Thin Film Solar Power

Reducing Balance of System Costs for Large Open Field Plants

A report prepared through the Cornell-Queens Executive MBA program.

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Ed Dodge – Lead
Stan DeForest
Adrian Martinez
Doug Puerta
Greg Rau
Roger Showalter
Steve Vergamini

Cornell University The Johnson School
Cornell Queen's Executive MBA
Queen's School of Business

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Executive Summary

Balance of system costs for thin-film photovoltaic solar power plants were investigated by a team from the Cornell-Queens Executive MBA program. The team traveled to Germany where we visited with a number of leading developers and visited multi megawatt open field power plants utilizing CdTe thin film photovoltaic modules. The primary mission was to document best practices and identify areas where balance of system cost reductions could be made in the construction of the plants.

Balance of system is defined as all of the components that go into an operational system aside from the photovoltaic modules. Modules account for 50-60% of overall system costs and module efficiency is well established as the primary cost driver in the photovoltaic industry. This research report looks at the other 40-50% of system costs with the purpose of identifying areas where those costs can be reduced. The balance of system components that were investigated include the racks and foundations, inverters, cabling and electrical components, operations, maintenance, installation labor, and management overhead.

The team identified a number of best practices that are being utilized in best of breed installations as well as areas for improvement. Racks and foundations provided by leading vendors are all already highly optimized and utilize driven posts or ground screws for the foundations, galvanized steel for the substructure and high grade aluminum for the cross members and module supports. These systems will continue to be optimized for improved installation times leading to marginal cost reductions, but are already significantly improved over older designs that utilized wood racks and concrete foundations. Prefabricated cabling solutions are also being utilized that greatly improve installation costs and system reliability over wiring that is spliced and connected in the field. The move towards prefabrication of all possible components improves costs and reliability.

Electrical subsystems including the system voltages and inverters represent the greatest area for BOS cost reductions. Raising system voltages from 600vdc to 1000vdc and above allows for the use of smaller gauge wiring and hence less copper, larger and more efficient inverters, and longer strings of panels with fewer parallel connections. Technical issues with the panels themselves limit system voltages to 900vdc for CdTe today. Regulatory issues in the USA also require anything above 600vdc to be specified as High Voltage requiring specially licensed electricians, increased site security, and more

permits and inspections. This regulatory burden does not exist in Germany and is a significant cost factor. Inverter designs continue to improve and while centralized inverters are the most cost effective today for large systems, opportunity exists for decentralized string and micro-inverters to be cost effective in the future.

Overall labor costs were found to be minimized through the use of pre-fabricated and assembled components. More industry standardization will lead to the use of kits which combine the modules, aluminum supports, and cabling that can be quickly installed onto steel substructures that must be custom built for each site. The team investigated the use of very large panels that are now coming available and found potential cost reductions as well potential installation difficulties resulting from the need for trucks and specialized equipment to install the panels when conventionally sized panels can be installed by hand.

Operations and maintenance were found to be areas where developers and system integrators can earn steady revenues over time by leveraging their technical expertise by providing support contracts. Centralized monitoring benefits from economies of scale and support contracts are also very effective at providing internal quality control feedback while providing confidence to banks and investors offering development capital.

Ultimately installation costs are secondary to the effective production of electricity. Systems that produce more kW/hrs of electricity annually with reasonable installation costs will provide greater value than systems where all upfront costs are minimized at the expense of electrical production. Balance of system needs to focus on providing the greatest system reliability and not simply lowest cost. Issues such as inverter concepts and operations and maintenance always must emphasize first the production of electricity and secondly the reduction of investment costs. Thin-film solar power plants are a very new industrial activity and the industry is still in the steep part of the learning curve. Many obvious low hanging fruit have already been harvested such as optimized racks and cabling. Future cost reductions for these power plants will come primarily through improved module efficiencies, higher system voltages and improved inverter technologies. Regulatory issues in the USA represent a notable structural cost that must be addressed as the industry matures. The future looks bright for thin film solar as module production is ramping up quickly worldwide, the technology is improving, and the costs are steadily coming down.

Introduction

This report has its genesis as a Global Business Project in the Cornell-Queens Executive MBA program at Cornell University's Johnson School of Management in Ithaca, NY and the Queen's University School of Business in Kingston, Ontario. The objective was to complete a consulting report involving research overseas for an existing international business. Our team was composed of seven students from the program. This research topic was suggested by the solar energy group at General Electric, who wished to gain greater insight into the best practices for managing balance of system costs in the construction of large scale solar electric power plants.

Thin Film Solar Power Plants

Large scale multi megawatt photovoltaic installations have emerged in recent years as a viable opportunity for producing renewable energy. Large scale solar power plants had never been cost-effective using crystal-silicon (x-Si) modules because the costs were too high and adequate government supports had not been available. In 2002 the first large scale production of cadmium-telluride (CdTe) thin film modules came online at First Solar, Inc. CdTe offered a significant breakthrough compared to traditional x-Si modules. Besides being a third of the cost per watt, CdTe offers performance characteristics that are more suitable for solar plants because they perform better than x-Si in ambient light and overcast conditions.

In 2004 Germany implemented aggressive subsidies for solar power via feed-in-tariffs which guarantee a fixed price for electricity produced by solar in order to boost the share of solar use and meet goals for reductions of CO_2 emissions. In 2004 a 4 MW system was built, the largest at that time. In the years since many solar plants larger than 1 MW have been built in Germany and other countries including Spain and the United States. The largest solar plant in Germany, now under construction, is 40 MW and a site in the US has been contracted for 500 MW. Germany has benefited from their early and enthusiastic support of solar power because many of the world's leading solar companies have made their headquarters and manufacturing there. Germany is in a position to export their products, services, and expertise worldwide.

Balance of System Costs

Balance of system (BOS) refers to all the components in a system aside from the modules themselves. These components include foundations, racks, inverters, and cabling, as well as operations, maintenance, and managerial overhead.

Balance of system costs are a significant concern in the construction of solar power plants because they comprise 40-50% of overall system costs. CdTe modules are less efficient per square meter than x-Si modules and that drives the relative cost per watt higher for CdTe since more racks, cabling and space are required. Since solar power is still very expensive compared to conventional fossil fuel electricity, it is imperative to reduce any and all costs wherever possible. Large solar power plants have only been being built for a few years and the industry is still in the steep part of the learning curve. Systems designs from 2004 have already been completely overhauled and rethought as new designs are developed. Technical advancements are enabling more robust systems to be built at lower costs. Our mission was to document the best practices in the industry and identify remaining areas where costs could be reduced.

Site Visits with Integrators

Our team made two separate trips to Germany in August and September of 2008 and met with five leading firms in the industry and visited examples of their installations. We also spoke with other firms in the US and Europe who provide components.

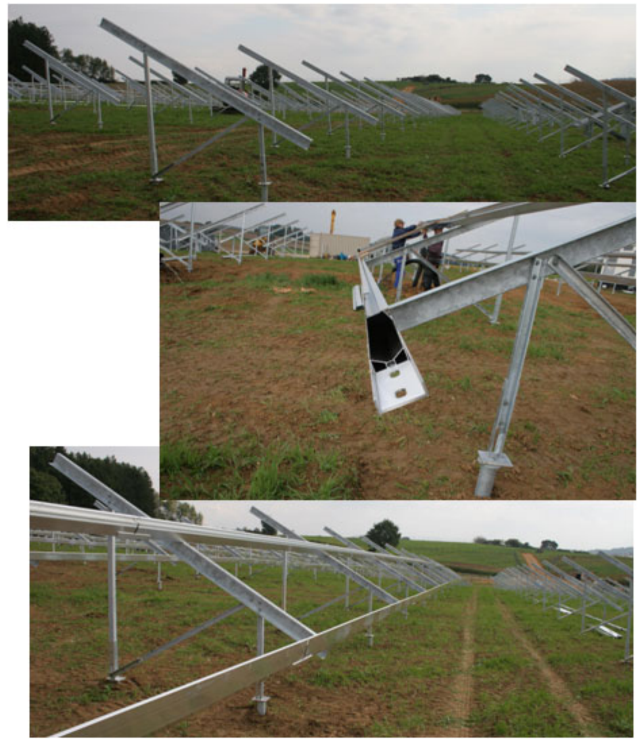
The companies we met in Germany included Phoenix Solar who is a solar power specialist and deserves special recognition for their efforts to document extensive analysis on BOS improvements for the benefit of the industry. We visited Ecostream, who is a division of the Dutch firm Econcern, and one of the leading renewable energy developers in Europe. Gehrlicher is a German firm specializing in photovoltaic installations who additionally markets cabling and rack systems suitable for large thin film installations. Colexon is another leading photovoltaic site developer operating in a number of countries. Finally, Terrafix is an innovative site construction firm whose screwed-in earth anchors offer superior strength over conventional driven posts and who was able to show us a variety of sites from a number of different developers. All of these firms demonstrated great hospitality and willingness to help us and their efforts were greatly appreciated.

Phoenix Solar

Sulzemoos

We visited Phoenix's demonstration and test site near their home office in Sulzemoos. This site has a peak capacity of 1.8MW, with three 500 kW and one 250 kW Xantrex inverters. The site uses First Solar CdTe modules and demonstrated some of Phoenix's innovative racking and cabling designs. Both the rack and cable designs were developed by Phoenix to lower costs, improve installation times and overall system reliability. The racks use a single driven post and horizontally mounted panels which were angled at 30˚ tilt for this site. The cables are pre-fabricated with sealed junctions that help eliminate costly and failure prone junction boxes. Phoenix has advanced monitoring facilities in Ulm, Germany where they remotely monitor all of their systems and dispatch technicians for maintenance. Additionally, Manfred Bachler from Phoenix has published numerous documents and given many talks regarding the optimization of BOS costs that were very useful for this report.

Terrafix



Terrafix is a site construction firm with an innovative earth anchor and racks of their own design. With Terrafix we visited one site under construction and toured four other sites they had worked on with other developers.

Terrafix specializes in using ground screws for rack foundations as opposed to straight driven posts (like screws vs. nails). Terrafix excels at working in difficult terrain like bedrock or extremely soft soil where other anchoring methods fail. Their approach leads to optimized site costs by use of stronger anchors that can be spaced farther out and still support heavy loads. Terrafix strives to reduce labor costs by having products that are easy to install but are very robust and hold up well over time. One advantage of using the Terrafix approach is the ability to follow the terrain without the need for any grading. This approach is both more environmentally sound because it reduces erosion and leaves the land intact for future use, as well as cost effective by eliminating the considerable expense of moving earth to a uniform elevation or grade.

Ecostream

Ecostream is a leading Dutch solar energy developer and is part of the Econcern renewable energy development group. Ecostream has offices in eight countries where they are developing PV sites. They have completed a number of multi-MW solar plants.

The team visited two Ecostream locations: Moorenwies and Baustelle-Froscham. These were the first sites that the team visited. Moorenwies was a functioning solar power facility. Baustelle was not yet complete which gave us the opportunity to see the construction crew at work. Ecostream provides maintenance contracts for monitoring and operations.

Moorenwies

This facility cost €24,000,000 to build and was completed in December of 2007 after three months of production. Its power production is 6.4 MWp spread over 12.8 hectares (31.6 acres) and at the time of construction was Ecostream's largest site. The solar modules are monocrystalline silicon at a 30˚ tilt angle. Ecostream brands their own Chinese manufactured panels. The system uses four Sinvert 400 inverters from Siemens. The racks are Schletter FS4H four high horizontal racks. This site prices out to €3.75/Wp.

Baustelle-Froscham

This facility is expected to cost €13,000,000 to build and was under construction when we visited in August. The peak power production will be 4.35 MWp. The solar panel modules are CdTe by First Solar mounted at 25˚ and the site utilizes pre-fabricated wiring from Gehrlicher. The whole system prices out at €2.98/Wp.

Over the course of two years between these two sites EcoStream streamlined their construction methods, in particular through sub-contracting tasks such as electrical. One such example was the use of Gehrlicher's pre-rolled cabling system with built in junction boxes at the newer site, versus the use of custom cabling installation with fixed, larger junction boxes. Additionally, the newer site was also a more of a rectangular piece of land, where as Moorenweis was shaped like a "C" due to land restrictions. The switch to lower cost CdTe modules and increased construction efficiency allowed EcoStream to save on costs at the newer site.

Colexon

Malsch

Colexon showed us a government owned facility they built named Malsch during our August visit. A very unique feature of the Malsch plant was that it was built on a toxic nuclear waste dump and required specially designed concrete foundations. This facility's cost is €2,632,500.00, or €4.39/Wp. It was completed in March of 2007 after six months of construction done in two phases. The plant's peak power production is 0.6 MWp. The CdTe solar panel modules were produced by First Solar and are mounted at 25˚. The two inverters used were Sunny Central systems from SMA. Several panels had been stolen at night so they had to implement special fasteners to secure the modules.

The government employees responsible for monitoring the toxic waste dump were cross-trained to do grounds keeping and low voltage electrical maintenance. To assist with their many tasks, the workers employ the help of sheep to keep the grass cut on the facility. These sheep also serve as a signal to the local community that the reclamation of the site was successful, and that the site is safe and non-toxic.

Gehrlicher

Sonnenkraftwerk Haar III

We toured one of Gerhlicher's facilities during our August visit. We visited their Sonnenkraftwerk Haar III solar plant, which was also built over a waste dump. This facility's cost is unknown. It was completed in December of 2007 after three months of construction. Its peak power production is 1.1 MWp. The solar panel modules were produced by First Solar and mounted at 25˚. This site utilizes a decentralized inverter system featuring Sunny Boy inverters and a Sunny MiniCentral. Gehrlicher manufactures and utilizes proprietary racking and prefabricated cabling systems. Gehrlicher operates, maintains and monitors the systems for performance.

Foundations and Racks

Racks and foundations provide the physical structure of the system and hold all the panels in place. A number of companies are doing high quality work engineering durable and cost-effective racking systems. Designs continue to improve and should see ongoing refinements to optimize performance and cost. The solar industry has already learned many lessons about large solar field racks and most of the obvious improvements have already been made. Foundations have been optimized through the use of driven posts or screws replacing concrete footers. Material choices have moved beyond wood to a balance of steel and aluminum. Engineering designs continue to optimize strength to weight ratios, reduce the number of parts, and minimize installation times by using better designed components. Phoenix reported a reduction in weight from 170kg/kWp to 120kg/kWp when they moved from off the shelf components for their racks to a custom design shown in the photos below.

Old Wooden Racks – Juwi Solarenergie Morbach

2005

2006

Improved rack design – Phoenix Solar

Open field racking systems for frameless thin-film from Schletter currently cost from $.58 to $.82/Watt but those prices float with commodity prices for steel and aluminum. Installation costs an additional $.25/Watt. Pricing by watt is obviously affected by the module efficiencies, but it is expected that the square meter price will plateau and fluctuate with commodity prices unless there is a breakthrough in the use of materials. Installation labor costs can be reduced over time with design improvements that allow components to be assembled more quickly.

Rack and foundation costs are heavily driven by site-specific considerations such as the soil, terrain, wind and snow loading, tilt angle, and type of module. All of these factors need to be determined before a quote can delivered. The tilt angle leads to cost changes because it creates different wind and snow loads and that requires changes in the size and structure of the support poles. Pre-assembling the racks as much as possible helps to keep costs down by limiting field labor time. Lightning protection including lightning rods and extended grounding may be a requirement in some locations.

System FS – Generation 5

FS 3H

FS 4H

FS 5H

FS 6H

Standard designs use heavy gauge galvanized steel for posts and substructure and heavy gauge aluminum for cross members. Stainless steel and aluminum are sometimes used for foundation posts but generally galvanized steel provides the most cost-effective solution. The key differentiation among vendors is in making racks that install quickly to reduce labor costs, pack and transport efficiently, and provide durability.

Schletter uses 6061T6 aluminum which is a high grade aircraft grade rather than 6063T5 or T6 which is more common among competitors. Galvanized steel can be rated for 30-40 years outdoors.

	A-36 Steel- Galvanized	6061-T6 Aluminum	6063-T6 Aluminum
Tensile Strength	58-80 ksi	45 ksi	35 ksi
Yield Strength	36 ksi	40 ksi	31 ksi
Elongation	23%	12%	12%
Price – Nov. 2008	$96.50/100 lbs	$198/100lbs	

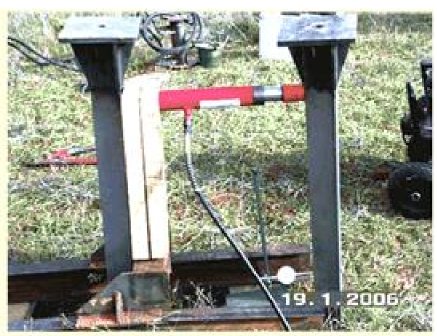
In the USA there is no national rating or specification (UL, ISO, etc.) for solar system racking so systems are built to local electrical and building codes whose enforcement varies by state. Wind and snow loading vary substantially by region and that greatly affects costs. In Europe the regulations are more formalized according to a number of engineering standards.

Site Testing

For every new site certain prerequisites must be accomplished to determine rack requirements:

1. Check local building, electrical and engineering codes that define snow and wind loads and the required strength of the rack solution, which will translate into the number of ground touch points per square meter and overall rack engineering.
2. Conduct soil tests for chemical composition and acidity, aggressive conditions require heavier gauge steel or stainless steel to battle corrosion. Test for bedrock and soil hardness to define type of post or anchor that is required.
3. Conduct pull tests to verify proper anchorage. Bedrock will require pre-drilling or chiseling and concrete if using poles, or the appropriate screw (short & fat). Some sites will not allow earth penetrations such as sealed landfills and these cases require concrete foundations which can be precast or poured on site.

Vertical tension and compression test

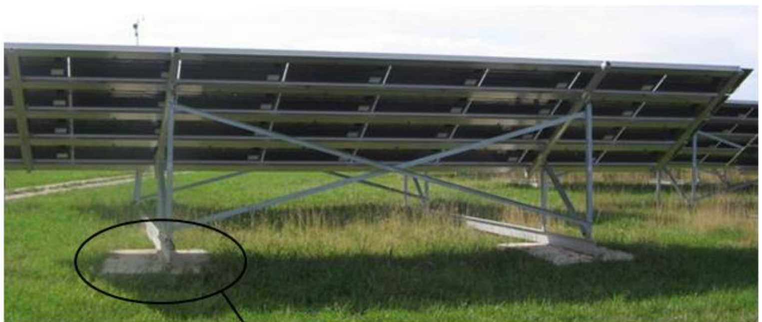


Measuring the horizontal deformation

There are too many variables to generalize a simple rule for what foundations and substructures will be needed, the only simple answer is to have portfolio of solutions that can cover all circumstances.

Foundation and Base

It is much more cost effective to use driven posts or ground screws than to use concrete footers for foundations. Concrete footers must either pre-cast and carefully placed on site or else individually poured requiring the transportation of wet concrete. Poured footers require each form to be dug out individually and then allowed to cure for around two days. The concrete will also then need to be removed eventually when the site is decommissioned. According to Schletter an optimized racking system using driven posts following the terrain should be 60-70% cheaper than the same sized system on graded land using concrete footers.



Concrete footers - no earth penetration. Highest cost, longest install time.

Ground screws-greater strength

Driven posts or screws can be installed at a rate of 150-200 a day and a crew of 12-16 should be able to install all the racks for 1MW in 1 month. Driven posts and ground screws both have their advantages. Installation time is similar when using appropriate machinery. Both posts and screws vary in length from 1-2 meters depending on soil conditions. Screws provide greater strength (typical pull strength of 4000-7000lbs) at higher unit cost and the greater strength allows for greater spread between penetrations and hence fewer ground touch points. Posts are far more common than screws as they are adapted from highway applications where they are used routinely for guardrails and signage. Ground screws are a more recent development and their implementation has vexed some vendors in the past. Terrafix seems to have a very effective method for installation based upon a high quality installation machine. Posts and screws are both able to go with rolling terrain but screws are able to deal with more difficult soil conditions where posts have failed such as bedrock or extremely soft soil. Just as a carpenter will choose between screws and nails as needed, we believe solar plants should make use of both types of ground anchors.

Driven post-lower unit cost

Schletter – Pile Driver

Terrafix – Screw machine

Legs made from galvanized steel are attached to the ground anchors and another consideration is the use of single or dual post racks. Dual post allows for wider spacing of ground touch points and slimmer support pieces. Single posts are closer and use heavier components, but appear to be the most cost effective solution where the engineering requirements support it.

Single driven post

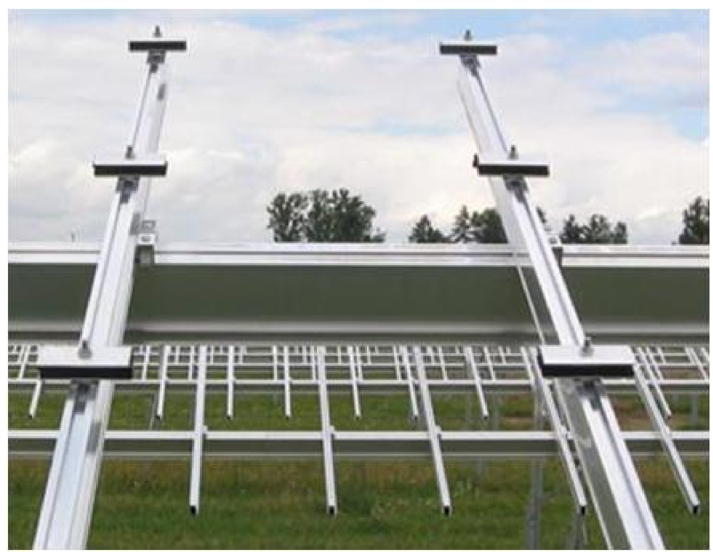
Dual earth screws - Terrafix

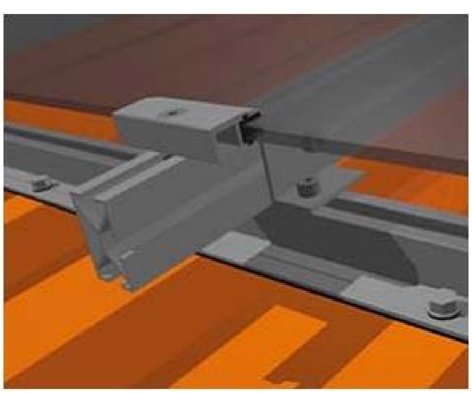
A very important cost consideration is to avoid grading the land to uniformity. Grading the land is costly and time consuming and also creates damaging erosion. The best solutions for anchors from Terrafix and Schletter follow the terrain and allow for a rolling solar field. Following the natural terrain leaves the land more intact for the future, and creates an aesthetically pleasing result.

Not grading the land also leaves most of the grass intact so that animal grazing may continue unabated. Grazing animals on the solar fields allows the land owner to maximize the use of the land and may be effective in maintenance costs if it can be used to avoid the cost of mowing. It is very common on German sites to see sheep grazing among the solar panels.

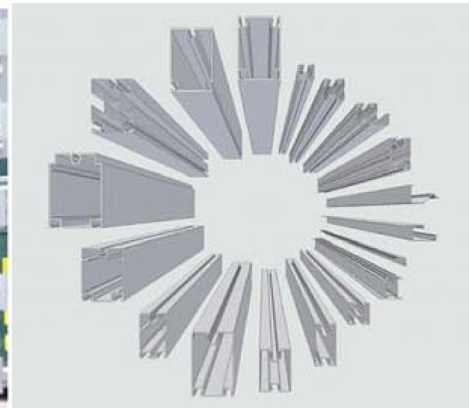
Cross Members

Module manufacturers provide requirements for appropriate fasteners and supports for their individual panels. The upper part of the rack is generally made from aluminum because aluminum can be readily extruded into complex shapes allowing for a wide variety of fasteners to be developed. Aluminum is also much easier to handle and manipulate for installers which allows the workers to more easily position the modules.





Aluminum cross members are extruded in a variety of designs to match different types of modules. Every kind of module has some element of custom mounting requirements and various clips are used for frameless designs. Rack manufacturers work with the major module makers to design parts. Framed modules are usually assembled in vertical orientation while unframed thin film modules are generally mounted horizontally. For thin film, as many as seven panels are stacked horizontally above one another. The most optimum design seems to be four panels in a stack. Stacks of six or seven high have significant wind load exposure.

Wood –No Good

First Solar frequently uses pictures of sites developed by Beck Energy with seven panels in a stack. We visited one of these sites and saw the use of laminate wood for the cross beams. This laminate wood is not rated for outdoor use and utilized tar paper in an attempt to keep rain water off even though humidity will affect the wood anyway. This site utilized the tallest rack structure we saw in our visits and would have a very large wind load.

Many early solar fields used wood in the construction of the racks. Wood does not offer the longevity of steel and aluminum. It is difficult to manufacture with the same level of precision as steel and aluminum, and it warps and shifts over time. Some reports indicated that wood frames shifted significantly in their first year of life requiring extensive maintenance and in some cases caused panels to break. Wood construction would also require a significant amount of labor if constructed in the field. All the vendors we spoke to indicated that they would not use wood in any of their sites.

Beck Energy Site – Dimbach
First Solar Promotional Photo

Tar paper covering laminate wood

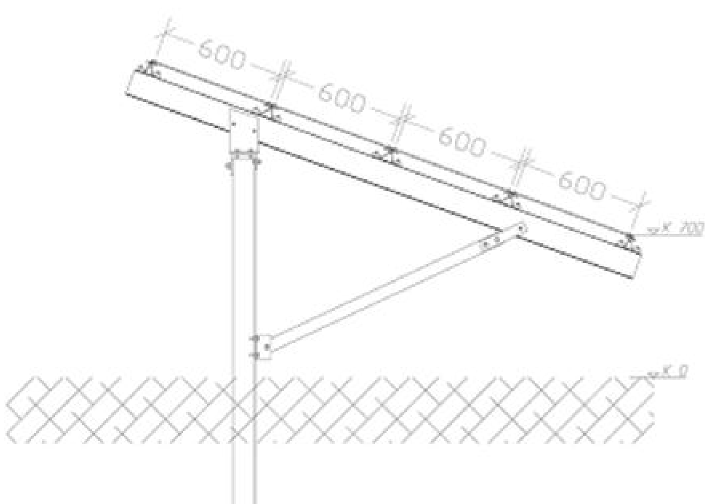
Suntechnics sites
http://suntechnics.com/us/installations_2cm.htm

Rack Recommendations

Racks will need to be improved over time with the goals of improving strength vs. quantity of material and improving the labor efficiency of installations. Similar to the PC or auto industries where continuous and gradual improvements to steel chassis are the norm, solar rack makers must continue to optimize and tweak their designs over time. Emphasis needs to focus on prefabrication, reduction of parts, high strength to weight ratios, and compact packaging for shipping.

Built in raceways to channel and protect cabling should be a consideration in future designs as many systems leave cables hanging loose and exposed to potential damage and vandalism. Cables with damaged shielding represent a potential safety threat to workers or people passing by.

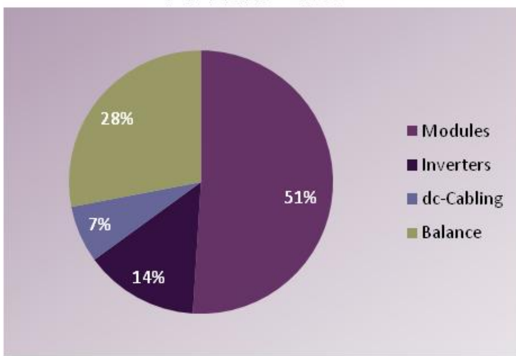
A prefabricated solution can be designed that will encompass the module, aluminum supports and the wiring harness. This kit can then be installed onto a steel substructure that varies from site to site. Anyone who also wishes to develop full systems would be well served to design an integrated approach to modules, connectors, cross-members, and connectors that fit all together as an easy to install kit.



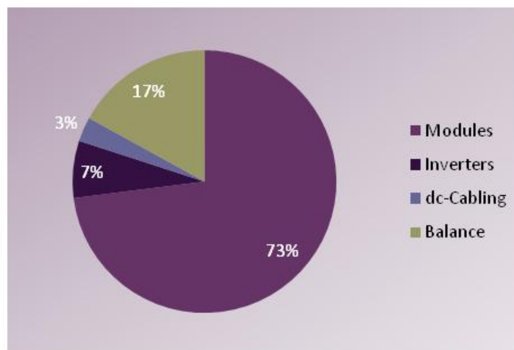
Inverters and DC-Cabling

The lower efficiency of the thin film modules and their lower operating voltage means that the inverter and DC cabling costs for thin film systems are comparatively higher than those PV plants using crystalline silicon (x-Si) modules. According to Phoenix Solar, the cost allocation for the inverters of a thin film PV plant in 2005 was 14% of total project costs and the dc-cabling was a further 7%. By comparison, a crystalline plant had respective cost allocations of 7% and 3%. Therefore, this 21% represents an increasingly large portion of total costs and represents a crucial part to reducing total costs for a thin film PV plant.

Cost Allocation for Thin Film PV Plant - 2005



Cost Allocation for Crystalline PV Plant - 2005



Source – Phoenix Solar, BOS Cost Savings Presentation

Pre-Fabricated DC-Cabling

New cable designs and modifications, specifically pre-fabricated dc cables, have allowed the price of the cabling to come down in the past few years. Using these pre-fabricated cables is a current best practice among PV plant integrators. Gehrlicher touts their unique design for these cables which we saw Ecostream using in the construction of the Baustelle-Froscham PV plant (we believe the product is manufactured by Pyrsimian). The main advantage offered by

Field wiring requires costly junction boxes and is prone to failure these pre-fab cables is the faster and easier wiring of the entire system, coupled with an increase in the reliability of the wiring. This adds considerable savings even though the material cost may be about the same as before. Another manufacturer of pre-fabricated cables is Lumberg, who claim that their product offers up to 30% shorter installation time, because everything is supplied pre-assembled and ready to plug. There is no on-site crimping required. As such, the labor costs for the cabling are at least 30% less than the previous method of having an electrician cut and wire all the cables. There is also the benefit that the molded connectors and junctions increase the reliability of the cabling, thus reducing the long term maintenance costs. The down side of using pre-fabricated cables is that the wiring scheme must be completely engineered in advance with little flexibility out in the field. Phoenix claims that using these pre-fabricated cables exceeded their own cost savings estimate by bringing in total savings of 80€/kWp. Note that that the costs for cabling will fluctuate with commodity copper prices.

Ecostream site Baustelle-Froscham using Gehrlicher cables.

We can expect continued lowering of dc-cabling costs per watt due to the increase in thin film module efficiency expected to come in the next few years. As module efficiencies increase there will be less cabling required to make the same amount of power. The savings in cabling costs is more or less directly proportional to the module efficiency. Therefore, the expected 25% increase in module efficiency to come by 2010 should translate to an approximate 20-25% decrease in cabling costs.

Raising system voltages to 1000Vdc

A step that would lower both the cabling costs and the inverter costs would be to raise the dc-voltage of thin film systems to match the higher voltages now being used by some crystalline-silicon module systems. Most thin film installations have a maximum system operating voltage of 600Vdc at present because of limitations in the modules. However, some x-Si PV modules can now use system operating voltages of up to 1000Vdc. The higher voltages have less electrical loss which allows for thinner and longer cable strings, and fewer costly parallel connections. The net effect is less copper required.

Phoenix Solar claims that this change alone, when implemented in x-Si plants, reduced the total cabling of a 1MW plant by over 38% in copper wiring. Raising the operating voltage also reduces the inverter costs because the higher voltage means that larger 1MW inverters can be used. These larger units are less expensive on a per Wp basis. In addition, Phoenix solar claims that where before two inverter/transformer buildings were required for a 1MW x-Si plant, only one building is now required. It is difficult to quantify exactly how much cabling and inverter costs would reduce if the operating voltage were raised to 1000Vdc, but Phoenix Solar claims that it was able to save 60€/kWp by going from 600Vdc to 900Vdc with improved First Solar modules. More savings are possible at 1000Vdc and above. This is one of the best opportunities to reduce inverter and cabling costs for thin film PV plants. To do so, the thin film modules must be improved so that they can handle the increased current and would it also require grounding the (-) pole of the array. Moving to a 1000Vdc maximum system operating voltage is one of the few remaining “low hanging fruit” opportunities left for system integrators to lower the BOS costs in the near future.

Unfortunately in the USA, anything above 600 volts is considered 'High Voltage' and requires special permits and high voltage licensed electricians. This regulatory issue of the National Electrical Code presents a significant hurdle in developing cost effective solar plants in the USA. Currently the only environment where 1000Vdc is allowed is behind a fence in a licensed power plant. The cost overhead of building a solar plant in such a controlled environment using more expensive labor undermines one of the great advantages of large PV systems, which is the basic ease of installation. Large solar fields, outside of regulatory issues, are pretty straightforward to construct and multi MW sites can be online in a just a few months from the beginning of construction when building in open farm fields. The regulatory constraint that would require the most technically advanced and cost-effective designs to only be built in extremely limited locations, is an unnecessary burden that needs to be addressed with the NEC and other standards bodies.

Colexon – Malsch
SMA Inverters

Ecostream – Mooreweiss
Siemens Inverters

Grounding is another area of difference between Germany and the USA. Traditionally the US has always enforced much higher requirements for grounding and this entails higher costs through the use of extra copper wiring and grounding rods. Additionally, the electrical code in the USA requires conduit to be used in most cases when cable is to be buried. This adds to the extra cost for building PV plants in the USA.

Inverters

Among the most common themes we saw in our visits was the use of large centralized inverters in sizes up to 1.6-1.7 MW. Phoenix Solar estimates that they were able to lower the cost of the inverters by 120€/kWp by using 1MW inverters. Large inverters allow for manufacturing economies of scale to drive down the $/Wp cost. In addition, by designing their PV plants to use standardized ("off-the-shelf") inverters, rather than having inverters custom made for the individual PV plant, they were also able to save an additional 60€/kWp. Thus the current trend would appear to be using large centralized inverters as they currently represent the best value on a per Wp basis. Advances in technology, such as multi string capabilities and master/slave operation, have allowed these large units to increase their efficiency while lowering their per Wp cost.

Centralized Inverters versus String Inverters

However, there is still some debate on whether the centralized inverter concept is indeed the way to go. Indeed, in our visits we did see one site that used smaller string inverters instead of larger centralized ones. And even though that particular plant was only 1.1MW, there are several other examples of large new PV plants using string inverters such as the 5MW thin film plant in Murcia, Spain. The argument for using string inverters is that they provide a better overall value once the cost per kWh is computed by improving overall system efficiency and uptime.

gehrlicher.

2007

Field installation - Ecoparque Solar de Bullas, Murcia (Spain) 5 MW

We have constructed Spain's largest (and Europe's third largest) CdTe thin-film installation with 5 MW performance.

The installation is located in the Bullas region, one of the sunniest regions in Spain. Over 70,000 First Solar Cd-Te Thin-film modules and 375 SMA SMC 7000 HV inverters were used.

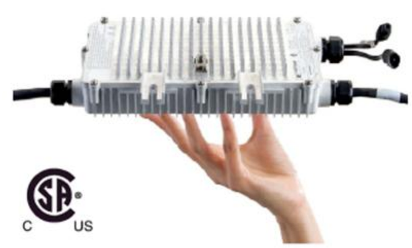
When other factors are considered, the decentralized concept can offer some advantages. Primarily, the cost of an inverter failure is much less severe with many small inverters as opposed to one (or few) big ones. A string inverter failure would only affect the string it controls, which would only be a small percentage of the plant. The rest of the plant will continue to operate even if it takes a few days to fix the problem. At the end of the year, one or two string inverter failures may not even have a noticeable effect on the total plant output. Since string inverters are only a few thousand dollars, it may be advisable to carry a spare inverter or two to allow for quick replacement. And since the voltages at these string inverters are lower, the replacement can be performed by an ordinary electrician. The failure of a large inverter, on the other hand, is a very costly event: it can shut the whole PV plant, or a large portion of it, down for days at a time and requires the attention of a highly paid electrician certified for high voltage. In the case of a remote plant, the response time just to get a trained repairman out there might take one or two days, before the repair can even begin. Additionally, the repair itself might require specialized parts that may not be readily available, thus adding to the down time. It is therefore conceivable that string inverters represent a lower cost option if the total plant lifetime plant cost is considered with the downside of a higher upfront inverter cost per watt. There is also potential for lower overall system reliability since inverters are often the system weak points and if a bad model were used repeatedly in a large system it would be a major maintenance burden.


SMA string inverters at Gehrlicher Hesse site

Micro-Inverters

Micro-inverters present a potential design shift for the future of PV plants. The idea with a micro-inverter is to convert the dc voltage to ac right at the module itself. The argument for micro inverters is that they improve overall system performance by optimizing each individual module. Thus each

Enphase Micro-Inverter Models M175 and M200

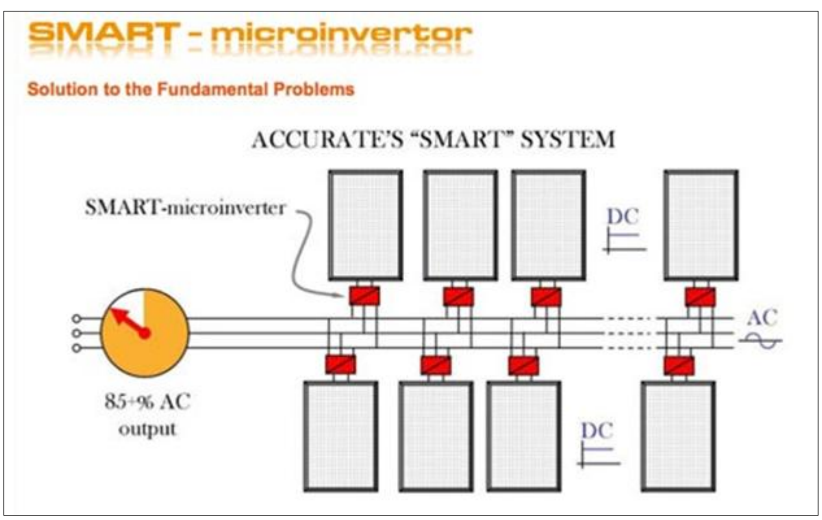


module is able to produce the maximum peak power (mpp) for the specific solar and weather conditions. Micro-inverters have the ability to thus maximize the power produced. According to Accuarate Solar Power, an upcoming manufacturer of micro-inverters, current PV system architectures, whether they are using large centralized inverters or the smaller string inverters have the following drawbacks:

- Shading can reduce output 40%.
- Soiling can reduce output 5-20%.
- Mismatch between panels can reduce output 15%.
- Centralized optimization reduces overall performance to the weakest panel in a series string.

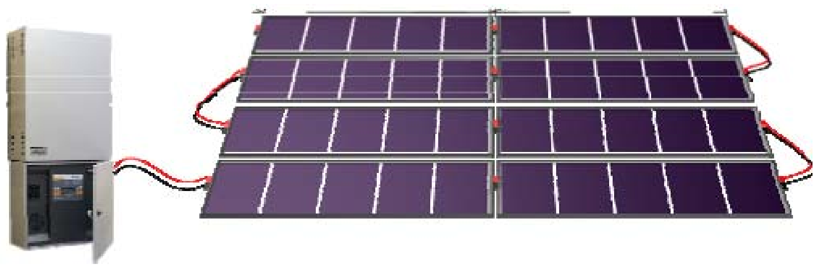
Accurate states that these problems combine to limit the plant output to 70% of the theoretical value. By maximizing the power at each module, Accurate says that the micro-inverters can increase the plant output to more than 85%. Microinverters use a massively parallel wiring scheme that eliminates mismatches lowering the voltage of units in series but would appear to be much more costly on large systems than today's cabling designs.

The micro-inverter also promises other benefits. They can provide more granular intelligence by proving module level data. Individual module monitoring can also help prevent module theft. Such a system can also be shut down the modules individually or collectively, helping prevent dc electrocution of maintenance and service personnel. And they would allow PV integrators to mix match a wide array of different module types in the same plant without penalty.



The main obstacle to micro-inverters is price. Presently large centralized inverters cost around \$.28/Wp versus \$.60/Wp for string inverter systems and micro inverters are about \$1.00/Wp. For large solar plants that use 10,000's of modules the costs alone for micro inverters are prohibitive. Inverters can be a source of failure and implementing thousands can multiply potential problems.   Additionally, micro-inverters do not provide any saving on the overall cabling. And most importantly, we have yet to see the micro-inverter being promised by Accurate in production.

Sustainable Energy Technologies



Sustainable Energy Technologies of Calgary is promoting another variation by utilizing massively parallel wiring schemes and their own low voltage, high current inverters. SET's claim is that the parallel wiring improves system performance by avoiding series string losses, though it does require more copper cabling than series. Their inverter platform has additional benefits as well, the low voltage of the system (>120v) is very safe and can be worked on by anyone, similar to household appliances. Their inverters also have superior thermal characteristics allowing them to perform well in high heat that is damaging to other types of inverters and requires air conditioning. SET is mainly focused on the rooftop and building integrated market where shading is a bigger concern, but if their electrical subsystem design proves effective it could be used for open field systems as well.

While it easy to dismiss micro-inverters and massively parallel wiring today as irrelevant because of their higher costs, they represent an important opportunity to significantly reduce the BOS costs of future PV plants. If micro-inverter manufacturers, such as Accurate Solar Power, are able to bring the cost of such devices down, then we may have a "game changer". We believe that it may be possible to one day have low cost micro-inverters incorporated into the PV modules themselves. Module manufacturers looking to differentiate their product may see this as a way to do so. Micro-inverters will probably have a bigger impact in the residential and small commercial market where there are few modules in the system with potential shading, and it makes more sense to pay a premium to maximize each individual module.

Inverter Manufacturing Issues

Currently the manufacturers with the largest market presence are SMA, Xantrex, Fronius, and Siemens. Manufacturers today are focused on lowering cost first over improving reliability. As a result, inverter maintenance is a common problem faced by integrators. Inverters typically only have a 10-15 year life span and so must also be replaced at least once in the lifetime of a solar plant. However, the feeling is that 10-15 years from now the inverters will be much cheaper and more efficient so that the cost to change will be worth it. Inverter manufacturers currently face several challenges. First, inverters have slower learning curve than PV module industry, thus the improvements are steady but not exponential. It will be difficult for the inverter manufacturers to keep up with the PV industry demands on continual cost cutting to keep up with the shrinking utility feed-in tariffs which drive the industry. Additionally, inconsistent national and state regulatory standards have hurt inverter manufacturers ability to grow in the past, limiting many to focus on regional markets. This hurts their ability to offer truly standardized products at lower costs.

Even without any new advances in inverter technology or manufacturing capabilities, we expect the price of the inverters themselves to decrease simply as a result of the increasing sales volume. Indeed, according to the Navigant Consulting Inc., this is the single largest factor that will lead to lower cost and higher reliability of PV inverters. Inverter prices have been dropping by about 10% with every cumulative doubling of production. Therefore, as the demand for inverters continues to grow, we can expect the inverter cost per Wp to steadily decrease. Using that guideline, once the sales volume quadruples, we could then reasonably expect inverter prices to correspondingly drop by about 20%. Being that large centralized inverters cost around $280/kWp at current prices, we could then expect another $50-60/kWp in savings to come from that increase in sales volume alone.

Transformerless Inverters

Regardless of how the centralized inverter versus the string inverter argument plays out, another possibility for inverters are transformerless designs. While there are some technical considerations yet to be figured out in order to satisfy electrical codes in some countries (in particular, UL 1741 in the USA), as well the inability to ground the negative pole of the modules as required, transformerless inverters offer cost advantages over the traditional transformer-included designs. Doing away with the transformer increases efficiency by 1-2% and it also means doing away with a large chunk of copper, representing significant raw material cost savings. One estimate by a sales manager of an inverter manufacturer is that transformerless designs would represent a 10% cost savings. As an added benefit, this also translates into smaller, lighter, and more compact inverters with corresponding savings in shipping costs. It was the opinion this same sales manager that transformerless designs will be an essential part of being able to continue driving down the inverter costs for future thin film PV plants.

Module Considerations

Large 5.7m^2 Modules from Applied Materials

One technology change that could affect installation costs is the introduction of larger sized solar modules. Typical thin film modules have dimensions of 0.6m by 1.2m. One production system offered by Applied Materials (AMAT) produces modules that measure 2.2 x 2.6 m (5.7m^2), roughly eight times the area of standard modules. This technology is based on that used for large flat panel displays and is known as the 'Gen 8.5' panel. T-Solar has a production line for these modules in Spain and Signet Solar recently installed a similar system in Dresden, Germany and is expected to ramp up production in Q3 2008. These production lines from AMAT can produce panels in full, half, or quarter sized. Applied Materials claims a 17% reduction of installation costs by using the large panels which reduce cabling and clamps, but there are currently no megawatt scale projects that use these panels to validate those claims.

There are several limitations to these panels. The primary concern is the physical size and weight (150kg) which requires them to be installed from a truck using a glass-handling boom. This type of equipment may not be safe nor practical to use for operation should the terrain be excessively rough, sloped, or muddy. Any difficulties encountered due to equipment needs and terrain constraints are also doubled due to the panel removal costs, as potential technological obsolescence may lead to the panel being replaced well before its useable life span. The site must be relatively flat, as the larger continuous surface would place higher stresses on the panel in 'terrain following' applications as often seen in Germany. Under ideal conditions, installation time will be significantly reduced; however wet or windy conditions will create delays in installing the panels and could

Large 5.7m^2 AMAT modules test installation by Phoenix Solar

nullify any time savings

In speaking with people who have handled the large panels such as Phoenix, who is featured in AMAT's installation video working on a test site, and Schletter who worked with AMAT on rack design, we found significant concern about the applicability of the large panels. Comments were that the modules are too big to handle and that the mounting system is not proven. Of particular concern were the glued rails on back of panels because they may create shear points where the panels can snap, and the panels are also not flush with rack and can flex (and could chip if touching each other). Schletter claims that one installer attempted to use conventional clips with the large panels and experienced panel fractures.

The affected BOS cost drivers are described as follows:

1. **Clamps and Brackets**
   a. 4 Small modules use 2 clamps each (2.8 clamps/m^2) = 8 clamps
   b. 1 Large module uses 5 clamps (0.9 clamps/m^2) = 5 clamps
   c. 8% reduction of clamping labor and material costs
2. **Module Cabling Connections**
   a. 87% fewer connections
3. **Support Rails**
   a. Small modules use 1.6m/m^2 of rail
      Large modules use 0.9m/m^2 of rail
   b. 43% reduction in rail material.

COMPARISON FOR A 10 MW SOLAR FARM

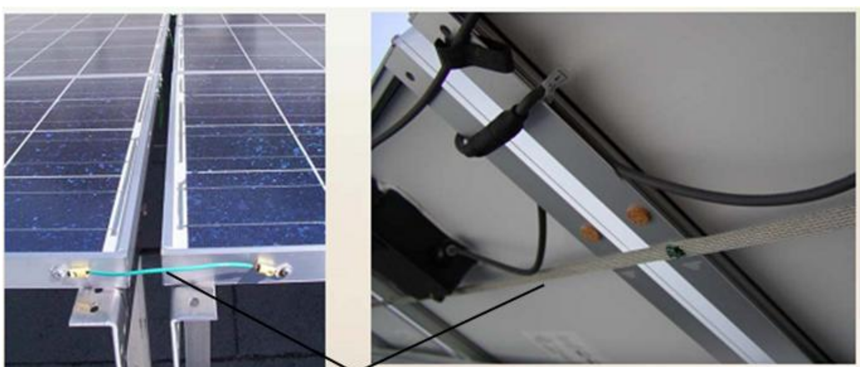
	Conventional 0.6 m x 1.2 m Thin Film Module	SunFab™ 2.2 m x 2.6 m Module
Module	150,000 (65 Wp per module)	20,000 (515 Wp per module)
Clamps/Brackets	375,000 (2½ per module)	160,000 (8 per module)
Module Cabling Connections	150,000	20,000
Aluminum Support Rails	75,000 ($31 per rail)	NA
Galvanized Steel Bonded Rails	NA	80,000 ($12 per rail)

Source: Applied Materials

4. **Installation Equipment**
   a. Equipment to handle large glass is common for construction glazing.
   b. 15-30% increase of costs for larger equipment needed to hoist large panels.
5. **Other**
   a. Quicker install time (might be negated or impossible due to terrain and weather).
   b. Theft reduction due to large size.
   c. Better shedding of snow.

Frames

According to installers we talked to, the installation difference between framed and frameless systems is negligible. The largest advantage of frameless systems is the elimination of the need for individual grounding of the modules. Framed systems should have the frame grounded, and we estimate that the time to ground panels is about 1-2% of total labor costs. The frames also reduce the pack density in shipping, although any shipping savings in frameless systems may be offset by increased damage. This discussion may be moot, as most large volume thin-film module manufacturers provide only frameless solutions whereas conventions crystal-silicon modules all traditionally have aluminum frames.



Grounding straps on modules

Package of First Solar Modules

Operations & Maintenance

Warranties

In all the large scale solar facilities we found that the majority of warranties offered by integrators are pass-through output and degradation warranties offered by panel manufacturers.

> **Warranty**
> Long life cycle with 25-year guarantee: The Ecostream module has a 2 year guarantee on production failures. We guarantee 90% of the initial power output in the first 10 years and 80% for 25 years. For the customer this is a guarantee that he will have a good return on his investment.

The negative implication of this is the possibility of having to service facilities built 24 years prior. One way integrators are able to mitigate this risk is through offering post-installation services to customers, thereby creating a consistent revenue stream while maintaining a "hands-on" approach from a centralized efficiency monitoring facility.

Operations

In the large scale solar field industry, more and more customers/investors are either not capable or willing to operate and maintain their PV plant(s) – they would rather concentrate on their own core competencies. This provides an excellent opportunity for additional revenue streams for integrators over a consistent period of time (typically 20-25 years). Many integrators are shifting their business model to include services, including operations and maintenance.

A major external advocate for integrator performed operations and maintenance are the many banks that provide the debt financing for solar projects. The organizations providing source capital are concerned about maximizing energy output, ultimately ensuring the greatest return (or chance of return) on their investment. These organizations will, at times, require that the owners of these large scale solar fields contract the operation and maintenance externally.

The advantage to integrators, besides the obvious continuous revenue stream, is the internal feedback loop (components, system design) and quality control. This internal feedback loop offers the integrator the opportunity to identify and correct trends in inefficiencies across multiple sites, allowing for permanent plant optimization and yield increases across all sites.

The most successful practice for operations and maintenance is the establishment of a centralized monitoring facility that monitors power output at both the utility access and output reports from the inverter manufacturers. This provides a system of checks and balances, and helps identify system inefficiencies. The identification of inefficiency would trigger a maintenance visit by technicians to further diagnose and correct the problem, getting the site back up to maximal efficiency. By complementing the monitoring with regular scheduled maintenance visits, the integrators can keep the facility producing the maximal level of output. Electricity production is ultimately the most important concern of any solar plant because that is the source of revenue.

Phoenix central monitoring at Ulm

Maintenance

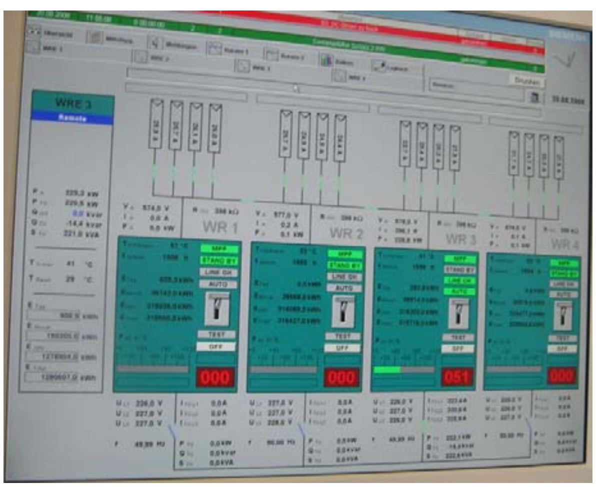
Site maintenance consists of several levels: grounds keeping, low voltage equipment, and high voltage equipment. Some owners do not want the integrators to operate the facility, but are willing to pay for long-term maintenance contracts. The ground-keeping tasks include cutting grass, maintaining security fences, and snow/ debris removal from the panels.   In most cases, the farmers or employees maintaining the site were paid for grounds-keeping maintenance.

The low voltage wiring maintenance is usually sub-contracted to electricians annually or on a case-by-case basis for problems identified through monitoring. Some of the larger integrators that are providing complete operation of their PV sites employ electrical experts as full-time employees. Some of these experts also have the ability to conduct high voltage maintenance as well.

For the high voltage maintenance, the integrators often pass on the maintenance responsibility to the sub-contractor that installed the inverters and connected the inverters to the utility input. This cost for this level of high voltage maintenance is often covered under warrantee, with additional costs for maintenance passed onto the customer. As the high voltage systems have risk of electrocution, reducing the risk of injury or death is very appealing to PV site owners. Often, this is a selling point for the integrator operating the PV site; offering cost-savings, civil risk mitigation, and power production risk reduction to their customers.

Monitoring

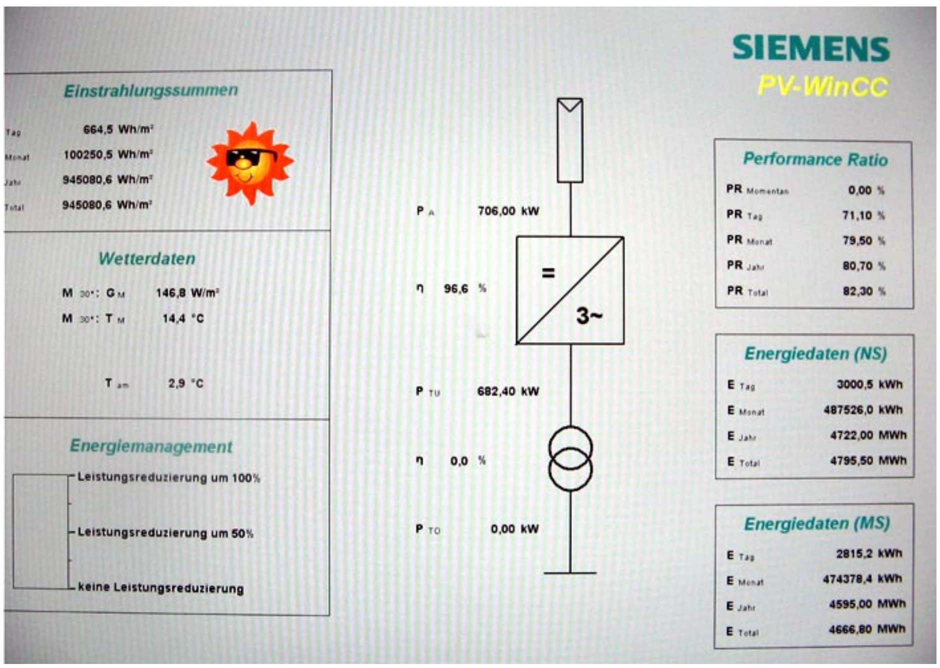
Some customers only want a minimal level of integrator involvement after the sale. Monitoring service is the lowest level of integrator involvement, and is often used to provide a "double check" of on-site inverter output measure. For example, the government owned site at Malsch used Colexon as the integrator, and utilized monitoring software installed locally by Colexon. This software had a dashboard on-site at the solar facility that was also viewed at a central facility by Colexon. This dashboard complemented a separate dashboard provided by the inverter manufacturer, and another dashboard provided by the utility company at the utility input junction. The government employees that monitor these 3 dashboards can troubleshoot any inefficiency in the system by cross-referencing these reports.



The advantage to the integrator is the ability to analyze further data in assessing the efficiency of current installation methods. This monitoring also can identify a problem before a warranty violation occurs, allowing the integrator to conduct repairs and stay in warranty. This helps company image and keeps existing customers content.

Most sites are employing string monitoring units (SMU) provided by the inverter manufacturers. For large solar fields string monitoring appears the most cost effective as it provides enough granular information to enable a technician to troubleshoot problems. The SMU's will identify voltage drops across a string of modules and the technician will be able to test to quickly find the source of the problem. All of the leading inverter vendors provide data monitoring capabilities and software. Phoenix has developed some of their data aggregation software that consolidates information from different types of systems into a common interface for their staff to monitor.

Our team feels that the investment in centralized monitoring is money well spent. The investment is not substantial, though difficult to estimate as it depends on the degree of sophistication employed. At a minimum network connectivity has to be in place at every solar site that will send data back to the central monitoring location. As more sites are added to the system the $/watt costs for the monitoring facility are reduced.



Conclusions

USA vs. Germany

We observed some interesting differences in the approach to systems between the USA and Germany. Some of these differences were cultural and some were technical. Culturally, Germans have a reputation for engineering for maximum robustness, while Americans tend to be focused on lowest up-front costs. Though on a regulatory level, Germany is much more inexpensive because it has fewer regulations, permits and paperwork. Akeena Solar of the USA presented a finding that the costs for installing residential or small commercial x-Si systems was $8/watt in the US than and $6/watt in Germany with the difference due primarily to bureaucratic issues.[1]

Subsidies are different in the two countries and motivate developers in different ways. German feed-in-tariffs emphasize and reward electricity production by guaranteeing a good price over time for electricity produced, and no subsidies are provided for installation. The American subsidies are almost all designed to reduce upfront costs through the use of tax breaks and cash payments based on watts installed. The American system provides no motivation to maintain production over time, and does not reward quality engineering. In the USA a system built in the shade that produces little electricity would receive the same subsidies as a same-sized system that was optimally engineered. Feed-in-tariffs reward operators for actually producing the most energy and poorly designed systems receive less benefit, which is appropriate. Feed-in-tariffs are being actively debated in the US and their implementation would be a welcome improvement.

German electrical codes allow for higher voltages to be used with less grounding. The German standards are certainly more inexpensive as they require far less copper cabling, but it represents a much lower safety standard than in the USA. American safety standards are among the highest in the world and these standards always entail higher costs, but for solar they should be reviewed to make sure they are not causing unnecessary bottlenecks that may choke the industry.

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[1] Akeena Solar, Inc., Barry Cinnamon, PV Installations in Germany Same Panels Much Lower Costs than U.S., presentation February 2008

Industry Costs and Goals

The US Department of Energy has a goal of $1/watt installed system costs for photovoltaics. The industry is not there yet but is getting closer. Current installed costs for large thin film plants are around €4/watt or $5.50/watt. Presently First Solar is manufacturing CdTe for close to $1/watt which is the best in the industry, and selling for $2-$2.75/watt and these costs are projected to continue to go down as more thin-film manufacturing comes online.

NREL - Total System Costs

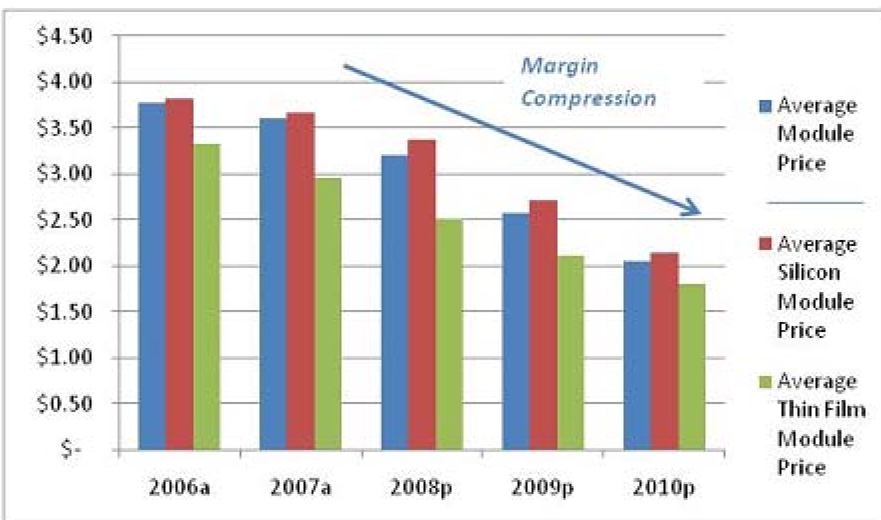
Large, Ground Mounted (nontracking) 2005

	System size (MWp)	$/Wp DC	Annual O&M ($)	SAM LCOE (IPP assumptions)*
x-Si $3.33, 13.5%	10 MWp	$4.8	120000	$0.23/kWh
CdTe $2.4, 9%	10 MWp	$4.4	120000	$0.20/kWh
a-Si/glass, $2.4, 6.4%	10 MWp	$4.65	120000	$0.21/kWh

Ground Mounted 2020 - projected

	System size (MWp)	$/Wp DC	Annual O&M ($)	SAM LCOE (IPP financing)
x-Si $1.25, 20%	10 MWp	$1.65	14000	7.5 c/kWh
TF 15%, $0.5/Wp	10 MWp	$0.94	15300	$4.1/kWh

Source: Ken Zweibel, National Renewable Energy Laboratory, 2005



Source: Sustainable Energy Technologies

Rapid onset of new production will see a module market that was sold-out in 2006-2007 have a 3 - 4 GW module surplus in 2009. Thin film capacity alone will grow from 400MW in 2007 to 3.4 GW by 2010. A-Si, CIGS and other forms of PV are entering production and will compete with CdTe for market share. All of these developments will contribute to lowering of prices for PV modules and improving the overall economics for solar power installations, even if it comes at the expense of module manufacturers.

in brief

juwi solar

Key figures of the Waldpolenz energy park (Muldentalkreis district, state of Saxony, Germany)

Construction of the first aluminum sub-structures for the solar modules on March 26th, 2007

Construction status at the end of July 2007

General overview	
Site	former military airbase in the townships of Brandis and Bennewitz (Muldentalkreis district, Saxony)
Surface area of the solar park	**110 hectares (about the same as 200 soccer fields)**
Installed capacity (total)	**approx. 40,000 kilowatts$_{peak}$**
Module surface area (total)	approx. 400,000 m²
Number of modules / type	approx. 550,000 modules / First Solar FS-265 etc. (thin-film technology; produced mainly in Frankfurt (Oder)
Number of converters / type	35 SMA SC 1000 MW stations
Light metal frame sub-structures	Leichtmetallbau Schletter GmbH (83527 Haag, Bavaria)
Estimated yield (total)	**approx. 40 million kilowatt-hours annually** (enough to serve more than 10,000 households)
Displaced pollutants	around 25,000 tons of carbon dioxide (CO_2)
Investment sum	**approx. EUR 130 million**
Financing	solar fund and loan, provided by Sachsen LB Group
Transmission method	feed-in supply into the envia network
Payment (remuneration rate)	33.18 - 37.96 euro cents per kilowatt-hour (according to date of startup)
Construction begin / Commissioning	February 2007 to December 2009 (in several building phases)
Service time	at least 20 years (but presumably 30 – 40 years)

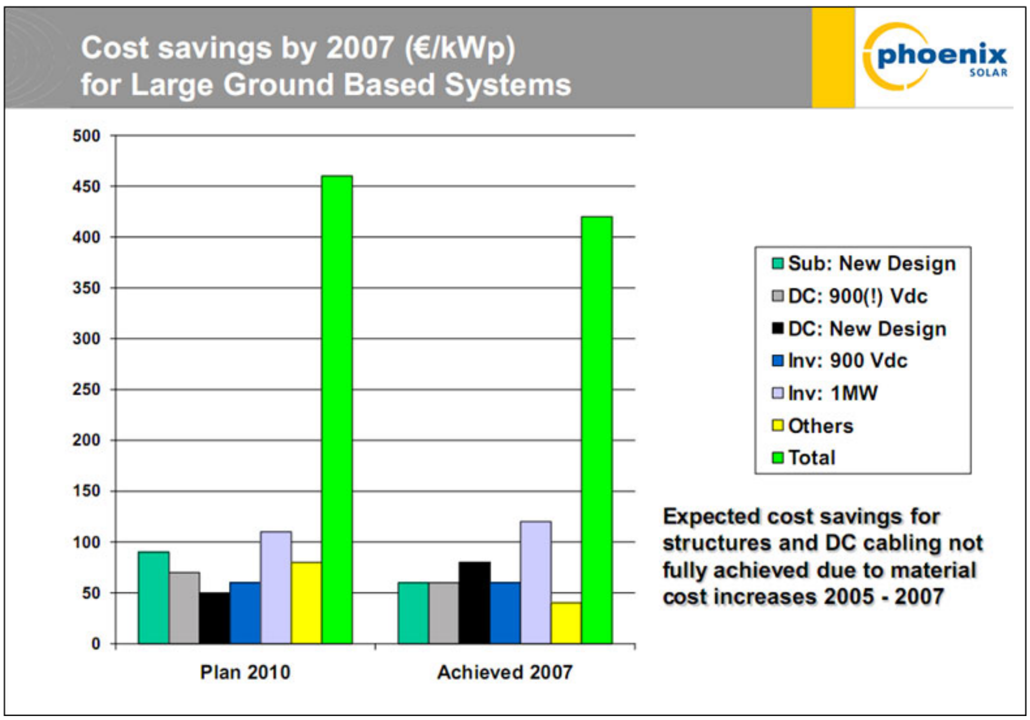
For more information contact:
juwi solar GmbH, Friedhofweg 10, 67295 Bolanden, Germany, Tel: +49 6352 70 66 8-0
Fax: +49 6352 70 66 8-88, E-mail: solar@juwi.de, Internet. www.juwi.de

Last updated: 20 August 2007; no responsibility is taken for the correctness of this information; compiled by: ch, lf

The most cost effective site that has been built to date is also the largest, the 40MW Waldonpolenz site currently being built by Juwi at a retired air field in Brandis, Germany at a cost of €3.25 per watt. It uses

550,000 First Solar CdTe modules over an area of 272 acres and has a projected total of cost €130 million.

Phoenix estimates that technical improvements in large thin-film systems should lead to €0.65/Wp BOS cost reductions by 2010 with an additional €0.04/Wp from better project management and economies of scale. Continued optimizations of the substructure remain as an immediate task. The prefabricated cabling yielded greater savings than Phoenix anticipated when implemented in 2006.



Trends and best practices for BOS cost savings

In our research we were able to identify a number of best practices, areas where room for improvement remain, and other technical matters worthy of discussion as the various technologies mature. The single biggest cost driver for solar power is also the most obvious, module efficiencies. Module efficiencies drive all other costs by raising the output of electricity per square meter of system installed.

Racks and foundations need continual optimization and refinement to reduce installation times and the number of parts, but we believe that the best systems in the industry such as those offered by Schletter, Terrafix, and Phoenix are already highly optimized and that future improvements will be marginal. Additionally, racks and foundations must be engineered to meet the requirements of each specific site and so costs will vary dramatically with the conditions. Racks and foundations, along with cabling, are all made from commodity materials, steel, aluminum, and copper, and hence costs will fluctuate with commodity pricing.

Pre-fabricated components clearly are more cost effective. Sending electricians into the field with raw wire, connectors and junction boxes consumes a lot of labor and material costs compared to molded wiring harnesses that just need to be clipped into place. Quality control is also much more difficult to maintain in the field compared to a factory. Pre-assembled kits for racks and cables that are designed to match the modules will be the best way to minimize costs for materials and installations while improving performance and reliability. Significant room for optimization lies in having greater coordination between module manufacturers, cable vendors, rack vendors, and system developers. An entire kit could be designed that would include the modules, aluminum support components, and cabling, completely pre engineered and mostly assembled. This kit could be mounted on a steel substructure that would vary from site to site. This kit methodology would maximize the opportunity to optimize materials and labor costs but would require extensive standardization and coordination that is not yet mature in the industry.

System voltages were perhaps the most surprising area we discovered where costs can be improved, and it represents a major regulatory hurdle in the United States. High voltage systems at 1000Vdc and above enable the use of smaller wires as well as more efficient and cost effective inverters. Unfortunately for the USA, anything above 600 volts is designated high voltage and requires specially trained electricians and sites must be registered high voltage environments. Europe has traditionally always used higher voltages (220V vs. 110Vac residential) and their standard bodies allow the 1000Vdc without special permitting.

Operations and maintenance are an excellent avenue for system developers to both generate revenue, improve system sales, and create a feedback loop internally that leads to improved system design. Most investors or land-owners will not be involved in the technical work of managing electrical production. Developers already have the technical expertise and it only makes sense to leverage that expertise over time. Central monitoring facilities which manage many sites will pay for themselves and their relative costs go down as more sites are added to the management list. Efficient operations also promote the greatest production of electricity.

Our final conclusion is that balance of system costs, or $/watt costs, are not the most important consideration for a solar power plant, engineering systems for maximum energy production is. Maximizing kW hours per year is far more important than install costs because this is the source of revenue. A system that was expensive to build but produces well has far more value than an inexpensive system that does not run efficiently. The most cost effective solar power systems are those engineered and operated to maximize energy production, while minimizing costs where applicable.

Ongoing innovation and technological change makes for a very dynamic marketplace that challenges assumptions in the thin-film industry. New products are emerging that have potential to alter paradigms in a significant way. Will parallel wiring emerge as a standard? Modules in new shapes and designs such as tubular Solyndra modules can potentially remake BOS requirements. The glut of modules expected in 2009-10 should send thin-film prices down. This makes for an exciting time for the industry and hopefully in the next few years thin-film will become cheap, common and reliable.

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