twenty-eight minutes after the two ingredients are mixed, they are not off by much more than a few seconds. Further, they point out that the hotter it is outside, the quicker QSIL brand encapsulants cure. While the clock is ticking down, you must first remove the air bubbles using the pump I demonstrate in the appropriately entitled "How-To" video in our exclusive YouTube video library. Removal of air bubbles is specified in the QSIL instructions and so this is not an optional step, the technical data specifies the need for "DE-AERATION" after mixing (unless the mix is done by machine, presumably inside a vacuum chamber). The "How-To De-Air" encapsulating products video available in our exclusive library depicts a nearly invisible jar that seemed to contain an equally invisible liquid. The truth is that I had already poured the two components, stirred them, and then used the negative vacuum pump three times prior to turning the recording device on. In reality, you will likely introduce air into the **first** of the two-part compound when you add the **second** part. Remember, this is extremely dense liquid that does not behave the same as if adding water to containers of similar proportions. Air is trapped as the two components initially come into contact and further when hand-mixing commences. In the demonstration video, when I appear to pour “PART A” followed by “PART B” into the nearly invisibly glass jar container I am simulating the act of pouring. I had already poured, stirred, and de-aired the contents of my miraculously invisible jar. I was not attempting to deceive as is evidenced by these couple sentences, quite simply it would have been tedious for you to watch me pump like a fiend, then push the lever to allow air back into the jar, to repeat it three times over. The only benefit I suppose would have been to see how it looks when the air rises through the encapsulant under the effects of negative air pressure in the un-filled portion of the jar.

When utilizing the Mityvac hand pump as demonstrated in our video, each squeeze of the pump is extracting a small gulp of air from within the jar. An air-tight seal around the jar lid and the pump hose connection on that lid is essential for the Mityvac to achieve a vacuum inside the jar. Air is gradually removed from the portion of the jar not occupied by encapsulant until the absence of air in that empty chamber creates a powerful draw on the trapped air within the encapsulant (trapped air is visible in the form of bubbles). Eventually the air trapped deepest will be drawn up and out into the chamber which might require between three to five of the pump/release cycles. Once the jar is attached to the lid/pump device, manipulate the hand pump until the gauge reads approximately **-25** Hg on the outer dial. Allow the negative pressure to draw the trapped air upwards through the dense encapsulant, something that will happen fairly quickly for the shallow bubbles. If there are many bubbles rising at the same time, the bubbles will form what looks like the work of a very small bubble blowing toy. Bubbles will build in number to the point they can enter the vacuum intake tube that protrudes through the center of your jar lid (if you used a small jar for sure). This will ruin the tubing if you don’t clean it immediately: however, this can be avoided by releasing the lever and allowing air back into the jar when the collective assembly of bubbles starts growing in size. This pops the collected air bubbles that have been pulled up and out of the encapsulant, with each release of the vacuum you will notice fewer remaining within the encapsulant. You CAN significantly reduce the introduction of bubbles while mixing by moving slowly, carefully, and trying not to allow the mixing tool to break the surface so to speak. I say that because it might seem natural to treat the mixing of encapsulant the same as you would when mixing pancake batter, whipping the thick liquid into froth. Mixing such as this would require a vacuum pump the likes of which might be found on the International Space Station, the type they might use to suck suspiciously Octopus-looking space aliens out the escape pod hatch and into the dark void of space.

The best mixing is done with a steady, slow, swirling motion that needs to be executed at slow-motion movie speed. It will save your forearm muscles from an exhausting and difficult task as the fewer bubbles introduced when mixing means fewer maniacal pumps of the Mityvac to get rid of them. In conclusion on the topic, when using the quick-cure encapsulants you have a very limited time to complete steps you previously may have taken your time performing with slow-curing encapsulants. The clock starts ticking the second part “B” is added to the canning jar, and while there must be a sense of urgency, your actions must be gentle, controlled, and with hyper-focus on limiting air bubble introduction. After pouring, it takes the viscous liquid a few minutes to self-level, a process where it slowly expands until it has achieved a uniform coating commensurate with the volume of encapsulation material present. You must realize how quickly 28-minutes will pass and how much of this time will be consumed during the de-airing process. There must be ample time for the encapsulant to self-level so it is in your best interest to minimize the number of times you will be pumping air out of the canning jar. It is possible to have the encapsulant cure before it has had enough time to achieve any semblance of self–leveling in fact, it may still appear as it looked a few seconds after having been poured over the substrate, permanently. Therefore, when using quick-cure type products you must be able to complete all preparatory and application steps and still leave time for the self-leveling feature to work. To make it more complicated, if it is very hot outside the elevated temperatures will shorten that 28-minutes cure time and make it very difficult to fit all the tasks into the compressed timeframe.

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Curing Times: (generally)

QSIL 214: 28-minutes

QSIL 216: 4-hours

QSIL 219: 5-hours

HINT: Benefit from MY mistake, heed the warning about air temperature in relation to cure speed. In the not-to-distant past I was about to finalize a "WIP" by pouring the encapsulating product QSIL 214 which has an incredibly fast cure time of 28-minutes. Curing means that the encapsulating material undergoes a chemical process the result of which is a transition from a liquid state into gel-like sold. The day I had my experience it was HOT, triple digit temperature in my shop which accelerates the cure time, a fact I was unaware as I mixed my batch. Unaware I was past the point of no return and should have just tossed the batch out and started over, I poured. I noticed two things immediately, the jar was almost too hot to hold with bare hands, and the encapsulant was literally hardening in mid-pour like pictures I have seen where small waterfalls have frozen in mid-fall somewhere in the Arctic Tundra. Horrified, it took about another billionth of a second to realize I had just ruined a "WIP" because I could do nothing about the globs of unsightly and erratic patterns of clear topography I had created. At the same time I suspected that while it looked messy, it would probably work perfectly and so I mixed a new batch of QSIL. Not until after researching what had gone wrong and waiting until cooler evening temperatures, but this time it was successful. That next batch performed the encapsulation intended by the first batch and upon curing; it performed flawlessly and is in service at this time. The last hint has to do with the encapsulant as it is curing on the "WIP" whether it is the traditional, or quick-curing. There is something about encapsulant that attracts flying insects during the curing process. Perhaps there are fumes that insects are attracted to but if they land anywhere on the encapsulant they will forever remain a part of the solar module. You may attempt to extract them but usually they come out in bits, if at all, and so it is far preferable to keep them from landing on the encapsulant at all. After pouring and de-airing, cover the "WIP" with a sturdy piece of wood or glass, anything that covers the module and can support its own weight so it won't sag. If you are planning on installing Tedlar Backsheet, that becomes the permanent anti-insect barrier. If not simply remove the wood cover to check periodically until cured.

35) Preparing to Pour Encapsulant

35a) The first step is to position the "WIP" in such a manner that you will be able to pour the mixed and de-aired encapsulant over the exposed side of solar cell STRINGS, and after pouring, be able to observe the underside of the solar cell STRINGS with unobstructed access. You will need to visually monitor the progress of encapsulant as it self-levels in the space between the solar cells and tempered glass. The best solution is to create a work platform that gives you full access to the pour area from above, but also the ability to see the underside to gauge whether the self-leveling process is in need of your help. The most advantageous access position to see the underside while simultaneously providing stable, level support for the "WIP" is to use either an old unwanted table, or a piece of wood that has been cut with a hole measuring slightly smaller than the "WIP". Then you simply provide support for the wood surface that will allow you free movement UNDER the table as you visually inspect for air pockets. Unless your skeleton is made of Playdough, it is almost impossible to get a good visual inspection unless you are able to lay on your back, under the "WIP". So, if you cannot spare an old table, a thick piece of level plywood would be a suitable replacement. Cut out the same size hole as you would have from the table, use a pair of sturdy saw-horses, cinder blocks, anything that will allow you to lay on your back and easily look through the ‘WIP” after pouring the encapsulating material. On the next page you will see a photograph of the table I use for the encapsulating process, an old dinner table that had served its last meal some time ago. You need to take the appropriate steps to ensure that the table you cut open is NOT your spouse’ family heirloom, or perhaps still serving actively as the family eating platform due for service in its customary role this very day. Providing all is clear, and you have cut out the hole, you need only ensure the table is level, and that you have cut the proper size hole. The last thing you need to have happen is for the “WIP” to fall through the over-sized hole because I am not familiar with any solar panel capable of surviving a fall from such a height.

35b) With the table set up, place the “WIP” over the cut-out or on top of the configuration you have decided to use. The substrate must be completely level, not to the naked eye, but it must be confirmed by use of traditional leveling devices that use an air bubble within a transparent window. If you fail to level the substrate, there is the very strong possibility that the encapsulant material will flow unevenly and pool at the lowest point on the substrate. If you have NOT secured the STRINGS to the substrate, it is possible that the entire STRING will float out of position by literally floating on top of the shifting encapsulating material. Depending on the type of encapsulating material used, the curing time might be so quick that the shifting STRINGS might be permanently be frozen in the shifted position and you will have to work quickly to correct the problem. There are several leveling tools that can be used as demonstrated in the How-To demonstration video, which should also be used to make sure the table you are supporting the “WIP” is level. In order to make small adjustments to the “WIP”, have several pieces of cardboard about two inches square with which to prop up any low corners of the “WIP” to achieve a level state.

Pouring the Encapsulant

Once the substrate is level, well supported over a cut-out table or board, you can mix the two components of the encapsulating material. Watch the demonstration video to get the proper mixing technique as well as how to remove air bubbles from the encapsulant once the two ingredients have been mixed. Once appropriately mixed, and de-aired, it is time to pour the material over the exposed STRINGS. If you are using a quick-curing encapsulant, set a timer of some sort, perhaps the one that comes standard on the Apple iPhone, or a kitchen timer, anything to keep you aware of elapsed time. If you are unable to proceed to pouring within the first few moments, or if the de-airing process takes too long, be prepared to make the decision to abort the pour. You would abort to avoid having the encapsulant cure before you are ready for this to happen, not a lightly made decision because the mixed encapsulant becomes waste. Premature hardening does not necessarily mean you will ruin the project, it only means that it will require another batch of encapsulant to cover the areas not protected by the overly quick-curing encapsulant. Pouring is done directly out of the jar used in the de-airing process so that you don't introduce air into the encapsulant AFTER already having completed de-airing. Pouring the encapsulant is very different than pouring a similar volume of water because of the density of encapsulating material. Water being poured from a pitcher will react immediately to any change in the pour angle as we can all attest, but not so with encapsulants. They pour slowly, and react sluggishly to changes in pour-angle, but once the momentum is built up, gravity takes over and it will flow out quickly, more so than you will be ready for. Just pour in a slow, steady stream and make pour-angle changes slowly because the reaction will be delayed, but inevitable.

36a) Pour the encapsulant around the outside of the STRINGS following the shape of the outer frame. This will start the encapsulant flowing between the STRINGS. The Plumbers Putty "dams" made to economize the use of encapsulant will force the encapsulant to flow under the solar cell pairs the STRINGS because the encapsulant will only have one direction to flow, on top of or under the STRINGS.

36b) Pour the encapsulant next between the STRINGS on the inside of the main body of the substrate. Pour from the top, all the way down to the bottom, pouring a heavy enough stream to cover the gap and leave a small amount of material piled up and ready to flow naturally under the STRINGS.

36c) Pour the encapsulant now between the gaps between individual solar cells that make up the STRINGS. The gaps I am referring to are the ones you used the pencil erasers to establish, literally between the solar cell "pairs". By pouring in this small space you are providing the means for encapsulant to flow over and under the STRINGS from all four sides around each and every solar cell. You will have poured around the exterior of the STRINGS, the interior STRINGS, and finally between the individual solar cells. The self-leveling properties will allow the encapsulant to flow under the individual solar cells and STRINGS to which they are attached.

Curing Process and Final Bubble Removal

Within approximately fifteen (15) minutes of pouring the encapsulant there will be significant visual evidence of self-leveling because the entire surface of the substrate will be covered. This will be obvious while standing over the “WIP” and looking down at the back sides of the STRINGS but you will need to examine the other side as well to verify a uniform coating of encapsulant. Pockets of trapped air are the biggest concern hence, the purpose of this inspection which can only be conducted from under the “WIP”. If you followed the advice to build a function-specific table with the cut-out this inspection will be comparatively straight forward. There may be small pockets of air under some of the solar cells that are very large, perhaps half the size of a solar cell, or dozens of smaller pockets that look like bubbles. If you observe air pockets, don’t panic, many times the air will work itself out as the encapsulant self-levels.

There will be times when the self-leveling property of the encapsulant fails to push the air out and bubbles will be visibly present. Bubbles are unsightly and erode the professional appearance of the solar module and for this sake alone we would want to take steps to eliminate them. They also represent a long-term threat to the service life of the solar module for a couple reasons. One concern about air pockets is that their presence can lead to solar cell damage as a result of temperature related expansion or contraction. Solar cells that are surrounded by the soft, protective gel are protected from stress because the gel allows movement. Movement of this sort is tiny, barely measurable, but if an air pocket has separated a portion of a given solar cell from the protection afforded encapsulant it is vulnerable to micro-cracks. Moisture is a possible threat to any exposed portion of the solar cells and of particular concern would be any exposed tabbing or bus wire. These are highly susceptible to corrosion should moisture enter the environment or perhaps become a regularly introduced by condensation. Therefore, not all air bubbles represent the same risk, as a general rule of thumb, if the bubble is over a solar cell but does not involve tabbing or bus wire, there is very little long-term risk. If there is a bus or tabbing wire exposed to the air because it is within a bubble, there is a greater risk of corrosion if moisture enters the air pocket and then condensates. There is a reasonable chance no moisture will ever enter that void, but you will need to check on that specific area on a regular basis to see if there is evidence of moisture. If so, there will be corrosion within a very short time measured perhaps in weeks. Corrosion will lead to resistance, meaning heat, so you may be able to see signs of this by the presence of colorful bands radiating outward from the now visibly corroding tabbing wires. That is about the time to pull it out of service for the safety of life and limb. I have solar panels in service on my arrays that do indeed contain exposed air pockets exactly as I am describing. The few units that have these air pockets have been in service in excess of five years with no measurable decline in output and I have never observed moisture condensing on the inside of the solar panels in question. The presence of such an air pocket does not automatically mean that water drops will be forming on the inside of the substrate as one might expect. Remember that although there is a pocket of air, that air pocket is surrounded completely by a ring of encapsulant that will prevent any moisture to enter, therefore, no drops of water inside the substrate.

If you are constructing the wood substrate in conjunction with a glass or synthetic cover, moisture will be of particular concern because wood is so porous. This is why it is so very important to liberally paint the substrate with silicon caulking because paint, even primed, will not provide a sufficient moisture barrier. A little off-topic but definitely applies to the subject matter.

37a) Helping the encapsulant self-level might be necessary if using a fast-cure product.

Once you have poured the encapsulant as outlined in step # 36, the self-leveling properties will cause the dense liquid to gradually spread until uniformly covering the substrate. If you are using a fast curing product such as QSIL 214, the gradual pace of self-leveling could possibly lead to the encapsulant curing before the substrate has achieved a uniform, bubble-free coating. For example, if you have poured 16-ounces of QSIL 214 over a "WIP" has 36-solar cells; it may take an hour for the encapsulant to achieve the desired uniformity and clarity. It doesn't require a complicated algorithm to arrive at the conclusion that an hour to achieve a satisfactory condition is more than double the manufacturer stated cure time. In fact, the QSIL 214 will begin to solidify long before the substrate is covered so you must assist the process of self-leveling. Just as in the video demonstration, you may need to tilt the "WIP" as a means of using gravity to help spread the encapsulant. Tilting each side of the substrate up approximately eight (8) inches off the work surface (your cutout table) as I demonstrate in the video, you will be able to observe encapsulant

flowing comparatively quickly since there are no obstacles. In fact, you will take your cue on when to return the "WIP" to a horizontal position when the encapsulant surge nears the edge of the frame. While you are watching to make sure nothing is wasted by falling over the edge of the "WIP", the encapsulant underneath the STRINGS will be moving as well, just not as quickly because the cramped quarters (between tempered glass and the solar cells). The sudden increase in force behind the slow-flowing encapsulant usually does the trick and encapsulant will flow over the spots previously resistant to coverage. Perform this same tilting action around the four sides of the frame applying the same visual cues for when to return the "WIP" to the flat position.

37b) After tilting the substrate four times, one for each side of the frame, you may need to perform an additional step to remove smaller pockets of trapped air. These smaller air pockets will appear as great concentrations, numbering perhaps in the hundreds in a given spot since they are so tiny. Remember, we are talking about bubbles trapped between the substrate, and the sun-facing or **NEGATIVE** side of the solar cells. Having a zillion air bubbles between the business-end of the solar cell, and the incoming photons from the sun is a condition you must attempt to correct. When you scan the VQR barcode on the bottom right of this page, you will be directed to our exclusive YouTube library, specifically a video demonstrating how to free air pockets trapped between tempered glass and a solar cell. I demonstrate how to massage the trapped air out from beneath the delicate solar cells by applying downward pressure with paint bush bristles. I demonstrate how to corral the air pockets towards the edge of the solar cell under which they are trapped. Once near the edge, the bubbles can be gently prodded with the paint brush by applying gentle downward pressure. The pressure should start in the middle of the particular solar cell and then gradually moving the bristles towards the edge of the solar cell where the air will rush from under the solar cell and escape with a gratifying “POP(s)” as the bubbles burst.

The method involves the application of gentle downward pressure with the SIDE of the BRISTLES as opposed to a straight downward pressure. In fact, if the paint brush bristles were pointed exactly perpendicular to the solar cells and the straightness of bristles maintained while pressing the handle down, one could easily shatter the solar cells with just the bristles making contact. It is surprising because we would expect the bristles to yield under the pressure, which at some point they do, but well after the fragile silicon wafer would fracture. Watch the demonstration video and take note of my smooth motion with the paint brush as I gently massage the trapped air pockets towards the outer edges of the solar cells. You can actually witness the trapped air escape when the bubbles reach the outer edge and slip into the open. The bubbles expand and then quickly pop with a satisfying finality. The only way you are going to identify the presence of these trapped air pockets is if you can physically SEE the underside of your substrate. Remember, you CANNOT move the “WIP” off the table or work surface because the instability may cause the still-in-liquid form encapsulant to slosh (albeit a very slow slosh, but slosh nonetheless) and with it, the STRINGS resting inside the yet-to-be-cured encapsulant. Even if you could safely manage to lift it over your head to perform an inspection, marking the location of trapped air is a step that cannot be accomplished while suspending the “WIP” overhead. Marking the location of trapped air is helpful because attempting to recall exactly which of the 36 solar cells has the trapped air beneath after only a brief glimpse is a difficult feat at best. Releasing trapped air requires frequent comparison, inspection, and adjustments, tasks which might require working from UNDER the cutout table. Reaching up and over the side of the cut-out table is an ideal position from which to address the pockets of trapped air. Looking up through the "WIP" from under the table provides a direct line of sight to track your progress on air pocket removal and it makes the process more efficient because you are able to focus all of your energy on specific pockets of bubbles. To enjoy success by working from under the table one must possess reasonable hand-eye coordination since it is an uncommon angle to be working, like cutting one's own hair using a combination of mirrors. It can be done but it requires good hand-eye coordination due to the angles and the limited range of motion available to you. You will be looking directly at the **NEGATIVE**, sun-facing side where the bubbles are visible, and you must be able to set the paint brush down on the correct solar cell and apply the appropriate amount of pressure. It sounds awkward but with just a little practice it will become routine.

One final note about air pocket removal since there is a method I have yet to mention. Some will suggest the use of vibration to assist the self-leveling of encapsulating materials, something I have never done but am currently investigating.

Installing Tedlar Backsheet

The installation process is straightforward especially if you pre-cut the piece of Tedlar to fit the exact size of the substrate so that it fits directly into the frame. Minor modifications might be needed to accommodate unique attributes of an individual solar module. For example, small cutouts will likely need to be made in order to accommodate corner brackets or clamps added to lock a substrate onto a frame. The "WIP" should be perfectly rectangular aside from the objects mentioned above, so after minor trimming, the Tedlar Backsheet should lay directly on to the still-curing, tacky encapsulant. After making the requisite adjustments to your Tedlar Backsheet there will be a couple points that might appear higher than the surrounding surfaces. For example, the blocking diode will result in a bulge visible to the naked eye but will not affect the performance of the Tedlar. Once the Tedlar Backsheet is installed and encapsulant cured, it may appear mildly lumpy as it reflects the contours of the STRINGS it covers. Do not be concerned, the lumps are not a problem and will not affect output in any way.

38a) Unroll the Tedlar Backsheet and place it flat to smooth out any imperfections (wrinkles) which should not be present. The sheet will try to roll back into the shape it has been rolled into while stored in the shipping tube. Nothing you do will defeat the maddening proclivity of this sheet to curl back into a tight roll, almost cartoonish in its maddening persistence. It is more than an aggravating exercise because it

is possible for the STRINGS to suffer damage as a direct result of the self-rolling action. To prevent this from happening try to open the sheet up and have an assistant hold one end while you position the other. Having two people position the sheet will prevent uncontrolled contact between the Backsheet and the solar cells resulting in fewer installation issues.

38b) O**nce the Tedlar sheet is lying flat on the substrate, begin smoothing** it out. This is best done with a clean, DRY sponge or soft packing type foam which will be used to gently press the Tedlar Backsheet down against the "WIP". Use light pressure and remember there are fragile solar cells down there under that shiny white Tedlar Backsheet. Work the entire sheet in a methodical pattern, basically "wiping" the surface which will improve the bond between encapsulant and Backsheet.

38c) N**o adhesive is required when placing the Tedlar Backsheet** on because it is installed while the encapsulant is tacky to the touch. The Tedlar Backsheet will form a bond with the encapsulating material prior to it drying such that glue is not required. In the event the encapsulant has cured beyond the point of being able to hold the Backsheet, you may mix a small batch of encapsulant specifically to serve as an adhesive. That is exactly what I did for the demonstration video for this topic.

38d) Once the encapsulant cures, the edges of the Tedlar Backsheet needs to be sealed against moisture entering around the perimeter of the Backsheet where it meets the frame. This is accomplished by placing a bead of silicone caulking around the edges of the Backsheet where it meets with the aluminum frame. In this case, instead of using CLEAR silicon caulking, you can use WHITE since the Tedlar is that color and it will be much more aesthetically pleasing to the eye. A wide bead can be used to contain the gap or to bridge the distance between the edge of the frame and the edge of the Tedlar Backsheet. The only portion that you will NOT put white caulking on is the pair of outbound leads that we put through the two holes cut specifically for this purpose. Those will be sealed in the next step when we install the project box which houses the double terminal block.

The final step in your project is to provide the solar panel with a way to connect to other solar panels in your array OR directly to a charge controller. The two outbound "lead" **bus wires** that were brought up and through the two holes in the Tedlar Backsheet, one POSITIVE the other **NEGATIVE** will serve to facilitate the first leg of the required connection to the outside environment. The two **bus wires** just described must be connected by some mechanism that "hands off" the current that is generated by the solar panel. The two **bus wires** entering the project box carry the current, or for our example, the "baton". The current, or "baton", will need some mechanism for continuing on its journey from the solar panel, to the outside environment where it can be put to work.

The "hand-off" takes place on a device called a **terminal block** whose purpose is to provide the connection point from the solar panel, to the outside environment. It does so by accepting the outbound bus wires, both NEGATIVE and POSITIVE, which come from inside the solar panel and are connected to the screw terminals on one half of the terminal block. You then connect wires to the remaining half that are used to connect either to another solar panel such as on an array, or directly to a charge controller where battery charging may take place. Just as you needed to keep the polarity straight when joining end-runs at each end of the STRINGS, keeping these two outbound leads correctly identified is equally important. Getting the polarity crossed at this stage would have unfortunate consequences when you eventually connected the completed project to a load or a deep cycle battery bank. This is where marking the polarity directly on the substrate comes in handy for ease of ensuring you do not get it mixed up at this important hand-off stage.

39a) The project box (photo on next page) must be prepared to accept the outbound leads coming up through the Tedlar Backsheet. The project box will rest directly on top of the Tedlar Backsheet and therefore, two small holes must be drilled into the bottom of the project box to allow the two BUS WIRE leads to be brought up through the bottom of the project box. Once through the bottom of the project box, the BUS WIRE leads will need to be connected to the terminal block. The terminal block has two pairs of screws, one set for the leads coming from inside the solar panel, then two screws to accommodate the wiring needed to connect this particular solar panel with others in an array, or directly to a charge controller. Note the placement of the holes for accommodating the outbound leads originating inside the "WIP". In the second, or bottom-most photo on the next page, note the terminal block has the BUS WIRE leads coming up from inside the solar panel already secured to the terminal block screws. This was accomplished by simply using wire cutters to make a split straight down the middle of the BUS WIRE where it connects to the terminal block. By cutting straight down, perhaps a few millimeters, you will form a split which fits nicely around the screws on the terminal block. When you first handle the terminal block, you must back the screws out by turning them counter-clockwise in order to create the space for the BUS WIRE split to grasp the screw. Once you tighten the screws down with a Phillips screw driver, they will be firmly in place and will stay secure.

39b) A pair of holes must be drilled in the side of the project box in addition to the holes in the bottom to allow for the "connecting" wires (**red** for POSITIVE, **black** for NEGATIVE). The holes should be pointing towards the bottom of the solar panel because you want the outgoing wires pointing down, protected from the sun by running beneath the solar panel. The wires should be minimum 12-gauge AWG, stranded copper wire, the wire cross-section diameter determined in advance using the wire sizing formula described in detail shortly. You may connect this solar panel with others on your array, or perhaps this is indeed your FIRST completed solar panel so it will be connecting to your charge controller, which then feeds the power to the deep cycle battery or battery bank. The use of 12-gauge AWG for short distance connections is absolutely fine, but you may also feel free to use a different method altogether. For example, junction boxes as pictured on the next page are designed to allow your DIY solar panel to connect with manufactured models. They contain MC4 type connectors which have superior UV and weather protection and are designed to prevent damage to insulation and eventual decay caused by daily exposure to a grueling Sun. Using this type of junction box saves some effort when constructing a solar panel because the blocking diode will NOT need to be included within the solar panel so there will be no visible "lump" under the Tedlar Backsheet. This particular junction box contains the blocking diodes necessary to prevent the solar panel from drawing electricity back OUT of your batteries.

Terminal blocks are versatile in how connections can be made in conjunction with the Phillip's screws that hold the connection firm. Some people simply strip the insulation off the wire about to be connected and after twisting the copper strands, wrap the bare wire around the screw and then tighten them. Turning the screw head clockwise until tight, the copper strands are crushed beneath the screw head. This seems fairly sturdy, but I would discourage this practice in favor of a method better suited for long-term service life. These connections can be a source of electrical resistance which can be mitigated by ensuring that each connection has the highest integrity possible. In step (39a) I described the connection where the BUS WIRES coming from the solar panel interior are screwed directly onto the terminal block. This connection is an example of good electrical integrity so the next connection to the outgoing (outbound) wires should continue that integrity. Using a "Spade" terminal is recommended to make the remaining connection with the outbound wire. The spade terminal ideally should be soldered to the outbound wire where the connection is made to the terminal block.

A word about wire sizing…

Wiring plays an important role in a photovoltaic system because the current (electricity) must be transported from the point at which it is generated, to some other location where it is to be either stored, or put to work in some manner. Wire comes in a dizzying array of sizes, types, and composition. Some are insulated, some not, others made with solid copper, others with stranded copper, while other wire may not contain copper at all instead being comprised of aluminum. Some wire types we are fairly familiar with such as extension cords, appliance power cords, speaker wire, entertainment system type wiring, and computer cabling to name just a few. Wire designed for a specific purpose such as speaker wire for example, should only be used for the low wattage purpose it was designed. Wire needs to have many strands, more the better to carry the current and the greater number of strands, the greater the efficiency.

You may need to place the solar panel some distance away from the charge controller to access direct sunlight. There are certain properties related to electrical theory you should be made aware prior to making decisions about how far apart to place components. Not many people have a need to measure distances between various points on their homes or properties and so they might be surprised by the length of wire needed to connect a given solar panel to a distant battery bank. Unfortunately, lack of knowledge will not protect you from the effects of "**voltage drop"**, the loss of voltage in a wire due to resistance within the wire in which it is traveling. Stated differently, the more difficult it is for the electricity to pass through a wire, the LESS of it will actually get through. Some of the energy is lost to the effort of pushing the current through the wire, but the loss becomes dramatic if the wire used is too small to accommodate the volume of energy in need of transport. Similar to excessive heat, using wire with the insufficient size will drastically reduce the output of your entire system irrespective of how many solar modules you have deployed. In fact, the problem is exacerbated with each additional solar panel contributing current to the undersized wire. Too much traffic through a given wire will cause heat to build and as we have discussed earlier, heat is a condition that contributes to electrical resistance. A heavy volume of electrons simultaneously rushing towards the battery bank that encounters traffic (other electrons, lots of them) will cause the electrons to slow down as they bunch up much like vehicle traffic on a freeway during rush hour. As the traffic begins to slow as result of congestion, the electrons begin to lose some of their collective energy as they fight to move forward. If enough resistance is present the system can grind to a halt simply unable to cope with the heat generated by the traffic jam at which time your undersized cabling can possibly fail. Obviously it would require a significant volume of electricity and I am oversimplifying the process, but the answer is to use thicker gauge wire if you need to go longer distances. It can get confusing when discussing wire or cable sizing because if you have never had to examine wiring, you may not know the differences. In order to remove the mystery of how to determine the correct wire size I have included the mathematical formulas over the next few pages. Additionally, you will discover the AWG wire cross-reference grid that will allow you to quickly identify the AWG wire size corresponding to the math formula you will have solved. Wire is expensive and therefore, one may be tempted to use smaller gauge wire than what our formula results call for. This is a mistake of the highest order for several reasons, first of which is the safety of yourself, your family, or the structure on which you have mounted the solar module. Heat is the immediate byproduct and not the type that merely makes one uncomfortable; rather, we are talking about wire becoming a source of combustion.

Fire is the ultimate hazard which should be enough incentive to make the right choice, but so should the value placed on your investment. I mentioned earlier that wire is expensive, but there is a difference between being frugal by shopping for the best price on wire, and being foolish by trying to save money up front by purchasing a wire gauge that is knowingly too small. There is a price difference between the various gauges of wire for obvious reasons; larger gauge wire contains more copper strands within the cross-section to handle more electricity. As I cover wire sizing in greater detail later, I need to briefly interject a note about wire sizing numbers to minimize confusion. Wire size numbers follow the AWG or American Wire Gauge system, a universal method for wire identification across multiple disciplines. A unique aspect you must grasp immediately is the inverse relationship between the AWG size numbers, and the physical diameter of the wire being measured. As the wire being used gets fatter, containing a greater number of copper strands than skinnier wire, the number attributed to size decreases. So if thickest wire used on solar power generating systems is AWG-0, one might imagine a very tiny wire based upon the AWG sizing number. In reality, an AWG size 0 is a very thick cable, the type used to connect deep cycle batteries. We want the heaviest gauge possible when connecting batteries due to the large amount of energy involved. Conversely, when connecting solar panels together, you will see in the wire formulas that AWG-12 gauge wire is sufficient. Confusion notwithstanding, there is no excuse to use improperly sized cabling for any portion of a photovoltaic power generating system because I am about to teach the formula to determine the precise wire diameter for ANY portion of your photovoltaic system. If you do take shortcuts on wire size used, any money saved up front will be spent eventually when you must prematurely replace all of the wire when the improper size leads to unacceptable voltage drop. Insects, rodents, rot, and not to mention UV damage are ever-present forces that will need to be considered lest they serve to deteriorate the performance capabilities of the wire. Naturally these forces are present daily and it does take months if not a couple years, but eventually will lead to a measurable decline in solar output. Therefore it is not only size, but the type of wire that is in need of consideration. More will be said about this shortly, the point being that like any job, the right tool is needed and wiring is very much like a tool in this instance.

In order to calculate the size of wire needed to safely handle the system you are building, you need to have a couple pieces of information. With this information you will have the ingredients to make math calculations the results of which determine wire diameter needs for each stage of the project. Remember, you are going to need different wire sizes at some point in the development of your photovoltaic power generating system as it grows in size and complexity. You may be starting your very first solar panel today and thus, discussing wire gauge sizing might seem premature. You would be right, but I propose to you that while you are right today, that will change upon completion of your first DIY solar panel because you will want to put it into service immediately. By the second completed solar panel you are clearly going to need to be educated about wire sizing since the combined electricity from this pair of solar modules must be transmitted elsewhere to be stored for later use. Typically there is some distance between the solar panels and the battery bank considering the prohibitive weight of deep-cycle batteries verses the relative mobility of the solar panels. In order to expose the solar panel(s) to direct sunlight, it might require rooftop mounting, a location choice that would require some considerable distance between the solar panel, and the battery bank. The underlying goal should be to make every effort to minimize the distance between the solar array, and the battery bank. The longer the distance between these two components, the thicker the connecting wire must be in order to prevent voltage drop. There is a pair of math formulas available to help you make an informed decision about the exact wire size to use, but there are a few pieces of information you will need in order to calculate the specific wire size needed for your project as follows:

You will need to know the distance between the two points the wire needs to run such as from the location where the solar panels are deployed, to the battery bank located in close proximity to your inverter. Similarly for a residential deployment, from the solar panel mount, along the eve of the house, down the rain gutter, then to the battery enclosure. **The final step is to convert this measurement into meters** because the math formula is designed to calculate using meters.

You then need to know the system voltage, in our case, we are typically discussing 12V (12-Volt) systems because we are using a deep-cycle battery of this voltage.

Lastly, we need to know the “current” in amps, which will require a quick math formula or find the information right off the top of your deep cycle battery or battery bank.

If you are panicking because you see math, getting those old feelings of wanting to run out of the classroom, well don’t! This is very straight forward math that can be carried out on the calculator function on your cell phone. These are math calculations that provide you with information critical for the safety of yourself and your property. I am not sugar coating the consequences of using insufficiently thick or insulated cabling, you simply will NOT get the full payback on your system and you will be creating a dangerous set of conditions as we just covered. In addition to risks attributable overloading, you have to keep in mind how grueling the sunshine is to any synthetic material especially if the material was not designed for direct exposure. Wire that is not properly insulated will shed the protective plastic coating after constant exposure to UV radiation thus exposing copper stranded wire to the elements and to the possibility of a short-circuit. The best way to avoid such conditions is to start with the correct size cable to carry the load safely, and once the correct size is determined, you must protect the cable by either using conduit piping, or use properly shielded cable. I am referring to the cables that connect solar panels with each other, and from the solar panels to the charge controller which tend to be longer runs that sit fairly exposed to the elements. I use 10-gauge exterior outdoor well pump wire. The consequences of using insufficiently thick or insulated cabling, you simply will NOT get the full payback on your system and you will be creating a dangerous set of conditions as we just covered. In addition to risks attributable overloading, you have to keep in mind how grueling the sunshine is to any synthetic material especially if the material was not designed for direct exposure. Wire that is not properly insulated will shed the protective plastic coating after constant exposure to UV radiation thus exposing copper stranded wire to the elements and to the possibility of a short-circuit. The best way to avoid such conditions is to start with the correct size cable to carry the load safely, and once the correct size is determined, you must protect the cable by either using conduit piping, or use properly shielded cable. I am referring to the cables that connect solar panels with each other, and from the solar panels to the charge controller which tend to be longer runs that sit fairly exposed to the elements. I use 10-gauge exterior outdoor well pump cable because it is designed for being buried basically forever so it is fully weather insulated, waterproof, and tough as nails. It is economical because with each strand you purchase you get double the useable linear footage because you are able to split the wire right down the middle and use both halves independently. It may require the help of a good sharp blade, but once you separate the two halves, each may be used independent of the other half as needed to complete your system. As you will see by the results of our calculation for the example based upon a typical 36 cell, 72 watt solar panel, the AWG size is very modest and will result in a modest cabling investment, so let us take a look at the formulas. The math formulas are to determine the thickness of wire needed to safely transport the electricity generated by your solar panels.

The first formula after the photo of well pump cable is to determine the “current” or amps using the formula at the top of the box. We need to identify the current (or amps) in order to solve the next math formula from which we will discover the “CT”, or cross-section of the wire needed for our project. Once you have the cross-sectional size of the wire, you then simply compare the cross-sectional area to the closest AWG wire size in the horizontal chart.

The formula: (L x I x 0.04) ÷ (V ÷ 20) =CT

L=50 feet, or 15.1 meters / **I**= 3.27 amps (from our first calculation) / **V**=12 because we are charging a 12V deep-cycle battery, and CT= what we are solving for. We then fill in the data above into the formula to determine the cable cross section in mm^2, which is then compared against the AWG corresponding wire size

It looks like this:

(15.1 (meters) x 3.27 (amps) x 0.04) ÷ (12 (volts of battery) ÷ 20) = CT

(1.97) ÷ (0.6) = CT/ **3.28**mm^2

After learning the current or amps, you are now set to work the second formula.

Next we cross reference against our chart to find the AWG size that corresponds with the

Power ÷ Volts = Current or P ÷ V = I

Let us say that you have one 72 watt (designer watts) solar panel completed so we will use the "Power" (which also means Watts) figure of 72, since we expect to generate 72-watts from this solar panel. We are charging a 12-Volt deep-cycle battery so we now have the second part of the equation, so let us solve it.

P ÷ V = I / looks like this: 72(Watts) ÷12(Volts)=3.27(Amps)

Now for the second equation which will give you the "cross-sectional area" in millimeters squared (mm^2). You then convert the resulting answer to your equation into "AWG", or American Wire Gauge which is the size you will purchase to complete your wiring.

The formula: (L x I x 0.04) ÷ (V ÷20) = CT

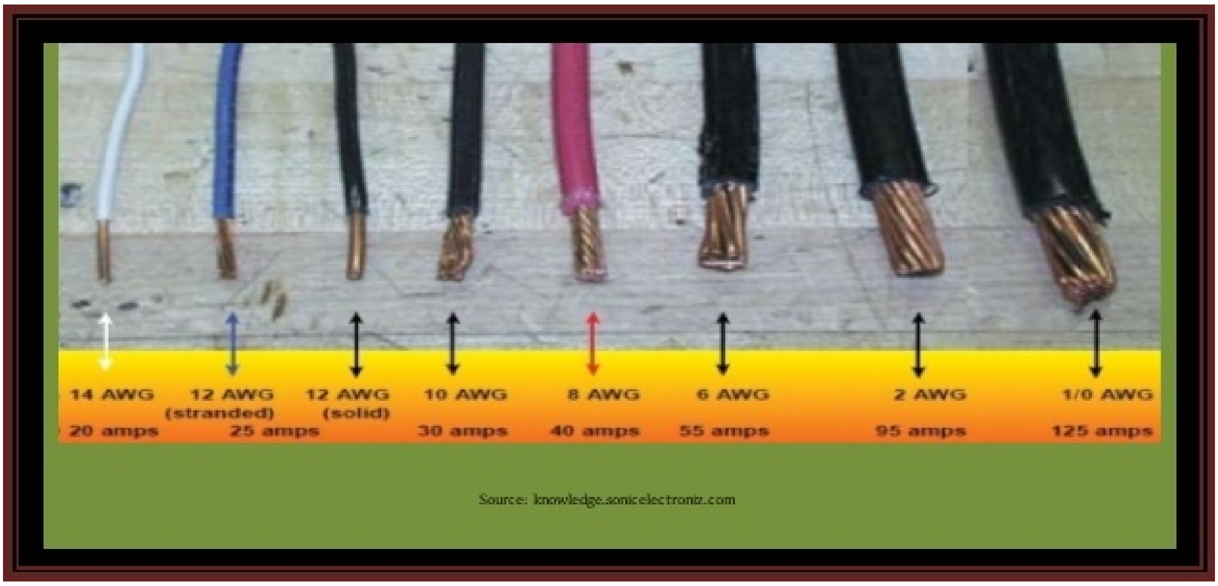
Where L= Cable length measured in meters / **I**= Current in amps/ **V**= System voltage/ **CT**= Cross-sectional are of the cable in mm^2

Cross-Sectional Area (mm^2)	American Wire Gauge (AWG)
21.14	4
16.76	5
13.29	6
10.55	7
8.36	8
6.63	9
5.26	10
4.17	11
3.31	12
2.63	13

Cross-Sectional Area in mm^2 that we calculated above. You can see this chart below the wire size photo, which would lead us to the column closest to the Cross Sectional Area number we calculated of **3.28mm^2**. You can see the highlighted figure 3.31 is immediately adjacent to the similarly highlighted number 12. The smaller number is the closest to our calculated Cross Sectional Area and therefore, it is the column from which we will get the AWG size.

It is possible for you to find yourself making a judgement call if your Cross-Sectional Area figure does not fit neatly, you know, doesn't seem to be close to any number. As you saw in the formula I provided as an example, our answer was 3.28 which did not exactly match the numbers in the Cross-Sectional Area column. We chose the number (3.31) because it was closest to the number I calculated. It was coincidence that we were only a few basis-points off from a number appearing on the chart. You may come up with figures that are not as close, but the process is the same in that you simply need to find a number on the AWG that is closer to the figure you arrived at, in some cases it will be 50-basis points off from the choices offered you on this chart. Don't overthink this one.

As the photo to the left depicts, 12-AWG wire is comparatively small in the scope of possible wire sizes to employ in your photovoltaic system. For the connections between solar panels (solar modules), the AWG-12 size wire can remain the same, but once you branch out to link the solar array to a distant battery bank, performing the calculations on wire or cable size becomes necessary. This will ensure that the electrons have ample space to move freely and efficiently. When considering the type and size of cable to make the connection between solar panels and the battery bank, remember it is not ONLY the size, but you must factor in exposure to the elements and chose a wire that is appropriately sized AND protected.



Protection may come from a solid structure around the wire as it runs between solar array and the battery bank, a pipe essentially made from either PVC or metal that physically houses the wire. You could also purchase wire that comes already encased in a protective sleeve designed to keep the wires dry and protected from decay related to UV exposure. Using either method will allow the wire to remain in service for time measured in decades as opposed to just a year or two if you opt to deploy an un-sheathed or non-insulated wire. It may not last even a year depending on your climate, so this is an area of your wiring that you will want to invest an appropriate amount of focus so that you are not creating a future maintenance headache. Once you deploy the solar panel, typically you will not need to perform maintenance since there are no moving parts. Cleaning the glass regularly to maximize efficiency is about the only attention you pay to the panels; they will sit up on their mounts and absorb the free energy from the sun.

The comparative lack of need for maintenance is one of the more attractive elements of photovoltaic electricity generating systems. But, while we might not pay much attention to the system other than appreciating the resulting electricity, the UV radiation does pay attention to the photovoltaic system, day in and day out. The solar cells are specifically designed to tolerate decades of exposure to UV radiation, but the same cannot be said for other components of the system such as the wiring. Repeated exposure to sunlight will break down the insulation that protects wiring and over time, that insulation will crack and ultimately fail completely. Once gone, that copper stranded wire will be subject to all the forces nature can stack against it to include corrosion, animal, insect, and bird activity related damage (many creatures will attempt to take portions of wire for nests and bedding), all of which serve to reduce the service life of the wire or cable in question. Heavy protective insulation must be provided for any wire exposed directly to the sun or to the earth should you bury your cable runs. One excellent way to provide physical protection is to use conduit, the plastic PVC type that is easy to cut, inexpensive, and impervious to UV radiation so there is long-term peace of mind for the safety of the cabling. You may elect to use cable that is specific to photovoltaic systems in conjunction with the MC4 connectors for joining the solar modules, the ultimate in UV protection but also the most expensive option. Connecting deep-cycle batteries always requires a larger cable size typically the type of battery cable that is sold at auto parts stores specifically for this purpose. Never use alligator type clips on battery terminals, and the cables should have factory installed terminal connections since unequally tightened connections on the battery terminals is a source of electrical resistance. Each of the battery terminals on a given battery bank needs to be tightened at as closely to each other as possible to reduce electrical resistance. As I indicated earlier, battery banks require the heaviest cable you can fit such as AWG-0, or even AWG-4 because of the volume of electricity present. There is no possible way you should even consider wiring of lesser gauge when making battery connections, the standard must be the two sizes I indicated, anything smaller and I can almost state with certainty will lead to serious consequences. Equally large wire (I use 4-gauge AWG) is required for connecting the battery bank to the inverter, the device that converts the Direct Current (DC) electricity to Alternating Current (AC), the type we get from wall outlets in homes, offices, etc. Depicted on page 105 is 10-gauge wire designed for use with outdoor well pumps, no better protection is available when the only option is to bury the line connecting solar panels with the battery bank. The gauge depicted is outstanding for the purpose outlined, but you could also use a 12-guage wire of similar construction, the type made for low-voltage exterior lighting commonly known as “Malibu Lighting”. This cable is similarly insulated for extreme underground conditions and is designed to withstand the ravages of being buried in wet, cold, and difficult environments for many decades. I would hazard to bet that many of us have encountered buried “Malibu Lighting” cables that were placed underground by previous owners of our homes that have been buried in excess of two decades but look as good the day we unburied them as the day they were buried.

Sealing the Tedlar, Project Box and Connecting “Connective” Leads

40a) Sealing the Project Box to the Tedlar is a simple matter of applying a healthy dab of caulking under the project box which will seal the holes punched in the Tedlar for the **bus wires** that come up from the interior of the solar panel. Once the dab is applied, push down gently on the project box to spread out the caulking and to force it over and around the holes in the Tedlar. Then run a bead around the project box itself to seal it to the Tedlar. Don’t push too hard, there are solar cells on the other side.

40b) Connecting outbound red and black wires to the open ports on the terminal block located inside the project box. This where to use the spade terminals, on these wires you will use to connect your solar panel with others or to the charge controller. You simply need to position the spade terminals so that they can be placed under the screws on the terminal block and then tightened (the screws that is). The POSITIVE wire should be red, and it will be connected to the terminal block opposite the **bus wire** serving as the positive outbound lead, the one which has the blocking diode attached. Remember that you will not be able to see the blocking diode since we have covered it under the Tedlar Backsheet but it can be seen as a lump in the upper right corner (or possibly the left depending on personal preference). Knowing where the blocking diode is important because it serves to identify the POSITIVE polarity. Not all blocking diodes are large enough to provide the “lump” I described in which case you will either have to rely on the polarity markings made previously on the substrate and frame, or through visual inspection through the front of the solar panel. In order to identify the POLARITY, turn the solar panel over and observe the tops of the outer-most STRINGS on the inside of your “WIP”. You now know that the tops and bottoms of each STRING will have opposite polarity, and you also know how to identify polarity based upon where the tabbing wire “end-runs” are soldered to the solar cells from which they protrude.

Examine the “WIP” and in particular, the end-runs that are at the same end as the project or junction box. Take note the exact STRING that has tabbing wire protruding from the non-sun facing, or the POSITIVE side of the final solar cell on that STRING. Remember that the outermost STRINGS on the substrate will be where the “outbound leads” originate from, from the “end-runs” on those two STRINGS on the top half of the “WIP”. The same half that will contain the two holes cut in the Tedlar Backsheet over which you will have placed the project or junction box. Now, looking through the front of the “WIP”, follow the path of the tabbing wire where you are looking for the end-run that is bisected by a short strip of **bus wire**. This short strip of **bus wire** will have a blocking diode on it which is absolute proof of the POSITIVE outbound **bus wire**. You will see a small strip of **bus wire** after the blocking diode that will then protrude up through the Tedlar Backsheet and it then is screwed onto the blocking terminal. It is opposite this POSITIVE bus wire that you would insert the spade terminal at the end of the **RED** cable and tighten the screws. Once you identify the polarity on one STRING, you will have by extension found the POLARITY on the other STRING because it can ONLY be the opposite of the first one you identified. The “connecting” wires will trail out of the project box and face the bottom of the “WIP” as discussed earlier. You may use a dab of the white colored caulking to seal the holes in the project box where the **red** and **black** wires exit thus denying moisture and insects’ entry. Then the lid can be added to the project box, screwed into place, but NOT sealed. You may wish to inspect the connections later so using caulking now would make that difficult.

Deploying your Solar Panel

Upon completion of that final step of sealing, the solar panel it is ready to be placed into the direct sunshine for testing. The two wires protruding from the project box may be connected to a multi-meter and the output of the solar panel tested. You would want to first test for voltage, then amperage, just to ensure that the final product is working to satisfaction. You have been testing the “PAIRS” all along the handcrafting process so there should be no surprises here. Follow the demonstration video for testing solar cell pairs that is available on the How-To video library if you need a refresher on how to use the multi-meter to test solar panels. It is the exact same procedure for testing the “PAIRS”, save for where the test leads attach to the solar panel. To attach the multi-meter you simply match colors on the test cables with the colored wires coming off the solar panel. **Red** multi-meter cable attaches to the **red** connection wire coming off the solar panel. The **black** test lead connects to the **black** connection wire coming out of the project box. I might add that this would be a very good time for alligator clips for test leads coming off the multi-meter since these will provide excellent electrical contact and this frees your hands up to make adjustments to positioning or altering the tilt angle during the testing process. Remember, the multi-meter should not be held while in use for measuring or testing anything, it is safer to place it on a clean, dry surface until testing is complete. Naturally you would be in the noon hour sun, or close to it, **facing south**, and the solar panel tilted to a close approximation of 60°. The nice thing about testing the solar panel for the first time is that usually you will not have mounted it yet.

This is an ideal time to learn how the angle at which you set the solar panel affects the output as you manipulate the angle of your solar panel in relationship to the sun. Tilt-angle is important because there is a direct relationship between output, and the angle of the solar panel in relation to the sun overhead. The ideal situation is to have the sun sit perpendicular to the solar panel because this position provides a direct, head-on path for photons to pass directly into the NEGATIVE, sun-facing side of the solar cells. In such a case the maximum number of electrons will be exposed to the inbound photons resulting in a greater output. Similarly, if the tilt-angle is overly aggressive, less of the photons will penetrate into the solar cells because some will be deflected by the tilt-angle similar to how sloping armor protects tanks from direct shots at them.

We are discussing electrical current as opposed to armor penetrating munitions but I think you see the point. The goal is to find a tilt-angle that will provide you the highest output for a given season, winter requiring the smaller tilt-angle because the sun sits comparatively low on the horizon during the shorter days. Conversely during the longer summer days the sun will cross the sky at a much higher angle, about 25° higher depending on your specific location. The sun resting higher in the sky will require a much more aggressive tilt-angle, but also yield a much higher output providing heat is not excessive. When it comes time to conduct your tests, simply set the solar module on a small strip of cardboard that is resting directly on the ground for the duration of this performance assessment. The test lead cables from the multi-meter are easily long enough to allow it to rest on the ground (and for safety reasons you should NEVER hold the multi-meter while actively testing ANYTHING) so you may use two hands to control the movement of your panel during testing. With the test leads attached via alligator clips, you may then face the solar panel into the direct sunlight starting perpendicular to the ground. Note the LED screen on your multi-meter and make a mental note of your voltage reading. Now slowly start tilting the top of the solar panel back, away from the sun and take note of the change in output. As you slowly tilt back there will be a point at which the output numbers will stop increasing and in fact, will begin decreasing. Go back to the tilt-angle where you experienced the highest output and if you possess the appropriate gear, measure this angle. It will be different depending on where you reside on the globe, but one fact is constant irrespective of geography and that is the condition leading to the high solar output. In other words, no matter where on the globe you live there will be an optimal tilt-angle that can be identified using the method I am describing. Not all sunshine will provide the same solar output even if the tilt-angle numbers (the actual tilt-angle stated in degrees) have proven to be productive in another geographic location. The sun's rays must pass through 92-million miles of open space before striking our planet and ideally, have a direct path to the solar panels. The distance is not necessarily a problem for these photons traveling at nearly the speed of light rather; it is the clouds, fog, smog, and other pollutants that obstruct the inbound photons. The farther the sunshine must pass across our lower atmosphere to reach a solar array, the weaker will be the resulting solar output.

Once you have the ideal tilt-angle established, remove the POSITIVE test cable from its port on the multi-meter and before plugging it back in, change the setting on the multi-meter to the ampere test position. Plug the test cable into the far left port as you have done for testing all of the "PAIRS" and write the number you see in the LED screen. You may also experiment with your tilt-angle perhaps as a verification of the results you achieved while establishing your ideal tilt-angle. You should be able to replicate the output level at the angle you had previously established to confirm the accuracy of your decision on the optimal tilt-angle setting. The Earth is moving in relation to the sun and therefore, even a seemingly inconsequential thirty minute delay can lead to different ampere and voltage measurements. As the Earth rotates, every second that tics by changes the orientation of the solar panels relative to the sun so a measurement taken at noon will be much stronger than those taken two hours later. In that time the sun will have changed its position in the sky relative to the solar panel being tested leading to lower output. I mention this to alleviate concerns you might have after having measured output at high-noon that will NOT be as high two hours later in the day. Here again is a topic that exceeds the scope and purpose of this book but the concept needs to be discussed as it directly affects the performance of your solar panel. I covered the formula earlier in the book for establishing the "Optimal Year-Round Tilt-Angle" for those who are not planning on altering any angles after installing the solar modules. Naturally you want to achieve the highest output possible from every solar panel you deploy because if you do not, you will have to compensate for the reduced output by installing more solar panels at a growing cost in time and money. Just as you would tune a car engine to ensure maximum fuel economy, a properly calculated tilt-angle improves the performance and in essence, ensures maximum "mileage" from the solar panel(s).

Now that you have it built, what now?

First and foremost, pat yourself on the back! Seriously, this is a magnificent accomplishment! You will naturally want to be showing this off, not in a boastful way, but with pride of accomplishment of what you have built with your own two hands. You will probably be the only person that you know who can do this, which gives you the opportunity to illustrate to friends and neighbors how committed you are to the pursuit of things you firmly believe in. Whether you are motivated by energy conservation, climate change, you want to live off-grid, work in remote areas, reduce our dependence on foreign energy sources, or outfit an RV or boat; you now have the skills to make it happen. Once you begin to see the benefits of being able to construct your solar power generating system, the first solar panel will be followed by several more as you add new solar panels as you complete them. Either way, this book has provided you with the solution to the high cost of solar panels that will fit your budget because you decide when to invest money or time.

The adventurous individuals whom undertake this type of project are probably going to be fairly creative when it comes time to deploy their completed solar panel. The applications are just about unlimited in terms of where solar modules can be put to use however, there are two specifics you should know in order to get the highest possible output.

1) Face the solar panel SOUTH (if you live in the Northern Hemisphere) wherever it is deployed. If you have an iPhone, they have a compass application pre-loaded as a standard feature visible as an icon resembling a compass.

2) Tilt the solar panel at an angle to improve the exposure of the solar cells in relation to the position of the Sun in the sky. The best hours for achieving a maximum charge are between 9am and 3pm, and that depends on where on the globe one lives. During the winter, you may get 4.5 hours in California but almost 6 hours during summer. A tilt equal to approximately 57° is generally a good year-round optimal tilt-angle for those that do not intend to shift the angle of their solar array throughout the year. If you do not have equipment for determining what a tilt angle of 57° looks like, try this method. Use a traditional round clock, the type with numbers around the perimeter of a circle with the pointed “hands” indicating the time in hours and minutes. Draw an outline of this clock on a sturdy piece of cardboard and then as accurately as possible, draw in the numbers indicating the hours of the day replicating the appearance as closely as possible. If you have access to a computer and printer, Google Image has the exact clock template you see in my photo example on the next page.

   Next, use a ruler and draw a straight line across the entire cardboard starting at a point between the numbers “10” and “11”, specifically the third “tic”, running straight across the clock face and through the third “tic” between the numbers “4” and “5”. That was difficult to describe so the picture should clear it up. Go outside and place your solar panel at a straight upright position with the cardboard clock perpendicular to the frame of the solar panel. Now slowly tilt the solar panel backwards while keeping your clock true level with the numbers “9” and “3” parallel with the ground. As your solar panel comes into an angle that matches your line drawn on the face of your cardboard clock you have achieved the close approximation of the optimum permanent tilt-angle.

Set the support device to this angle and then mount the panel to your properly tilted rack. Of course there are more accurate methods for establishing tilt angle, tools specific to that purpose however; I am speaking to the DIY spirit of the matter here where we find a way! If you are placing the solar panel on the roof of any vehicle such as a boat or an RV, make sure you leave space between the mounting surface and the underside of the solar panel.

Heat has been a topic well covered thus far so you should have a healthy appreciation for any measures required to keep the solar panels as cool as possible. Maintaining air flow around the solar panel(s) is the only step required generally when mounting solar panels on the topside of vehicles of all types and this also applies to residential rooftop mounting. A couple inches are all you need to provide for air to circulate under and around to evacuate any stale, hot air that might otherwise negatively affect the output. Any solar panel resting directly on a roof of any type will collect heat under the solar panel so a little breathing room goes a very long way to keeping the solar panels cool.

The original purpose of this book was simply to provide detailed instructions on handcrafting a DIY solar panel. However, I feel compelled to address the natural questions that might follow the completion of your DIY solar panel. I am limited in how much detail I can offer in terms of advice because there are so many variations to vehicles, buildings, boats, and I think you get the idea. I strayed off plan when I ventured into the lesson about “Tilt-Angle” which I wrote for the person who has never set the tilt-angle on a solar panel or solar array, some whom may have solar modules in service currently but set the angle by estimation. The benefit to setting the proper tilt-angle is quite simply a demonstrably higher output, something every one of us should be intently focused on. I have heard people talk about simply adding more solar panels to increase the energy deposited into the battery banks and that thinking reflects a lack of appreciation for the value of efficiency. Instead of adding more solar panels it is far wiser to first ensure the solar panels you currently have deployed are providing the greatest possible output. For example, if one had an array containing eight (8), 100-watt solar panels mounted without measuring tilt-angle, you may get reasonable performance but it will NOT be optimal. In fact, let us say for the sake of conversation that with a properly measured tilt-angle, each solar panel mounted on this array can increase output by 10-watts, not an overwhelming number. However, our example involves eight (8) solar panels so we are not improving a single unit by this number but rather, the whole rack of them improve by 10-watts. Now our improvement is indeed significant because with a mere adjustment in tilt-angle we get to experience the equivalent of adding another solar panel to the rack without actually having done so. I have provided a fictitious example but I assure you that it is not far off the trail of reality. In fact, there is a rule of thumb in the photovoltaic industry that it is far more economical to conserve, than to add generating capacity. The exact ratio is probably impossible to firmly quantify but the general figures are that for every $1 saved through conservation saves $3 in photovoltaic equipment. It would take some fancy calculator work but you can see the logic and besides, anyone pursuing photovoltaics is going to be open to conservation, they go hand-in-hand. Like the rule of thumb implies, reduce consumption and in turn, you need less equipment to support the demand.

Charge Controllers - regulate the flow of energy that a battery receives from the solar modules (solar panels). Solar panels begin generating current as soon as they are in contact with direct sunlight however, if it is light outside, there can be current generated even through cloud cover. If a solar panel is connected directly to a battery without any form of overcharge protection, there is a strong likelihood of damage to the battery up to and including the possibility of catastrophic failure. The reason for this is that the solar panel does NOT know when to stop sending current to the “load” it is supporting. It just keeps sending everything it generates even if the receiving storage device is full and in danger of exploding. The end result could be a melted battery case which means the sulfuric acid that WAS inside the battery is now on the floor of the RV, boat, or garage floor. I speak from experience; in my early “experimenting” phase I conducted an empirical exercise by removing the charge controller to gauge the alteration in charge rate. As luck would have it I was beckoned away from my project for some national emergency no doubt, but when I returned, I found four deep-cycle batteries that looked more like balloon imitations of deep-cycle batteries than, well, batteries. It did not take nearly as long as I had ever suspected, but once that point of no return is reached, say goodbye to those batteries. There are so many variations in charge controllers that I cannot even begin to describe them all. The goal you should have in mind when you select your charge controller is to plan for future expansion. Do not purchase a small unit that is only capable of a couple hundred watts and under 10-amps if you are intending to add more solar panels as you complete them. Keep in mind the pace you have in mind for handcrafting your panels and perhaps purchase a model that will accommodate the next six-months of solar panel building followed by deployment of the completed solar panels. Then in that time if you have added more solar modules, upgrade to one large enough to really accommodate your expansion.

MPPT charge controllers are preferable to standard controllers because they allow the voltage generated by the solar panels to be higher than what would normally be needed to charge a given battery bank. Voltage is not an issue with a single or even a pair of 72-watt solar panels. However, by the time you get to your sixth (6th) DIY 72-watt solar panel, you will need a serious charge controller.

How are volts determined from an array of solar panels?

If an array is wired in “series” (positive lead connected to negative lead of the next solar panel) the volts being sent to the battery is ADDITIVE. This means that charge controller receives the combined voltages from the collective number of solar panels on the array in question. A solar panel containing 36-solar cells will produce 18-volts since each individual solar cell contributes 0.5 volts. So if you have a deep-cycle 12-Volt battery to charge and you are using six, 72-watt solar panels, they will provide 108-volts, almost 5-times the Voltage needed. Five times you ask? Recall that in order for a solar panel to charge a given battery, the solar panel must generate 150% of the battery being charged. A twelve volt battery then requires a solar panel capable of producing 18-volts, something possible with any solar panel made with 36 solar cells. In our example we are using six solar panels, each capable of 18-volts for a total of 108-volts. Subtract the 18-volts needed to charge a 12-volt battery from the 108-volts provided by our six solar panels and we arrive at 96-volts difference. Divide 96 by the 18 volts needed to charge the battery and the answer is slightly more than 5, or five times the volts needed. It doesn't take long for the acid to boil in the absence of a charge controller and the battery will not tolerate much of this condition. In fact, Firefighters now receive special training to handle structure fires that are being fed electricity from solar panels that don't know the structure they are atop is on fire. Building code calls for clear labeling of emergency shut-off switches on photovoltaic systems for this very reason, Fire Fighters need to know where to shut the photovoltaic system down. Of course, the size of a given system dictates the hazards associated, so I don't want to give the impression a thermonuclear detonation is imminent if you generate too many volts; rather, use a charge controller if you are connected to a battery and you won't have to worry about such hazards. There are very small "trickle charge" solar modules that produce less than 10-watts which can be used to charge batteries of all types because that small module is only providing enough current to keep the battery topped off. Such a small charge could not possibly damage a battery with so few Watts being delivered.

Batteries- are necessary for storage of the energy generated by the solar panel or solar array (multiple solar panels on a rack). It is generally not possible to run electronic devices directly off the electricity generated from the solar panel because the electricity supplied might be inconsistent and thus cause problems for the device. For example, a cloud bank may pass overhead drastically reducing the output of the solar panel or array which would certainly interrupt the operation of your respective device. Conversely, if a device is being powered by the stored energy within a deep-cycle battery, the device in question can operate irrespective of the occasional cloud passing overhead. Solar generated electricity is DC (direct current), you would need an inverter to convert the energy into AC if powering a device is normally plugged into a typical wall socket. When using solar panels to charge batteries you are generating DC, or direct current electricity which is the same as the rechargeable (or secondary) batteries being charged and therefore requires no conversion. The specific traits and underlying scientific principles in regard to both types of electrical current exceeds the scope of this book, but as a basic piece of knowledge you must have is to understand there is a difference between the types of electricity and they are NOT interchangeable without assistance from equipment capable of converting from one type of current to the other. Generally speaking, anything that you have which requires a charge from a power cord and then can operate independent of the power cord after receiving a charge, is running off a battery meaning it can charge off a 12-Volt DC power supply. By extension, it means that the charge can come directly from a solar panel because batteries come in many different shapes, sizes, voltages, but they all have one thing in common which is they charge directly from DC sources because THEY operate from energy stored in DC batteries that are permanently installed inside the devices.

You should strongly consider the use of rechargeable batteries for all of your battery needs since you are handcrafting the most efficient battery charging tool there is, which by the way, charges the batteries for FREE from the Sun.
The fiscal savings from using rechargeable batteries is measureable especially if you use many devices that require "AA", "AAA", "C", "D", or "9v" on a daily basis as I do for my motion sensor operated security lights all around the interior and exterior of the house and yard. Purchasing rechargeable batteries will cost more initially, especially for good quality batteries, but you will save that purchase price many times over as the

payback period is surprisingly swift. Not all rechargeable batteries are equal; you will want to inspect the storage capacity to select something well above 1,000 mAh for starters.

Primary batteries are the type most consumers purchase from grocery or hardware stores. They convert chemical energy into electrical energy by a process of “redux” reactions which are beyond the scope of our reading today other than to specify that it is a one-way process in primary batteries. You guessed right, we must throw these away once they have been exhausted. Landfills have untold millions of tons of this toxic scrap as used batteries make their way into public landfills. Used batteries need to be disposed of properly, treated like hazardous waste, but most people simply toss them into the trash receptacle. Not so with rechargeable batteries which can be used hundreds of times before the ability to hold a full charge degrades.

Secondary batteries are the rechargeable type I mentioned above which are far preferable to the primary type for a variety of reasons, the financial benefits being only part of it. The golf cart batteries I use are a good example of a much larger secondary battery that has significantly more storage than its smaller “AAA” cousin but they operate essentially the same in the chemical process sense. The battery or bank of them will require careful attention to ensure you get the longest possible life from them especially considering they will cost around $100 each for top-quality batteries. There is a significant difference between the deep-cycle battery we use in photovoltaics, and the traditional automotive battery even though they are virtually indistinguishable if resting side-by-side. Automotive batteries generally exist for one purpose and that is to provide the short burst of energy required to turn an engine over when the ignition key is turned. Of course it is a complex process that involves other components in the automobile such as an ignition coil and starter but the automotive battery is designed to provide the sheer jolt of amps required to turn the engine over. Naturally the battery will hold enough energy for you to listen to the radio with the engine off, for a short while anyhow, but if you should happen to leave the headlamps on while shopping for a typical grocery store trip you may have a dead battery upon returning to load your groceries into the trunk. The auto battery simply is not designed to continue to feed a “load” such as headlights without getting immediate recharging from the alternator as the engine idles or drives. It is designed with the purpose intended and for many years the typical lead acid battery has done a decent job.

Photovoltaics require a different performance standard from deep-cycle batteries that an automotive battery cannot provide; a storage device capable of holding a significant amount of energy. Equally important in this equation is the ability to slowly convert the stored chemical energy into electrical energy and continue doing so for many hundreds of hours (providing appropriately supplied with incoming current). Golf cart batteries are excellent examples of deep-cycle technology as they are able to provide fuel sufficient for driving 18-holes of golf complete with golfers and gear. If the golf cart batteries were removed and replaced with automotive batteries, the golf cart might get through the first hole, maybe? They continue to deliver energy longer than even the most expensive automotive battery because the internal construction is vastly different. Auto batteries tend to emphasize “cold cranking amps”, which translates into a massive burst of energy lasting a brief moment as the driver of the auto turns the ignition key to start the motor. The battery unleashes the stored energy in a burst that we can hear in the form of the engine turning over meaning the battery is proving energy to turn the starter motor. That motor contains a gear wheel with teeth that fit into a similar gear at the end of a cam-shaft located inside the bottom of the engine block. When the key is turned in the ignition, the starter motor turns the gear it is attached to, which causes the cam shaft to rotate, which then causes the pistons to rise and fall. Fuel is injected into the combustion chamber while the motor is turning and the battery then provides a small spark to the combustion chamber. The spark ignites the fuel-air mixture that is now inside the combustion chambers of the slowly turning engine causing chain reaction explosions (controlled of course) commensurate with an gasoline engine running as it is designed. Once the engine is running there is no longer a need for energy to be taken FROM the battery and instead the engine starts to replace the energy expended to get the engine started. The shallow cycle of the auto battery means that it is capable of delivering a powerful, but short-lived burst of energy that can be repeated but a few times before depleting the charge. This shallow cycle design is opposite of what is needed to store electricity generated by solar modules. To maintain optimal health and achieve full service life, automotive batteries must be fully recharged by the vehicle while driving, back to a state of full charge. Anything less will result in reduced amperage availability for cold-cracking on the next trip so the vehicle needs to have a fully functioning electrical system. If the electrical system is compromised and unable to provide the needed recharging after each use it may only take a single day to permanently damage the battery. Based on that last sentence alone we can see how ill-suited automotive batteries are for photovoltaics. We need a battery with very thick lead plates as they play an important role in how the battery stores, releases, and then accept a charge. Instead of delivering 570-amps for turning an engine, we need far fewer amps going out steadily, perhaps for many hours if not many days.

Since deep-cycle batteries are so expensive, and so critical to the health and usefulness of the entire photovoltaic system they warrant special attention and care. The typical lead-acid deep-cycle battery will require frequent inspection to ensure there is the proper water level inside the battery case. Without enough water the battery will NOT charge properly and can become permanently damaged. You need to remove the water caps in order to inspect the amount inside the battery, which is a simple process of unsnapping the covers. Once open, peer inside to determine the level which should come to the bottom of the vent cap you are looking through. Each of them must be checked as there will be approximately 8-fill caps to inspect. If water is needed, take great care when pouring into the battery to prevent splashing of sulfuric acid while pouring. **Distilled** water is the only thing you should add because regular tap water contains minerals that will build up on the lead plates interfering with the performance and reducing the service life of the battery. Battery care and maintenance should become part of your weekly routine. Maintaining water level is the easiest way to help achieve full service life, but there is one more aspect you need to control. Depth-of-discharge is a term referring to how deeply depleted a battery gets before being recharged, something that is generally within your sphere of control. You should have some method of monitoring the level of charge in your battery bank on a real-time basis. Whether using a multi-meter to take a voltage reading or hard-wiring a more sophisticated battery monitoring system, you need to keep the batteries from being run down without being recharged. Of course the battery bank is going to get depleted as you draw energy out, I don’t want to cause undo concern about drawing energy from your batteries. By all means, use the stored energy! That is why it is there, the single most important thing for you to take away from this paragraph is that it is BAD for the deep-cycle battery to be LEFT in a state of discharge for any length of time. Go ahead and deplete the battery by 70%, just don’t leave it in that condition for very long. They can take the depletion, just not the chemical condition within the case after being depleted.

Keep a box of Baking Soda handy and consider it as essential safety equipment. It neutralizes sulfuric acid should it spill or splatter on your skin. ALWAYS wear protective gear when checking water, yes, even while checking! When adding water to a battery you MUST WEAR EYE GOGGLES and RUBBER GLOVES the type that protect against acid so they must be rubber. It is a great idea to also wear an apron made from a material that is resistant to the sulfuric acid as even tiny droplets that get on your clothes will cause discoloration. It is a good idea to remove jewelry such as rings, bracelets, or anything that dangles or can possibly make physical contact with any portion of the battery you are inspecting. Having a fire extinguisher nearby is not a bad idea as well, but once you have the proper gear on, you should also notify someone around you of what you are doing. In the unlikely event you become splashed with acid or something goes terribly wrong and a battery arcs, you will want assistance from someone close by to either rescue yourself, or call for help to deal with the consequences. Nothing would be worse than to suffer an injury that affects your ability to see and have nobody within close enough proximity to render immediate aid. Nobody expects accidents to happen and yet they happen at every station in life, every occupation, hobby, and past-time therein lays the possibility of injury from the most innocent of sources. Batteries are not exactly innocent source material but they don't need be horrifically dangerous either. They should command your respect for the potential of serious injury by wearing the protective gear I mentioned, maintaining the baking soda nearby, communicating when working alone.

Inverters are necessary to convert the DC electricity stored inside the battery or battery bank into AC electricity for use with your appliances. There are a great many types of inverters designed to fill different roles. For example, virtually every auto parts store will carry a few small inverters in the 80-200 Watt range with built-in cigarette lighter plugs which clearly indicate the mobile application. Those are light-duty models ideal for use with smaller electronic items like phones, or book readers like the Nook, and have a built-in fuse that will shut the unit down if over-stressed by the load. Heavier duty models will be required for electric items like construction related drills, small electric saws, or electronic gear that does not require sine-wave quality electricity. When we get into the inverters of heavier capacity, typically you will not see any evidence of quick and easy application identifiable by a cigarette lighter plug. The inverters destined to serve heavier loads like what we would expect in a residential, RV, or boat application that are typically serviced by multiple solar modules will NOT have an option to use with a cigarette adapted plug. They require a more sturdy connection with the battery bank including a heavy fuse between the two. Wire size is critical here as these cables will carry all the current required by the loads plugged into the inverter. The size should be no less than AWG-4 and if space allows, go larger (remember, larger wire will have a smaller AWG number to identify it) because the larger the wire, the more electrons it can transport efficiently. I have personal experience with this, having used wire vastly too small for the job, my inverter started to melt where the wire connected to the unit. Luckily I was home at the time and could smell something burning, but it certainly brings home the idea that bad things can happen if you don't respect the limitations of wire capacity. These larger inverters will have two power ranges listed, "Continuous" which is the top range of watts it can support while working to support the appliances plugged into it. Next is "Surge" which is a demand placed by most appliances as they initially power up after being turned on. Typically this demand for power at start-up is considerably larger than what the appliance will use while in normal operation. The inverter must be rated to handle the load you will ask it to support because if you don't, the unit will simply shut down as a means of protecting itself and the appliance. Most units will have two GFCI receptacles, low battery alarms and automatic shutdown to protect the battery bank from total depletion. They also will auto-detect and shut-down when overloaded or over-heated, capabilities not available in the much smaller mobile units.

Pure Sine Wave vs. Modified some of the electronic equipment operated off an inverter may be highly sophisticated computer or entertainment equipment. These pieces of equipment have higher sensitivity to variations in the frequency of the electricity powering them. These sensitive electronics detect that there is a difference between the electricity supplied by the inverter verses a typical residential wall outlet supplied current. The specific appliance will turn on and operate, but there will be obvious and unacceptable feedback both visually and audibly. Sound will be heard from TV speakers that are like an awfully irritating Cricket that cannot be silenced even by muting the volume. This is an excellent example of electronic sensitivity where the TV is reacting to the difference in wavelength between grid-utility supplied electricity at 60 Hz, and the inverter supplied 60 Hz. A "modified sine-wave" inverter is designed to work with household appliances to include some TV's and computers as not all appliances will react poorly to this slightly different wavelength of electric power. In fact, small microwave ovens, food processors, small refrigerators, fluorescent lights, small vacuum cleaners, sewing machines, fans, drills, sanders, buffers, DVD players, stereos, satellite equipment, musical instruments, to name just a few items that work without any noticeable difference. The minor difference between the cycles, grid utility verses inverter, don't interfere with normal operations unless the electric appliance is highly sensitive, usually translated to mean highly sophisticated. The higher the sophistication, the "cleaner" the source electricity must be. Grid supplied electricity is precisely distributed in wavelengths measuring 60 per-second without any variation. Modified sine-wave inverters are not as precise as the electric utility grid; it is simply not how they are designed. They are very capable and successfully provide power for a wide range of devices, but the devices that are sensitive require a "Pure Sine Wave Inverter". This type inverter is able to perfectly mimic the wavelength present in the utility service providers at 60 Hz so the equipment requiring "clean" electricity will function without any perceptible difference in performance. It is ideal for computers, LED and Plasma TV's, and other high-tech entertainment equipment whose performance capabilities require the precision and consistency. I personally use a SunForce Pro Series 650 Watt Pure Sine Wave Inverter for my LED TV, satellite receiver, Sony PlayStation, and surround sound system since each of these items perform poorly unless provided clean power from the grid or pure sine wave inverter. When you select the model that will service your system, keep in mind the types of equipment you have selected and the relative technical sophistication. Purchase a unit that works best with the highest level of technology you intent to operate from the system you are designing. I am just warning you now that Pure Sine Wave Inverters cost more, and have a lower Wattage rating than do the Modified Sine Wave units because of the level of sophistication required to mimic utility provided wavelength. The natural tendency is to try to get by with the lesser priced unit because there is such a sizeable price difference. You will be disappointed with the performance outright and you will regret not having spent the additional money for the appropriate gear for the intended load.

Final Safety Briefing

You now have the resources to engage in an activity that you can take great pride in as a true "Do-It-Yourselfer"! The concept of doing things for oneself is not new, in fact, prior to the Industrial Revolution when so many items became mass produced, if you could not repair or even build something, you went without. Of course in any civilized society there will have been specialization of trades where certainly a great many products were bought and sold, but the follow-up maintenance and repairs would fall on the owner of the products. It was a necessity to have skills ranging from carpentry to husbandry, with some bartering thrown in but this faded slightly with the introduction of mass production. The introduction of consumer goods of every description being made available coupled with the development of the railroad system meant that cheaper goods were available to replace anything that broke down. The Great Depression again was cause for many to re-invent the pioneer spirit as the money needed for repairs or replacement of broken items was not available. Necessity again forced a return to the practice of self-repair until the post-World War II influx of technology and products. Factories formerly used to mass produce military hardware turned to satisfaction of consumer demand for goods many of which will have come about as beneficiaries of the war. Such a condition prevailed in the United States until comparatively recently when economic events have strained the American middle-class to the extent that the need for DIY is more likely to be practiced. Who among us feels comfortable simply taking our vehicle to the "shop" and accepting the quoted price and punch-list of problems listed in said quote? Or simply give the go-ahead to a plumber we called out because of clogged toilet to dig up what the plumber claims to be a tree-root related sewer line blockage which he will gladly take care of at a cost of $3,000? No, I think we are more likely to thank the person giving us this information and then swiftly dismiss them without authorizing any work so we can investigate how to perform the repair ourselves to save money. For example, I have personally rebuilt our clothes dryer that is currently in service spending less than $55 when I had been quoted $150 to replace the part NOT COUNTING THE TRIP CHARGE! Before I started the project I had no clue as to how a clothes dryer works, and certainly no experience repairing such a device but thanks to the Internet and a stubborn streak, I figured it out. I am sure you have the same experience if not with a different appliance or automobile, that is just who we are. The point is that you can do this activity! There is no limit to what humans can achieve when given the information needed to proceed, and the will to push ahead in spite of the fact whatever the task is, it is NEW and unfamiliar.

Now, having said that about what you are capable of doing, I want you to exercise good judgment when participating in this activity. There are going to be times no matter what the activity we pursue as avid DIY practitioners when the inner voice is telling us that "we don't know what we are doing", a voice you should listen carefully for. There is a difference between moving forward while being uncertain of exactly what to do, and being reckless, the difference between them being a very grey area. What does that mean in terms of handcrafting DIY solar panel(s)? Every step of the process described herein might be totally new to many readers. The first time they sit down to perform a step in the "How-To" manual; it is likely to cause a bit of trepidation, especially if new to this task. There is no need for trepidation because the contents of this book, the instructions, the "How-To" video demonstrations, combined with the ability to ask me questions via email all serve to provide the antidote to trepidation which is confidence. You might be treading on unfamiliar ground from the time you lay out the raw ingredients, but keep this in perspective, think of other tasks you currently perform that once seemed outlandishly impossible when you started. Maybe you personally don't have an "outlandish" example on which to draw comparison but it need not be an outlandish activity. Take more routine activities as examples because this is really about the mental perspective, the mind convincing you that a given event or activity is within your grasp, or not. Let us say for sake of conversation that you are worried because you have never done this before and as such, you might make a mistake leading to a horrific consequence. Perhaps you feel under-qualified because you have no previous experience soldering wire, or you don't completely understand how it all works. Then there is the possibility of being afraid of failure, meaning you follow the instructions to the letter and the solar panel is not producing anything because that is just how things go when you have attempted new projects.

I answer the first proposed concern with a suggestion that you look inward to evaluate your personal list of achievements. I ask this so that you don't sell yourself short on the skillsets required for the handcrafting process. I want you to first examine what you are doing this very second. You are reading a book about handcrafting solar panels starting with only the raw ingredients. The fact you are on page 124 means that you now have a significant knowledge base on the subject but more importantly, you are taking action on your interest. There is great comfort in knowledge because I guarantee that by page 124 of this document you have been exposed to virtually every step thus eliminating any unknowns. Fear of the unknown is a universal human condition that can be mitigated by knowledge. The more you understand about this process, the less you will fear it and by page 124, you should be feeling pretty good about the possibilities of a successful outcome. The first time you drove a car (providing you have) there may have been fear since it was a new activity. Driving is not a risk-free activity, tens of thousands of Americans lose their lives annually but we can take steps to minimize our personal risk and the safety technology built into our vehicles is making crashes more survivable. Plumbing is another great example of a category of DIY repairs that we now regularly delve into thanks largely to the Internet where we can easily find detailed answers to questions previously held close to the vest by those in the plumbing trade. Armed with knowledge we have the confidence to move forward and successfully complete repairs that would formerly been unthinkable. For example, a decade ago I would have called a professional plumber to run a snake through the drain system in my home because that task was beyond the scope of tasks I felt comfortable taking on, fear of the unknown. Today I can say with pride that I have already tackled this activity successfully after experiencing a complete blockage of a sewer line by tree roots. After researching the particulars online I was able to rent the equipment needed and accomplish the task thanks directly to the information available to me via Google. Once informed I felt confident to boldly attempt an activity previously outside my comfort zone and as a direct result I can add plumbing to my list of skills. This formula is repeatable on so many fronts that it is difficult to identify a repair that would NOT be within our grasp. Information, common sense, coupled with and a can-do attitude will see almost any project through to success. It feels wonderful to complete the task at hand knowing that future issues of that nature can be addressed in-house, forever insulated from costs related to third-party service providers. Confidence begets confidence and so once empowered, continue with your learning because knowledge IS power.

Let us discuss over-confidence, the other side of the equation that might tend to work against common sense. Have you ever heard the expression, “you know just enough to be dangerous”? It applies to situations where an individual dives into some project after arming themselves with just enough information about the subject to skirt the surface, but not enough in-depth knowledge to make informed decisions while making forward progress. This condition might lend one to take steps that they think are correct based upon the very limited knowledge they possess that might actually turn out to be incorrect. From that point forward the error will either cause problems, or not, but the individual will not know because he or she will be blissfully unaware of any dangerous conditions they might have created. A game of chance in essence whereby one has a 50% chance of having made the correct decision while being equally likely to have erred. In the context of photovoltaics, at least during the handcrafting phase, such a 50/50 prospect for failure will likely result in a solar panel that simply will not generate any current. A fairly harmless outcome in terms of danger, but catastrophic in terms of your resulting confidence because I can personally attest, nothing dashes enthusiasm like staring at a big, glaring ZERO on the LED multi-meter screen when testing a newly completed solar panel. In fact, a symbolic punch in the gut such as this might dampen your enthusiasm permanently depending on personal temperament A dead solar panel resulting from a wiring error is a very high-possibility scenario that need not be experienced by anyone following the instructions contained herein. You should NEVER guess if you reach a point where you are uncertain of what to do next when following the course of action laid out for you in the pages of this document. Guessing places you directly into a game of chance, that 50/50 roll of the dice condition where you will either perform the step as indicated in the instructions, or you will perform the step as your common sense dictates based upon your instincts. The outcome of your misstep might be nothing, or it might lead to a malfunction, but why guess? If the outcome might possible lead to wasted time, effort, and dashed enthusiasm, why do it?

If you do NOT know how to proceed during a given step! All I am asking you to do is **STOP** if you are uncertain and go research the issue! Return to the relevant portion of the instructions, read the material, watch the How-To videos, or email us, but do not assume that you are taking a harmless step by guessing. An inert solar panel is distressing enough emotionally, and the risk generally stops there, but that might not always be the case. Guessing can have lethal consequences in other areas of photovoltaics especially when we start talking about live solar modules generating current and sending it to a battery bank. An improper connection on a deep-cycle battery could lead to an immediate and violent reaction, perhaps the result of a guess about wire polarity should cables or wires be incorrectly labeled, or not at all. The information available online can empower, but also deceive us into a false sense of confidence. I must seem like I am talking out of both sides of my mouth, on one side telling you that information is available to empower you to tackle any task, then immediately saying that can be dangerous. Aware of the "double-speak", I merely want you to understand that it is perfectly fine for you to challenge your boundaries, but recognize when you have hit a point of uncertainty. That is it! Once recognized, **STOP**!

The Internet resources of which I have made reference might include Google, or perhaps web sites specific to the topic under review. For every subject imaginable there will be many sources online and the greatest challenge will be to select the version of information you find easiest to follow. Be careful during the search because you just might discover that the field is full of seemingly conflicting information about what the next step should be leaving one more confused. Like many other aspects of life in the digital age, we are deluged with data and the challenge becomes clearly identifying which is the best source of information to satisfy the situation. I suggest you take notes on the choices that fit within the boundaries outlined in great detail within this document to compare with information you have learned during your online research. If there is still an area of uncertainty, email us and we can weigh in directly on the question that pertains to the project in question. The type of question we can field will be limited to the handcrafting process as this is directly related to our expertise so it is natural for you to look towards us for assistance. It is assistance we are glad to render as you gain proficiency on your project and we think you will find that we have indeed covered all the bases thus eliminating your need to seek out additional guidance but we are here if you do. Questions outside the scope of handcrafting your solar panel are another matter as we can expose ourselves to legal jeopardy offering technical advice sight unseen should something go awry on your system. Having said this, we will do everything possible to help you secure the information you seek so that you can make the best possible decision on how to continue moving forward. Unfortunately we live in a litigious society that can lead to costly lawsuits when things go differently than expected, particularly if something bad happens as result of our directions. Therefore we will do our best to enlighten you, educate you, steer you to the best source of information that we have so that you can make an informed decision based on current "best practices".

Repairing Damaged Solar Cells

The occasional solar cell will come along

T whereby every effort you make to solder tabbing wire to the bus bar or bus tab will fail. You will have done everything correct starting with application of Rosin Flux, properly measured tabbing wire strips, a solder tip in good working order, good lighting, and yet, when you pull the solder gun away after thinking you have just done a great job, the tabbing wire pops off the **bus bar**. No explanation, nothing obviously wrong with the **bus bar**, so you attempt the second soldering with the same outcome and now you have an awkward situation. Perhaps only one of the **bus bars** is responding this way, but one is enough to render the solar cell useless because without all **bus bar** surfaces making excellent electrical contact, you will have just created the proverbial “weak link” in the STRING under construction. Refer back to page 39 and examine the empirical exercise I conducted whereby I purposely omitted tabbing wire from one out of six **bus tabs** on the back, POSITIVE side of a solar cell “PAIR”. The direct result of the missing **bus tab** solder was a diminished output that would limit not only the faulty “PAIR”, but would negatively affect the entire solar panel if allowed inclusion as is. Usually you will encounter this kind of problem while constructing “PAIRS” but it can happen while constructing STRINGS. It most often occurs to the POSITIVE bus tabs, perhaps due to their comparatively small size, exposure to intense heat during soldering of the opposite side of the solar cell, but either way the result is the same. Once the **bus tab** fails to accept the solder there is a good chance that the specific **bus tab** will NEVER accept the solder no matter what actions you take.

Absent the thin coating of silver that is applied during the manufacturing process no amount of Rosin Flux or Rosin Solder will force the bond to hold. Each progressive attempt will only serve increase the damage to other parts of the solar cell as it is repeatedly exposed to heat from the solder tip and possible rough handling as more aggressive measures are employed. The only option would have been to surgically remove the problematic solar cell and replace it with one that is not compromised. **UNLESS** that is, you use conductive paint as demonstrated in our “How-To video! A damaged bus bar or bus tab does not necessarily or automatically require replacement of the problem solar cell as I demonstrate in the video that can be accessed by scanning the QR Barcode above this paragraph in the appropriately labeled box. You may repair **bus bars** and **bus tabs** in-place without requiring time-consuming extraction thus saving the forward momentum you had until encountering the issue with uncooperative **bus bar/tab** surfaces. The nice part about the conductive paint is that it helps not only maintain forward momentum but has a fiscal benefit by reducing the occurrence of defects so you toss fewer wrecked solar cells. Every time a bus tab has failed (prior to discovering conductive paint) I would have extracted, then tossed out the offending solar cell. I can safely say that my photo of shattered solar cells would have been markedly smaller had I known of this paint long ago.

The end, good luck!!