2DEGREESKELVIN

Why Pre-Construction Module Testing is a No-Brainer

Introduction

When you go to the supermarket to buy eggs, what is the first thing you do before you put them in your trolley? You open the pack and check for cracks. The last thing you want to do is to pay for half a dozen eggs and when you get them home, they are damaged and your plans for your egg-based culinary masterpiece are scuppered…

It's the same thing when it comes to solar modules. In fact, its much worse from a financial perspective. The silicon based cells used within solar modules in most cases are extremely brittle and if these cells are subjected to mechanical stresses then micro and macro cracks are likely to occur which will have a negative impact on the operational performance of the module itself, all be it in some cases only as the modules age.

So, if you could see damage on your brand-new solar modules, would you be happy? Would you knowingly install them in your brand-new solar farm? Would you be comfortable that you have paid for damaged goods? I fear not…

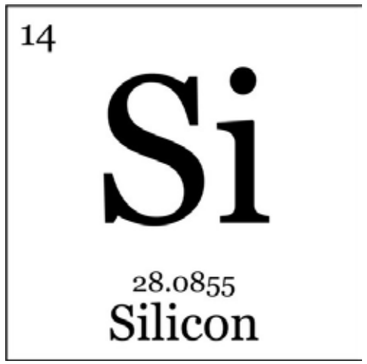
Let us start by following the physical journey of a solar module from the point of manufacture through to operation in-situ on the solar array itself.

The Journey of a Solar Module

Phase 1 - Manufacture

Silicon is the second most abundant element on earth but converting sand into high grade silicone is a complex and energy intensive process. In most cases quartz sand is used and subjected to extreme temperatures to form silicon in its raw rock-like form. The next stage is to melt these rocks of silicon together to form ingots. Manufacturers will focus on the atomic structure of the material ensuring that atoms are aligned in the desired structure and orientation. An element called Boron is added to the process which ensures the silicone has a positive polarity.

Polycrystalline cells are made by melting several silicon crystals, and often are recognized by their fractured glass crystal structure appearance. Monocrystalline cells are made from a single crystal of silicon, and usually produce cells with more of a flat & consistent appearance. It is at this stage due to the nature of a crystal-based material that natural structure boundaries can create weakness where stress-raisers will occur, which is what manufactures are attempting to minimize with their quality protocols. From the ingots, a wire saw is used to slice thin discs or wafers. These wafers are 700 times thinner than they are wide, so extremely thin and therefore brittle. In most cases an anti-reflective finish or coating is applied at this stage which helps with light absorption.



Phase 1 - Manufacture

Following that, grid fingers and bus-bars are applied enabling the distribution of current from the crystalline material to form an electrical charge. The quantity and design of these grid fingers and bas-bars has advanced significantly over the last few years, all to add efficiencies and also to minimize losses for any cracked or isolated areas of each cell. Individual wafer cells are tested and graded at this stage before they are assembled into modules. This is to ensure that mismatches are minimized, grouping similar power output cells all together in certain batches. We'll come back to this stage later in the article, but this is really the first area which a purchaser of solar modules (as long as the order is sufficient enough) can have an influence on what you actually get in your modules, in relation to high grade cells.

Multiple wafers or solar cells are arranged in a matrix-type layout, to form 60 cell modules (6 x 10 cells), 72 cell modules (6 x 12 cells), and more recently, splitcell arrangements in 120 & 144 half-cell arrangements. Bus-bar tails are soldered together in series, usually in a number of loops (typically three on traditional 60 cell modules). These three loops are terminated in the junction box positioned on the rear of the modules, where the positive and negative direct current (DC) cables come out of, for connecting multiple modules together in a string.

In most cases a thin layer of glass is applied to the front (sunny side) of the module and an encapsulation material is added (EVA) together with a durable polymer-based back-sheet is added to prevent water, air and dirt ingress. The back sheet also ensures electrical containment. There have been some material selection boo boo's over the years which is no being observed in 5-10-year-old modules in the field, with chalking, powdering, cracking and bubbling type deteriorations being found. These will ultimately lead to premature option of the modules, so owners need to be weary of this element and ensure high quality back sheets are used, and provenance is proven.

Phase 1 - Manufacture

Finally (in most cases) a frame is added to provide strength and durability, and is usually adhered to the glass, wafer, EVA & backsheet sandwich with a silicon mastic material. And there you have it, a fully manufactured solar module. These modules will be tested (Flash & Electroluminescence) and sorted into banded grades (within their respective power classes), they will have a unique serial number applied to the front and back of the module and then be grouped for shipment. This is a critical stage in terms of ensuring the provenance of each and every solar module. Purchasers should insist on being provided with the factory test data, which can be compared at a later date with on site test data.

As you can probably envisage this is a highly complex process which takes years of research, experience and technology to perfect. However, as this product development is still fairly new in terms of a mature technology, there have been many learnings and enhancements in manufacturing processes, materials used and quality checks conducted to ensure that field-based issues do not come back to haunt manufactures. In fact over the last 10 years solar module manufacturing has transformed itself in to an ultra-high tech industry with billions of dollars/pounds of R&D poured in to get it right, as the world has adopted the technology on a massive scale as part of the renewables revolution.

There are currently over 300 different manufacturers of solar modules around the world, all claiming to be tier 1 this, and high quality that. The secret is to do your research and invest in quality assurance to minimize the chances of picking the wrong one. Manufactures are doing their bit to minimize the number of defects introduced into the product at the manufacturing stage. However, there are still variances in approaches and shortcuts being made (to save money in most cases) which purchasers need to be aware off as part of the manufacturing process.

Phase 2 - Manufacturing Plant to Solar Farm

First off, we start with packing the modules for shipping. Modules are usually stacked on their sides in a vertical orientation on a wooden pallet, and then grouped and secured together with plastic strapping. A cardboard box is placed over the top before additional plastic strapping is applied horizontally to secure the box in place. Pallets are loaded into either articulated lorries or straight into shipping containers for ongoing distribution around the globe.

In most cases, in Europe at least, modules are transported by cargo ships from Asia. Multiple container movements on land as well as rough seas can and have introduced micro-cracks into solar modules. This has been evidenced by testing at the port or in a local distribution warehouse close to the port of destination.

Phase 2 - Manufacturing Plant to Solar Farm

Once back on terra firma at the country of destination, modules within containers and/or articulated lorries head to the new build site where modules are offloaded. Telehandlers and bobcats unload and distribute module pallets around the site. The installation team then cuts the strapping and removes the outer boxes to expose the PV modules within. Installers then release the plastic strapping, making sure that the modules do not fall over and one at a time manually handle the modules towards the array.

Modules are positioned in the pre-determined orientation on the mounting structure and secured into place with a clamping system. In the past, physical damage to modules has been introduced to the process at this stage. Installers have walked on modules, and placed point load forces with knees, hands and elbows which will have introduced multiple fractures to the cells themselves. 2DegreesKelvin have tested sites with over 70% of the sample tested with significant mechanical point load damage. Multiply this up and the impact on production in extreme cases is alarming.

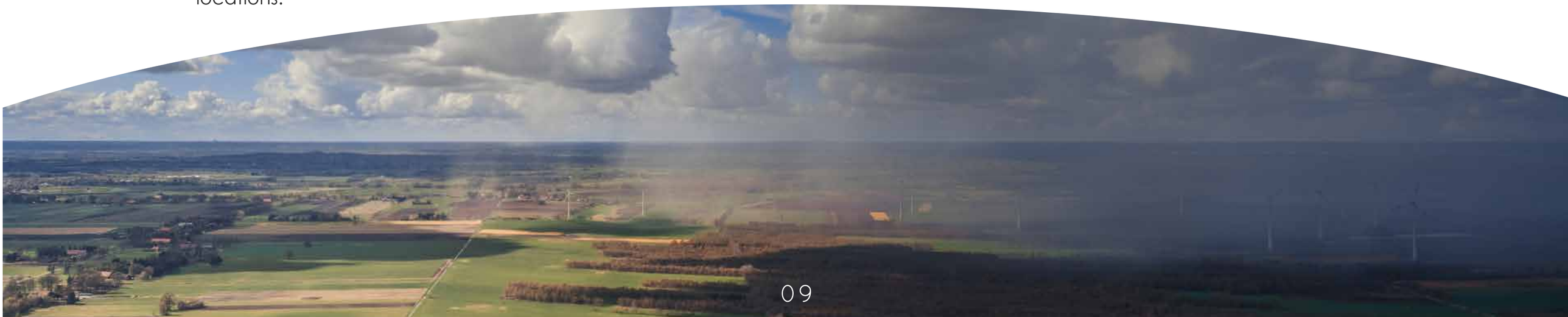
Installation quality protocols are one of the easiest and most inexpensive measures you can introduce to drastically reduce the amount of cell damage on your new build solar array. It's also critical that the structure, clamping system and modules are designed well and are compatible, and clamps are not over tightened. Modules are then connected to form strings and strings are connected to either string combiner boxes or string inverters dependent upon site design. The preconceived idea with solar is that its 'fit-and-forget', but we know through O&M & testing and assessment experience that this is not the case. Hence, we move on to the third and final phase of the journey of the solar module.

Phase 3 - Operational Phase

Not much action in store for the modules during the operational phase, or at least that's what most people think. The modules themselves and the mounting structures are designed with wind & snow loadings in mind. However, this does not eliminate the mechanical stresses introduced through physical loadings. Extreme weather conditions (including hail) can introduce micro-cracks to cells or even if micro-cracks are already in place, these stresses can worsen and mature cracks and areas of power isolation within cells can develop.

As well as wind, snow & hail, another factor is thermal expansion due to extreme cold and heat temperature differentials. Expansion and contraction can also introduce physical forces which cause new cracks to form or existing cracks to propagate further.

Module damage can also be introduced during the replacement process, where new modules replace broken ones for example, and the modules can be miss-handled (often by single operatives) and clamps can be overtightened, in some cases causing module stresses local to the clamping locations.



Phase 3 - Operational Phase

Another common cause of spider cracks (spread crack patterning on cell), is projectiles. These can be caused by stones being ejected by grass cutting equipment for example. Three other causes of projectiles are quite hard to believe…

- 2DegreesKelvin have found certain sites being peppered with golf balls. These have obviously been aimed at the modules maliciously and cause in most cases glass fractures and modules needing replacement.

- The other common projectile-type of failure is actually caused by birds. Some people believe (although there are no scientific studies on this) that from above birds see the solar farm as a large water mass and are dropping stones with the aim of stunning prey. Others have found shellfish shells (cockles & muscles) on sites that are a considerable distance from the sea. This suggests that the birds are dropping these shells onto the array in the attempt to open up the delicious treasures inside.

- The final factor that we have seen in only a small amount of cases is actually sabotage or damage being introduce on purpose. This is not something that we believe is very common at all but has happened.

Technical DD on Module Manufacturers

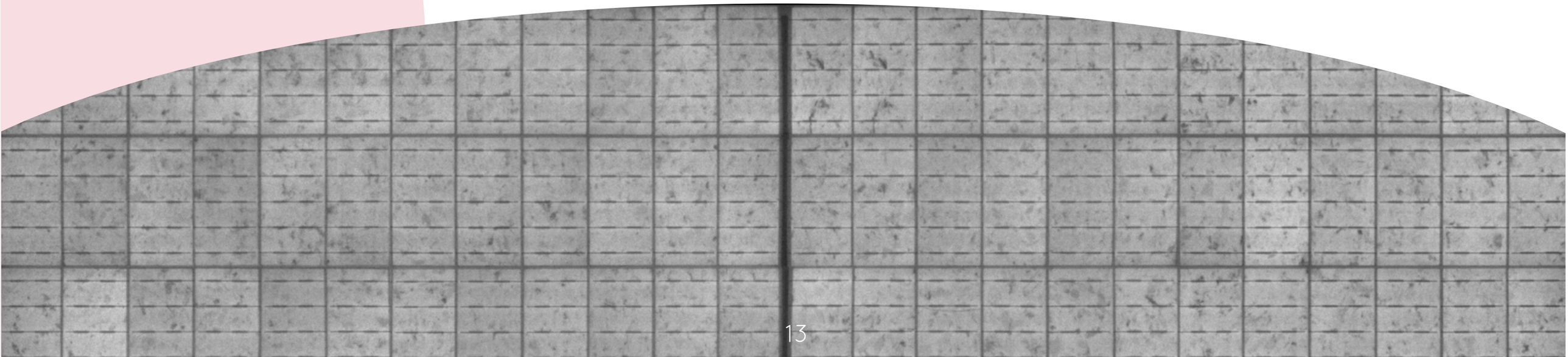
Do your research, employ specialist quality expert consultants to ensure that manufactures and products are selected against a solid criterion. There are expert companies out there (some of which 2DK partner with) who can go in to Asia based manufacturing facilities to conducted thorough audits and checks on the process, their quality systems and validate the provenance of the various elements all coming together to form your modules.

The provenance of the cells historically has been one of the underlying quality challenges for purchases, as in many cases manufactures buy in cells and just carry out the construction of the modules themselves, rather than the manufacture of the cells from the silicon ingots. As a purchaser, you need to be very aware of this as part of your due diligence process.

There are many other checks that should be conducted as well, covering back sheets, EVA materials, glass materials & finishes, heating processes, grid-finger & bus-bar application processes, and the list goes on. Without these checks, there's a good chance that quality may be lower than you expect.

Check Factory EL & Flash Data

As part of any high-quality module manufacturer, they will have manufacturing line electroluminescence & flash testing test data which should be provided to the purchaser and will be unique to each and every module with its serial number. This will enable you to check whether damage has been introduced between manufacture and arrival on site and will also provide some confidence in the provenance of individual modules with serial number validation.



Pre-Shipment Inspection (packaging & shipping methods)

This is another suite of checks that the quality management expert will carry out, checking that module handling, packing & shipping methods are as high a quality as possible to minimize damages. There is a balance to be struck in terms of how to pack modules (weight & size v's impact on price), but purchasers would like to see robust methods of packing to protect their goods. You buy eggs in a 'fit-for-purpose' egg carton, you wouldn't throw them loose into a shopping bag would you?

Point of Manufacture Based Laboratory Testing

Another level of data validation would be to arrange a third-party independent set of module testing at either the manufacturing facility or in the port of origin. This categorically proves whether any defects found are manufacturing process introduced or not. If the test results are clean, then the manufacturer is off the hook to a certain extent.

Pre-Installation Testing (on-site)

This element together with the following point are the two best value services which often yield the most results which will inevitably affect the asset in a positive manner. Typically, depending on the volume of modules coming to a site (lot size) and the sampling approach that a purchaser desirers, a number of pallets are set aside from each container load (typically 3). From this three, one pallet is selected for testing and a handling team will carefully remove the strapping and boxes. Then a certain percentage of the modules within that pallet are tested (typically half), including the two outer modules (which are most prone to impact damage as the back sheets and glass areas are exposed to the sides of the box). These modules are put through a calibrated and certified mobile test laboratory which simulates standard test conditions (1,000W/m^2 @ 25°C) and electroluminescence (EL) and flash tests are conducted. Modules are assessed on a cell by cell basis against an agreed judgement criteria and module classification system. Modules with excessive damage or specific manufacturing defects will be rejected. If the number of rejected modules within a single pallet is over an agreed threshold, the second set aside pallet from the same container will be tested. If this pallet is rejected as well as the third, then the entire container load is rejected. If not, then the team move on to the next container. EL and flash data can be analyzed and compared with manufacturing data. The origin of certain damage, defects and deterioration phenomena's can be identified.

Post-Installation Testing

To ensure that the installation processes are of a high standard and damage is not introduced at the final stage before the modules are on the array, modules can be checked post-installation. During the pre-installation testing, modules are marked with a bright colour electric tape which is adhered to the back of the module junction box. A proportion of these modules will be tested with in-situ electroluminescence equipment once the modules have been installed.

This process will need to be conducted at night (EL only works at night) and purchasers should consider using a contractor who deploys a high-quality range of tripod systems to ensure EL images are good quality and are consistent. Ground based EL image capture (without tripods) will render low quality results and distorted images. These will also be difficult to assess. EL images are then compared with the factory and pre-installation EL images, to finalize the quality loop and confirm where (if any) damage has been introduced.

Advantages of Pre-Construction Testing

Dear Owners, Asset Management Companies , TA's & EPC's

Owners, Asset Management Companies, Technical Advisors & EPC's should consider the following advantages when it comes to pre-construction modules testing:

- Pre-selection of premium module manufactures – If a purchaser invests in this end-to-end quality assurance process, in the first instance the process will inherently enable you to predetermine only premium manufactures.

- Higher power class cells and modules - In some cases you get a few watts per module on top on average, which will compound across the entire batch. Even if you had an average of 1 Watt higher output than the power class, on a 5MWp site, this would equate to approximately 18.5kWp – for free! This tends to happen, when the module manufacturers are aware that rigorous quality testing measures are in place.

- Clear evidence where damage, defects & deterioration phenomena's originate from and who will therefore be liable. Thousands of sites around the world which have been built without these quality measures may have damages, but who pays the bill?

Dear Owners, Asset Management Companies, TA's & EPC's

- Minimization or complete avoidance of costly warranty claim processes.

- Enables a purchaser to get what they've paid for. Who wants to pay for damaged goods, right?

- Prevents avoidable power losses being introduced to an asset from day one of production, leading to more production and profits for owners & investors. Although microcracks in their early form have an insignificant impact on power output as the cracks have not developed enough to separate the grid fingers and current can still flow. As they mature, they will lead to power loss, its just a matter of when?

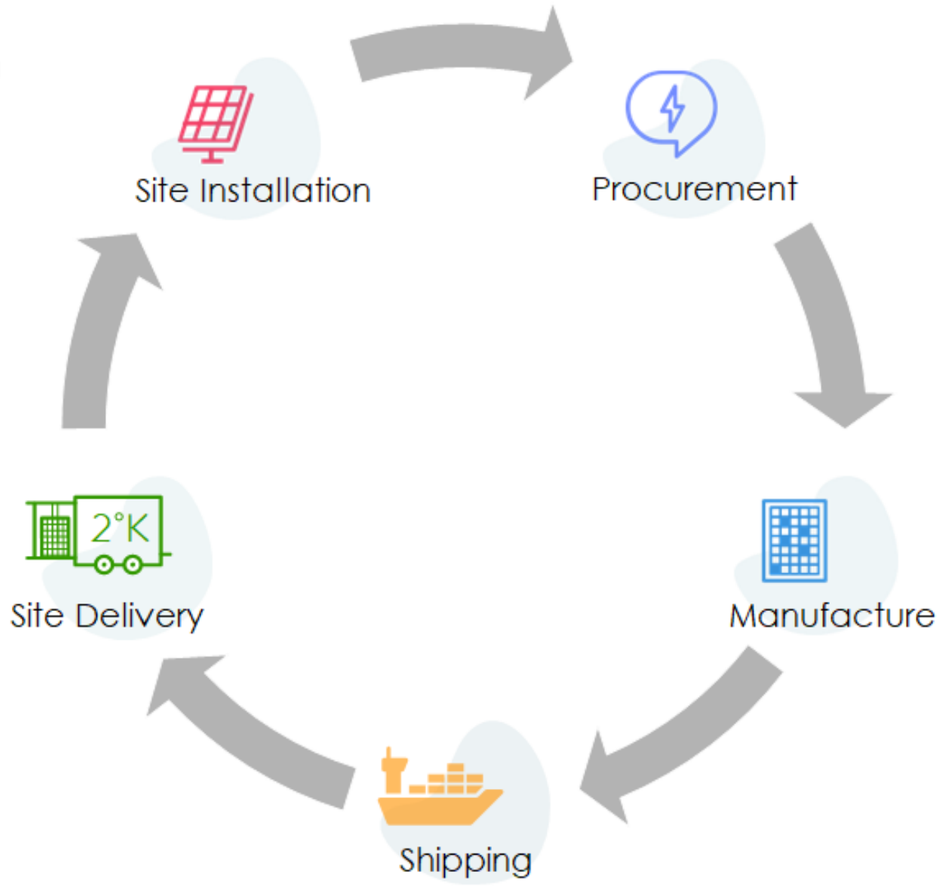
- Creates an asset life-cycle record of module origin, health and status which stays with the asset as it ages, adding value to an asset if it is sold on in the secondary market. 2DegreesKelvin have heard of cases where assets have been sold up to 5% over the market average due to them having rigorous module quality records.

- Cheaper lending – Site owners can obtain cheaper lending from funds & investors due to the high-quality approach and reduced risk levels.

The 2DK Way - 'Point2Point' Module Quality Process

With the support and collaboration of world leading partners and a market leading UK based on-site services capability, 2DegreesKelvin can provide a complete end to end module quality service. We have devised a unique and rigorous 5 stage module quality support process which can be applied to all module procurement, installation and commissioning campaigns, and provides complete peace of mind for asset owners, asset managers, TA's & EPC's that the risk levels for the biggest single CAPEX purchase on your solar farm are minimised.

- Point of Procurement
- Point of Manufacture
- Point of Shipping
- Point of Site Delivery
- Point of Site Installation



World Leading Partners

2DegreesKelvin specialise in the delivery of service excellence and for us to deliver this in such a board ranging suite of services, we must partner with the best in the business at each stage of the process. Check out our three principal technology & service partners and how they contribute to the delivery of our 'Point2Point' module quality process.

- CEA are an internationally acclaimed solar PV supply chain management & quality expert. They have completed more than 40GW of quality assurance audits at 350 factories worldwide. Specialising in reducing technical & financial risk, CEA deliver for 2DK (either as a principal contractor or sub-contractor) the up-stream portion of the supply chain quality management services. From the selection of the module manufacturer, to the shipment of completed modules.

- MBJ Services GmbH, specializes in solar module testing equipment on site using their world-famous mobile test centres. With the award-winning Mobile Lab, MBJ Services is the technology leader in the field of mobile testing laboratories with partners in all relevant markets.

- AePVI combine and automate classic and preventive inspections of solar power plants and employ a range of tripod and drone-based sensor systems through their international partners, providing a cost-effective check-up by systematic sampling or 100% screening. Specialising in high-volume EL measurement and analysis technology and services.

Wrap Up - Conclusion

So, the main take always from this article are that there are many ways that defects, damage & deterioration phenomena's can be introduced to the modules.

Manufacturers, Transportation companies, EPC's and O&M's all need to work smarter to avoid their negative contributions where possible. However, as we move into a subsidy-free solar world and project ROI is challenged, I would strongly advise not to scrimp and save on what's important to maximise the output & longevity of your asset long into the future, and invest in pre-construction testing.

Not only that, but ensure that you put money into the design of your solar farm, invest in top quality materials, components and installation teams. Gather as much information on where everything is on the site, where cables are buried, and never underestimate the value of spending money to determine the provenance of an item or material. The objective here is to design and build a solar farm which is reliable, generates high levels of consistent 'bankable' renewable energy and to have an asset which lasts the 25 year design-life period. Make the effort upfront to get what you pay for.

Back to the 'egg' analogy, take a few considered seconds to inspect your eggs for damage, defects & deterioration phenomena's. It's a no-brainer!

Wrap Up - Next Steps

Don't forget to connect with us via our social channels if you have any questions/thoughts on this report, or for any enquiries please do not hesitate to get in touch.

If anyone wishes to discuss any of this with me, then please get in touch via LinkedIn (www.linkedin.com/in/john-davies-ceng)...

...or email (john@2degreeskelvin.org).

Please also visit our new website homepage @ www.2degreeskelvin.org to see what else we do...

...and finally our YouTube channel, lets get 2DegreesKelvin to 100 subscribers!