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FINAL PROJECT REPORT

COST-BENEFIT ANALYSIS OF PLUG AND PLAY PHOTOVOLTAIC AC SYSTEM WITH MODULAR POWER CONVERSION

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PREFACE

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ABSTRACT

This report outlines the results of a study demonstrating the improvements in installation efficiency that are possible using a factory-in-the-field approach to constructing utility-scale solar photovoltaic plants. The study compared assembly speeds for two arrays, or functional units, at Skyline Solar's headquarters in Mountain View, California; a two-array demonstration system in Durango, Mexico; and the final 100 kilowatts (kW) of a 500 kW installation also in Durango.

Detailed time studies were done of the Mountain View assembly tests, and the results presented in this report show that significant amounts of time were spent walking and standing (both with and without parts in hand). In a well-designed factory-in-the-field, much of this nonproductive or minimally productive time could be eliminated.

Additionally, the Mountain View assembly project made clear that time spent in material handling (preceeding actual assembly) was significant and that industrial engineering was needed to improve the efficiency of material handling. Skyline developed specifications for material handling that are included in this report.

The first two arrays in Mexico were constructed at a rate of 1.9 kW per worker per 8-hour shift. For the final 100 kW system assembled, this rate had improved to 4.1 kW per worker per shift. The report projects that with full implementation of the factory-in-the-field approach on a future utility-scale photovoltaic project, an installation rate of 5.0 kW per worker per shift is achievable.

Keywords: PV, CPV, utility-scale PV, Skyline Solar, X14, factory-in-the-field

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EXECUTIVE SUMMARY

Project Purpose

This project was to identify and measure the improvements in installation efficiency that are possible using a factory-in-the-field approach to constructing utility-scale solar photovoltaic (PV) plants. The "factory" approach is contrasted with less-structured, though still well-planned, traditional construction methods.

Approach

SolarTech, a nonprofit solar industry association, partnered with Skyline Solar, a Mountain View, California, company that designs and manufactures single-axis tracked medium concentration PV systems. Skyline performed two test assembly projects at its headquarters to simulate the factory-in-the-field approach. They also oversaw the installation of a 7 kilowatt (kW) demonstration system in Mexico using more typical field assembly approaches. Finally, Skyline gathered data from a 500 kW installation, also in Mexico, where lessons learned from the factory and field demonstration experiences could be applied to a much larger installation.

Activities Performed

In addition to the activities described above, a detailed time study was done for the work at Skyline headquarters. Digital videos were shot of the factory assembly projects to support a meticulous analysis of the tasks being performed at 15-second intervals. A consultant hired by Skyline observed the entire construction process and provided detailed feedback on work methods and assembly times.

Results

There are four principal ways in which the factory-in-the-field approach lowers costs and improves labor productivity:

- Better supervision increases the percentage of time workers spend performing productive tasks.
- Working inside a building eliminates delays caused by high winds, inclement weather, and darkness.
- A factory setting makes it possible to install simple, inexpensive fixtures and tools to improve assembly speed.
- A factory setting makes it possible to dramatically improve the ergonomics of the assembly process, resulting in less fatigue, reduced risk of injury, and higher throughput.

Although not confirmed, it is the opinion of some construction professionals researchers spoke with that employees of the factory-in-the-field would not be subject to prevailing wage requirements of publicly funded projects in the United States. If true, this would offer another potential cost savings for that subset of solar projects.

However, the factory-in-the-field approach also adds transportation costs because each frame must be moved from the factory location to the solar field site. Therefore, it is important to locate the factory as close to the solar installation site as possible.

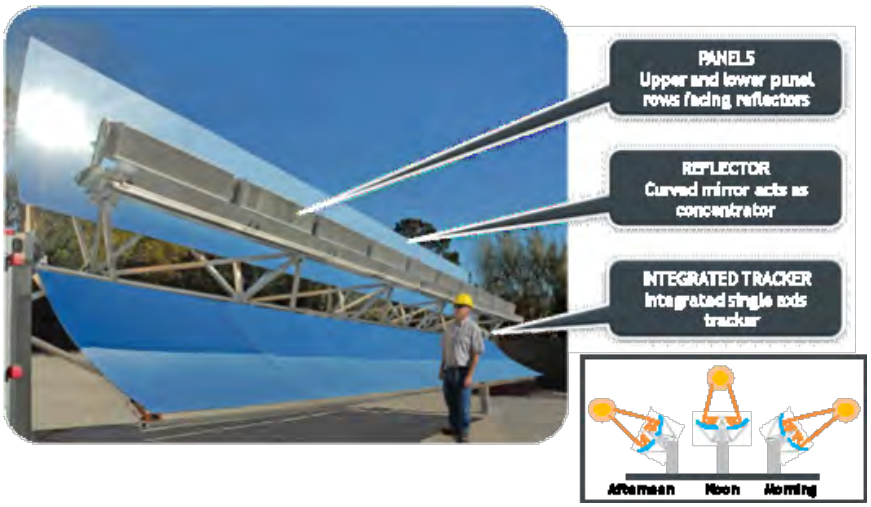
The results of this study confirm the hypothesis that factory-in-the-field methods will significantly reduce the labor hours required to install Skyline Solar systems. A pace of 4.1 kW per person per shift was observed during the final 100 kilowatts installed in Durango, and the research team believes a pace of 5 kW per person per shift is entirely achievable with full implementation of the factory-in-the-field model.

CHAPTER 1:
Skyline X14 System

1.1 Skyline X14 System Description

The Skyline X14 PV system is a single-axis tracked, medium concentration, photovoltaic system. Each functional unit is called an array. Arrays are comprised of a frame, 14 near-parabolic glass mirrors, and 20 PV modules (see Figure 1).

Figure 1: Components of an X14 System



The basic parts of an X14 system are: panels, mirrors, and the tracker.

Photo Credit: Skyline Solar

Each array is rated at 3520 W DC. Arrays are mounted on two posts and connected to a motor and gear set on one end. Tracking is controlled by a computerized control system that uses high-precision clocks and GPS coordinates to keep the system pointed at the sun. In a typical installation rows of 6 arrays are installed so that adjacent arrays share a post. Thus, only 7 posts are needed to support 6 arrays. Each row runs North-South and the mirrors rotate East-West.

1.2 Process Overview

In late 2011, four Skyline Solar employees built two X14 frames using "best known methods." The frames were built by two members of Skyline's design engineering team and two members of the field operations team. These individuals fully understood the design of the system, but had not previously assembled a frame.

X14 frames are built from several differnt kinds of members, joints, and stringers, as well as pins, clips, and a small number of threaded fasteners.

Because many of the members look similar to each other (and the same is true of joints), we felt that it was important to pre-position the parts so that it would be easy for the assemblers to find the right ones. There are five major steps in assembling a rack, so all the parts for Step 1 were put into one area for the east side of the frame and another for the west side. The same was true for all the other steps, resulting in 10 clusters of parts. Each worker was given a supply of pins and clips to store in his tool belt, with extras kept in a bucket near the assembly area.

The time to do this pre-positioning of materials was not included in the time studies, but it is not negligible – nearly 2 person-hours. In fact, we subsequently gave a great deal of thought to how to efficiently provide parts to assemblers to minimize unnecessary walking back and forth. This resulted in recommendations that will be listed later in this Chapter.

Each of the two assembly experiments was videotaped and the digital video recordings were analyzed to perform a time and motion study. Because a frame is quite long and narrow (38′ x 8′), we shot video from each end of the array to be able to see activities everywhere in the assembly area.

X14 frames are not actually designed to be disassembled without damage. Because we wanted to reuse as many parts as possible for the second test build, we used aluminum rivets instead of the stainless steel rivets that are specified in our design. Aluminum rivets are much easier to drill out. However, we did not consider that they are also much easier to install with hand tools because of their lower tensile strength. The implications of this will be discussed in Chapter 3.

1.3 Time Study

The primary goal of the time studies was to understand which activities took the most time and to identify inefficiencies so they could be eliminated.

The construction of a Skyline X14 frame consists of five steps.

1. Build the base
2. Build the A-frame
3. Build the Extended A-frame
4. Build the W-frame
5. Attach the mirror stringers with rivets

At this point, the frame is ready to be mounted on posts and connected to the motor assembly. Once that has been done, the frame is rotated so that 20 PV panels and 14 mirrors can be mounted. These steps were not part of the time study. They can only be done in the field, and therefore there is no "factory build" alternative possible. (X14 frames cannot be safely lifted after the panels are attached, though it may be possible to eliminate this constraint in future designs and allow both panels and mirrors to be installed in the factory-in-the-field. This could improve productivity significantly.)

1.3.1 First Test Build

The first test build focused on only Steps 1-4. It took 56 minutes (224 person-minutes) from start to finish.

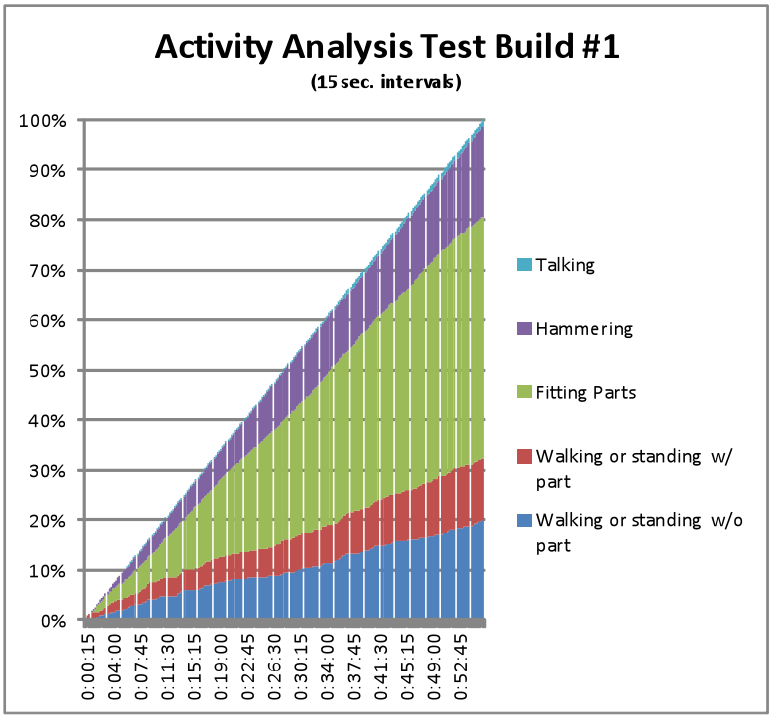
We did not perform Step 5, riveting the stringers, because it is time-consuming to remove the rivets. We also did not install clips on pins because the clips had just been redesigned and we did not have a stock of the new clip design.

A Skyline employee reviewed the video, stopping it every 15 seconds to identify what activity each of the assemblers was doing at that moment. The seven categories are:

1) Walking or standing without a part in hand
2) Walking or standing with a part in hand
3) Fitting parts (typically fitting a member into a joint or assisting another worker by holding a part)
4) Hammering (pins are hammered through holes in members and joints; the dimensional tolerances are tight, so anywhere from 1 to 10 hammer blows are needed to drive a pin)
5) Clipping (attaching a clip to a pin)
6) Riveting (or holding parts to assist the person riveting)
7) Talking (while not doing anything else)

Figure 2 shows how much time was spent on each activity. The X-axis is the elapsed time of the assembly process.

Figure 2: Activity Analysis from Test Build #1



The X-axis shows elapsed time, the Y axis shows the percentage of person-hours spent on each task.

The final distribution of time by task is shown in Table 1:

Table 1: Distribution of Time by Task for Build #1

Fitting	48.1%
Walk or stand without parts	20.0%
Hammering	18.0%
Walk or stand with parts	12.3%
Talking	1.6%

The time breakdown shows that there are significant opportunities for improving efficiency by reducing time spent walking and standing.

Clearly, attention must be paid to fitting parts as this activity accounts for almost half of the assembly time, but the total amount of time spent on walking or standing is also important. Even though the parts were prepositioned close to the assembly site, assemblers typically retrieved only one part at a time. For example, he would take 8 steps to get to the part, pick it up, take 8 steps back to the frame and then begin assembly. In a true factory-in-the-field, parts would be provided to workers in a way that would virtually eliminate the need for walking or standing without parts.

1.3.2 Second Test Build

The second test build was performed a week later by the same four individuals and included the clipping and riveting tasks. Figure 3 shows the completed frame. Mirrors and panels cannot be mounted until the frame has been mounted on posts and connected to the motor assembly.

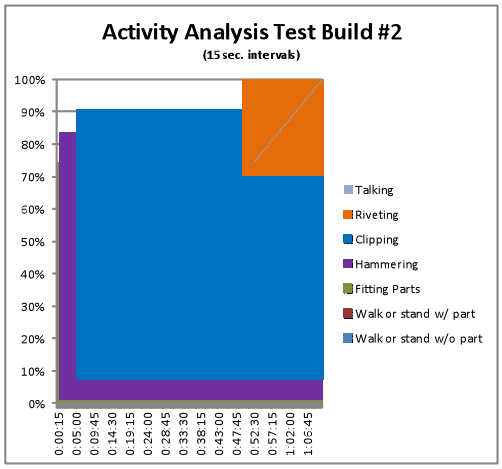
Figure 3: A Completed Frame

The completed frame from Test Build #2 is shown on a 40' x 4' plywood platform.

Photo Credit: Skyline Solar

As a result of including the clipping and riveting steps, the total elapsed time for Test Build #2 was 70 minutes (280 person-minutes). However, if we exclude riveting and clipping, Build 2 took 45 minutes compared to 56 minutes for Build 1. This shows that even a modest amount of experience can improve performance. Figure 4 shows the time breakdown

Figure 4: Activity Analysis from Test Build #2



The X-axis shows elapsed time, the Y axis shows the percentage of person-hours spent on each task.

The distribution of time by task is shown in Table 2:

Table 2: Distribution of Time by Task for Build #2

Fitting	41.5%
Walk or stand without parts	21.9%
Walk or stand with parts	10.8%
Riveting	9.2%
Hammering	9.0%
Clipping	7.2%
Talking	0.4%

The time breakdown shows that there are significant opportunities for improving efficiency by reducing time spent walking and standing.

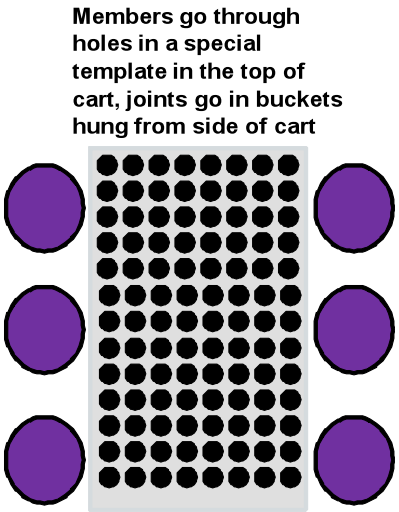
1.4 Key Learnings

There were three key insights from the Factory builds:

1. Reducing materials handling time can have a huge impact on total project build time. As a result of observing the test builds we developed specifications for two rolling carts and material handling layouts to improve assembly speed in the field. See Figure 5, Figure 6 and Figure 7.
2. The location of materials relative to the assembly location is critical for reducing wasted motion. In a well-structured factory setting, members and joints should be no farther than one step from the worker.
3. There are productivity gains that can be made by assembling one joint plus two to four members before beginning the rest of the assembly. This would be especially true if special fixtures were made to hold the pieces in place during the insertion of the pins and clips. One of the reasons why assembly sometimes slowed down is that the pins were being inserted at ankle height or above head height and the worker could not see when the pin and holes were not properly aligned. The more work that can be done with the pin between shoulder-level and eye-level the faster pins can be inserted.

Figure 5: Large-wheeled Carts Can Be Used to Move Materials to the Frame Assembly Area

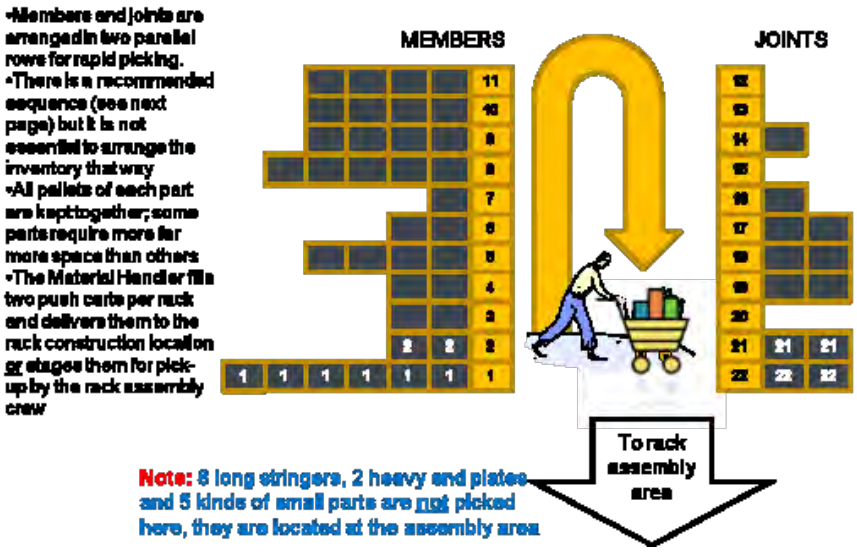
Weight per cart:
About 140 lbs (65 kg.)



Two carts with custom top templates and buckets hung on the sides of the frame can hold most of the parts needed for a frame. The actual templates differ slightly for the carts used on the west and east sides of the frame.

Illustration Credit: Skyline Solar

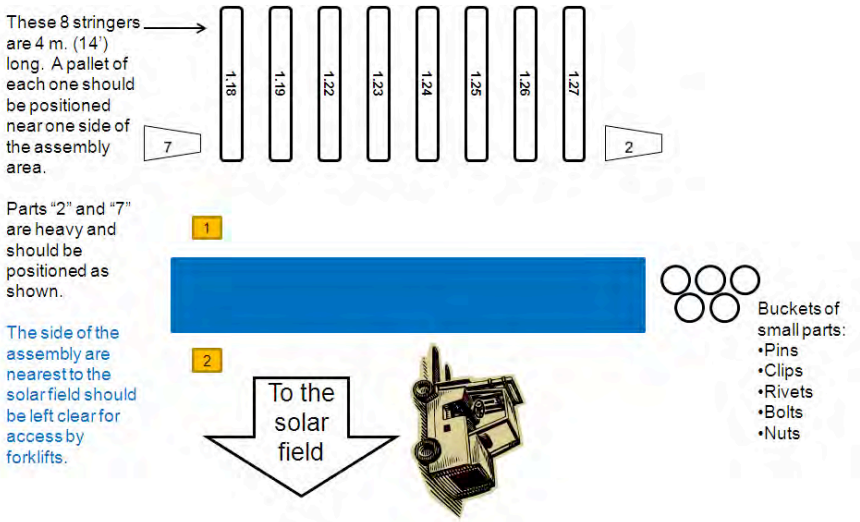
Figure 6: Proper Layout of Members and Joints Speeds Picking



One material handler can support several frame assembly crews if pallets of parts are laid out properly for efficient picking.

Illustration Credit: Skyline Solar

Figure 7: Overview of the Frame Assembly Area



Stringers and end plates are too large and heavy to be delivered by cart, so they need to be pre-positioned near the assembly station (blue rectangle). The small rectangles labeled "1" and "2" are the carts..

Illustration Credit: Skyline Solar

CHAPTER 2:
The Initial Field Build (First 7 kW)

The initial activity at the Durango site was the construction two demo arrays. The assembly work was done by Mechanical Engineering students from a nearby. They were supervised by a member of Skyline's Field Operations team.

Because these arrays were intended to be used only briefly in their initial location, they were installed on posts that were stabilized by above-grade concrete footings. With the exception of these footings, the system was the same as what was installed later in the 500 kW field.

2.1 Process Overview

Unlike the test builds described in the previous chapter, the initial Durango arrays were fully operational. Steps performed in Durango that were not performed in the Mountain View test builds included: attaching posts to the footings; attaching the motor; mounting the frame on posts; mounting the PV panels; attaching the mirrors; and completing all the wiring needed to make the system operational.

Figure 8 shows the components needed to build the two frames. The mirror crate is not visible.

Figure 8: Components of Two Frames

The frame components are shown shortly after being unloaded from the delivery truck.

Photo Credit: Skyline Solar

Frame assembly, up to the point where mirror stringers had been attached, took six workers 90 minutes (540 person-minutes). Figure 9 shows a frame slightly before the completion of that phase of assembly.

Figure 9: Frame Assembly

A large crew of eager students is completing construction of one of the frames. The top stringer, which holds the solar panels, has been installed and the mirror stringers are being removed from the wooden crate to the right.

Photo Credit: Skyline Solar

Contrast this with the 280 person-minutes of Test Build 2. The time did not include training time or breaks.

Frames were attached to a simple lifting strap and lifted by an excavator's boom as shown in Figure 10. Workers standing on the ground helped ensure that the frame was lowered to the right spot on top of the posts.

Figure 10: Lifting a Frame

The frame is being lifted into position on top of the posts.

Photo Credit: Skyline Solar

Once the frames were in place, the PV panels were installed on each side of the top of the frame. This was easy to do because the panels snapped onto the frame and each panel was connected to the adjacent ones using built-in cables with MC4 connectors. Panel installation took 40 person-minutes.

The next step was to install the mirrors. First, the frame was rotated 85 degrees in one direction and mirrors were bolted to the lower half of the frame. Each mirror was held in place with 4 threaded fasteners that screwed into pads that are attached to the glass mirror with very strong adhesive. Then the arrays were rotated 85 degrees in the other direction and the process was repeated. Mirrors were moved from their shipping crate to the frame by two workers wearing heavy gloves and gauntlets as shown in Figure 11.

Mirror mounting took 240 person-minutes, not counting the time to rotate the frame. Frame rotation time would not be significant in building a large solar field, so we did not count it in this part of the experiment either.

Figure 11: Moving a Mirror

Two workers removing a mirror from the crate at left.

Photo Credit: Skyline Solar

Once all the mirrors were installed, the wiring was completed so that the array would track the sun and feed power to the inverter. A completed array is shown in Figure 12.

Figure 12: Completed Array

This photo, taken near solar noon, shows a completed array. The concentrated sunlight is visible as a "flux line" on the solar panels.

Photo Credit: Skyline Solar

The completion of these two arrays was celebrated with a dedication ceremony attended by the Governor of Durango (Jorge Herrera Caldera) and the CEO of Skyline Solar (Thomas Rohrs) as shown in Figure 13.

Figure 13: Dedication Ceremony for the Demo Arrays

The Governor of Durango (with arm raised) attended the ceremony to dedicate the first two arrays.

Photo Credit: Skyline Solar

CHAPTER 3:
Applying Lessons Learned from the Factory Build to the Last 100 kW of the Field Build

After the Durango test build was successfully accomplished, the project developer (DelSol Systems) prepared the land for the 500 kW installation. The land was flat, so the required grading went quickly. Figure 14 shows the work in progress.

Figure 14: Clearing and Leveling the Land

Heavy equipment was used to level the land where the 500 kW solar field would be built.

Photo Credit: Skyline Solar

3.1 Differences between Initial and Final Field Installation Processes

As with any construction project, innovations and improvements were made continuously as the workforce learned by trial and error how to accomplish the necessary tasks more easily.

However, at the same time some of the challenges that arose could not easily be solved. The most vexing was related to rivets and rivet tools. As mentioned in Chapter 1, the Factory builds in Mountain View had been done with aluminum rivets to make removal easy in order to re-use frames and members for other test builds. In Durango, stainless steel rivets were used because the durability of steel is required to keep the frame rigid over 20+ years of service. The hand-held rivet tools that had worked so well on aluminum rivets were barely adequate for heavy

use on stainless steel. The gripping parts wore out quickly and, as they wore, became less effective. For example, it took 3 "pumps" of the tool to install an aluminum rivet but could take 6 with stainless steel when the gripping teeth were new and twice as many when they were worn.

We began using heavier duty tools in the final phase of the project and also bought enough replacement gripping teeth so that they could be replaced when they began to become ineffective. Nevertheless, riveting would have gone much faster in a factory setting where high-power pneumatic riveters could have been used.

In most other ways, the final 100 kW were built using the same methods as had been employed in the Mountain View factory build. However, by the end of the project the Mexican crew was much more experienced than the Skyline employees who did the test builds. Consequently, they were able to assemble a frame approximately 29% faster (200 person-minutes vs. 280). Their material handling was also much more efficient.

Figure 15 shows the completed 500 kW solar field.

Figure 15: The Completed Solar Field

The completed field covers more than one hectare (2.5 acres).

Photo Credit: Skyline Solar

CHAPTER 4:
Cost Benefit Analysis

Using the data from each of the builds, we have developed Table 3. It compares the time spent on each phase of the assembly of a Skyline X14 array under four scenarios:

1. The Factory Build in Mountain View, with extrapolations for the steps not performed
2. The 7 kW Test Build in Durango
3. The final 100 kW of the 500 kW Build in Durango
4. The projected reasonably achievable times for a 500 kW Build using factory-in-the-field off-site assembly at a location ¼ mile from the solar site.

This analysis excludes tasks that cannot be performed in the factory, including:

1. Preparation of the foundations
2. Installation of posts
3. Installation of inverters and transformers
4. AC and DC wiring except panel-to-panel wiring
5. Commissioning

All the times shown are measured in person-minutes per array. The array is rated at 3.52 kW DC.

Table 3: Comparison of Time Spent to Assemble a Skyline X14 Array under Four Scenarios

Scenario #	**1**	**2**	**3**	**4**
Scenario Description	2nd Factory Build in Mtn. View	7 kW Test Build in Durango	Final 100 kW of Durango Build	Utility-scale Factory-in-the-field (Projected)
Frame material handling	120 (1 emp x 120 m.)	60 (1 emp x 60 m.)	20 (1 emp x 20 m.)	15 (1 emp x 15 m.)
Frame assembly	280 (4 emp x 70 m.)	540 (6 emp x 90 m.)	200 (4 emp x 50 m.)	180 (4 emp x 45 m.)
Mount frame	NA	30 (3 emp x 10 m.)	30 (3 emp x 10 m.)	15 (3 emp x 5 m.)
Install panels	NA	40 (2 emp x 20 m.)	20 (2 emp x 10 m.)	20 (2 emp x 10 m.)
Install mirrors	NA	240 (3 emp x 80 m.)	140 (2 emp x 70 m.)	100 (2 emp x 50 m.)
Transport to installation site	NA	0	0	10 (1 emp x 10 m.)
TOTAL TIME in person-minutes	NA	910 m. (189.6% of an 8-hour shift)	410 m. (85.4% of an 8-hour shift)	340 m. (70.8% of an 8-hour shift)
kW per person per 8-hour shift	NA	1.9	4.1	5.0

We conclude that productivity in Durango more than doubled between the initial 7 kW (Scenario 2) and final 500 kW (Scenario 3).

Furthermore, an additional 22% improvement would be possible if mirrors and panels could both be installed in a factory-in-the-field setting. (Scenario 4)

4.1 Factory-in-the-field in the Concentrating Solar Thermal Industry

The factory-in-the-field concept is well established in the Solar Thermal industry, which is comprised almost exclusively of extremely large projects (50 MW or more). Figure 16 shows the state of the art as of three years ago for such facilities.

Figure 16: Factory-in-the-field Example from the Solar Thermal Industry

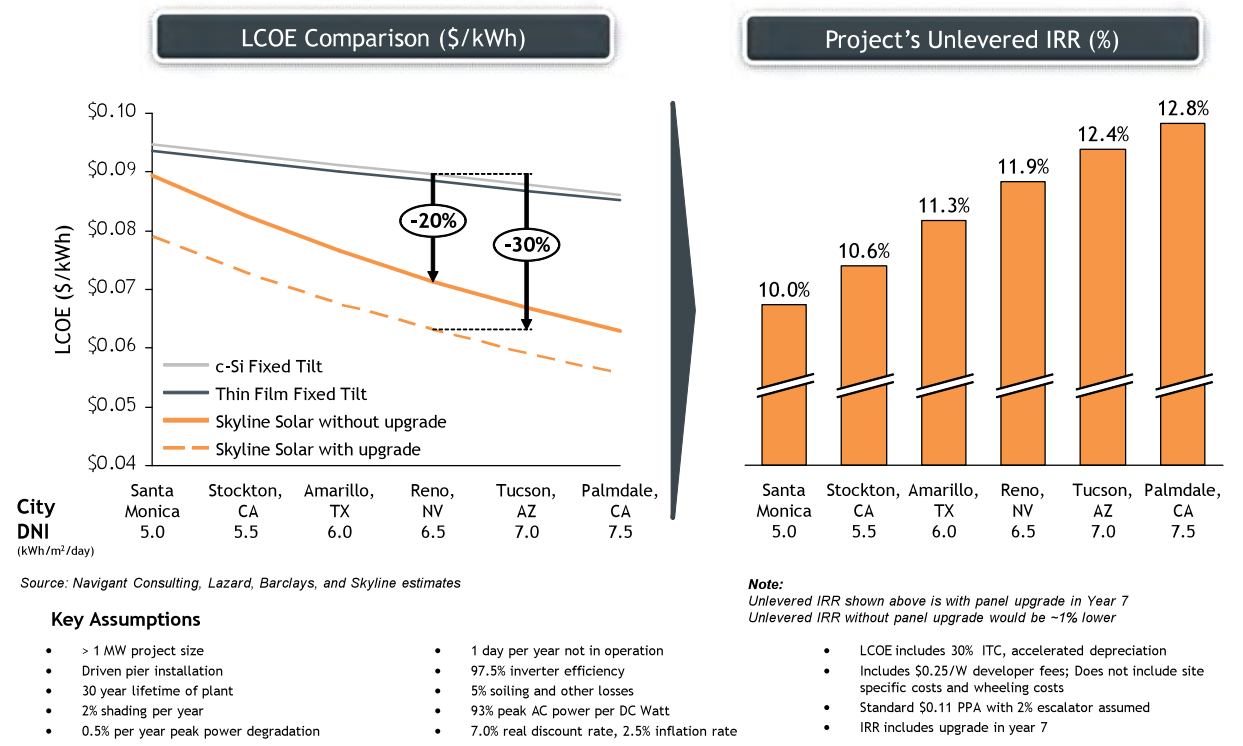
The factory-in-the-field concept is well established in the solar thermal industry. The photos show the assembly of frames and mirrors similar to Skyline's. The project under construction is a 61 MW solar thermal plant near Kuraymat, Egypt, about 100 miles south of Cairo. The photos were taken in mid-2009.

Photo Credit: Flagsol GmbH

4.2 Skyline's LCOE and IRR

Skyline's produces electricity at lower cost than fixed tilt thin film or Silicon panels, and the advantage increases in sunnier locations as shown in Figure 17.

Figure 17: LCOE and IRR Vary with DNI



The low cost of the X14 System is made possible by its low materials and installation costs. This, coupled with the fact that it tracks the sun over a 170 degree range of motion, results in very low LCOE and high IRR..

Illustration Credit: Skyline Solar

CHAPTER 5:
Observations and Conclusions

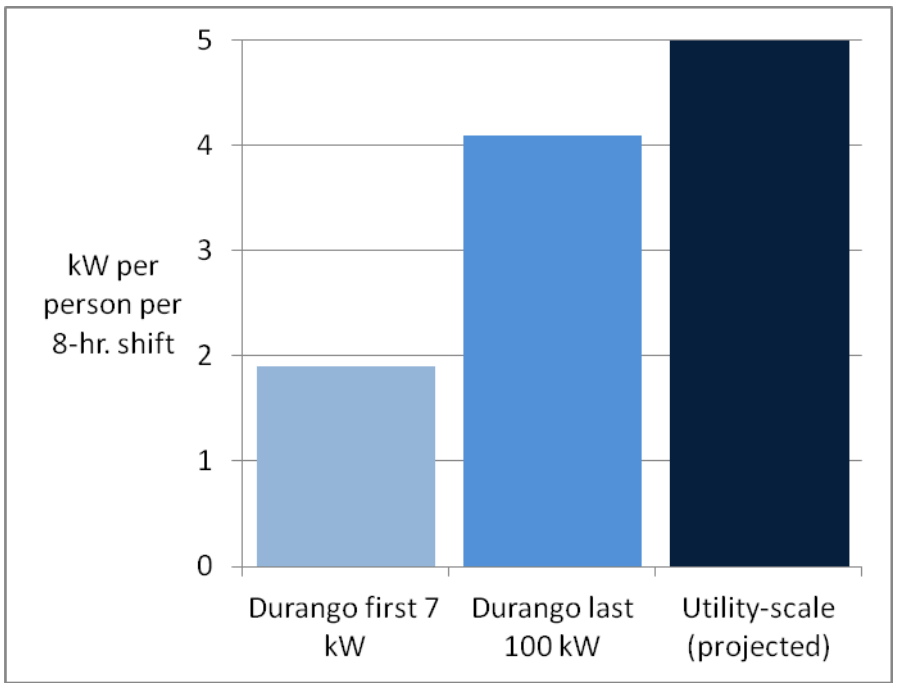
The most significant accomplishment of this project was the opportunity Skyline had to observe and record the learning curve of the assembly team in Mexico. This was the first large installation of an X14 system. It was also the first solar project managed by DelSol.

One challenge in this study was distinguishing between "sprint pace" and "marathon pace." The Skyline team who performed the test builds in Mountain View, most of whom were engineers in their late twenties, said that it would have been difficult for them to have sustained the pace of the test builds for a full work day. The data we have from Mountain View, therefore, shows the "sprint pace" of a team with limited assembly experience.

The installers in Mexico were not challenged to sprint; they performed at the "marathon pace" that is far more typical of what we would expect for all large projects. By the end of the installation, they had also accumulated vastly more practical installation experience than the Skyline engineers.

In conclusion, the results of this study, summarized in Figure 18, confirm the hypothesis that factory-in-the-field methods will significantly reduce the labor hours required to install Skyline Solar systems. A pace of 4.1 kW per person per shift was observed in Durango, and we believe a pace of 5 kW per person per shift is entirely achievable with full implementation of the factory-in-the-field model.

Figure 18: Productivity Comparison



CHAPTER 6:
Implications for Installations of Non-tracking PV Systems

Recall that there are four principle ways in which the factory-in-the-field approach lowers costs and improves labor productivity:

1. Better supervision increases the percentage of time workers spend performing productive tasks.
2. Working inside a building eliminates shut-downs caused by high winds, inclement weather and darkness.
3. A factory setting makes it possible to install simple, inexpensive furniture and fixtures to reduce wasted time.
4. A factory setting makes it possible to dramatically improve the ergonomics of the assembly process, resulting in less fatigue and higher throughput.

It is possible that these benefits can also apply to non-tracking PV systems.

The key determinant of whether they will, in fact, apply to such systems has to do with the size, shape and transportability of the subassembly. Factory assembly should offer benefits to non-tracking systems if all of the conditions below are satisfied.

1. The subassembly has dimensions that are suitable for transportation to the site. If public roads are used, these are reasonable maximum dimensions: width: 10 feet; length 50 feet; height 10 feet. If transportation is over private roads or open ground higher maximums may be possible, especially for width.
2. The subassembly must be rigid enough that transporting it will not cause bending or other damage to frame members or the panels themselves.
3. It must be possible to safely and easily attach the subassembly to the posts. Not all fixed-tilt mounting systems are compatible with this requirement.

We look forward to hearing that installers of non-tracking PV system have gathered and shared data on the productivity improvements offered by the factory-in-the-field approach.

CHAPTER 7:
Recommendations to the Energy Commission

7.1 Regarding Further RD&D Projects

We very much appreciate having been able to participate in the RD&D program. We encourage the continuation of the program, particularly on the topics of:

1. The value of non-dispatchable, but high likelihood of availability solar from large desert solar power plants.
2. The development of truck-mounted, low water-consumption solar field cleaning systems that are compatible with both flat-plate PV and linear mirror trough PV and CSP systems.
3. Energy storage for solar projects that offers approximately 15 minutes of output so that gas-fired power plants can spin up when solar fields go offline due to clouds.
4. Energy storage that can time-shift solar PV output by 3-4 hours to more precisely match peak summer demand.

GLOSSARY/ACRONYMS:

AC	Alternating Current
Array	The basic operational unit of Skyline's X14 System, consisting of a frame, 14 mirrors, 20 panels, a motor assembly and two posts
CPV	Concentrating Photovoltaic
Clip	A small metal retaining clip that prevents pins from falling out of place
DC	Direct Current
DelSol	DelSol Systems (Mexican company responsible for the Durango project)
Factory-in-the-field	A temporary, factory-like setting where all or part of the arrays are built. Depending on the size of the project, the factory may be set up in an existing warehouse or similar building, a temporary building constructed near the solar field, or even a heavy-duty tent. The factory would have lighting, AC power and furniture and fixtures necessary to efficiently produce frames or arrays. The building size for megawatt scale projects would be 2,000 to 10,000 square feet.
Frame	A lightweight rigid framework of a Skyline array. These are built up from members, joints, stringers, pins and clips
Joint	An extruded aluminum plate with holes; used (in conjunction with pins and clips) to connect Skyline frame members
MCPV	Medium Concentration Photovoltaic (concentration ratios of 5 to 50 times)
Member	An aluminum tube, ranging in length from 2' to 6', that is the primary component of a Skyline frame
Panel	A solar panel
Pin	An unthreaded fastener used to connect members and joints in a Skyline frame
PV	Photovoltaic
Space frame	See "Frame"
Stringer	A long, hollow member with a trapezoidal cross-section; it is thepart of the space frame to which the mirrors are riveted.
X14	The trade name of Skyline Solar's MCPV system; it concentrates light by a factor of 14