AMORPHOUS SILICON PV PANELS: ARE THEY A GOOD VALUE FOR THE MONEY?

Arne Jacobson, Richard D. Duke, and Daniel M. Kammen

INTRODUCTION: A MARKET ON THE MOVE

It is estimated that over 100,000 rural Kenyan families use solar energy to generate electricity in their homes. The majority of these families have chosen to buy a small (12 or 14 Watt) amorphous silicon photovoltaic (PV) panel to generate this power. In the late 1990's sales of these amorphous silicon (a-Si) PV panels ranged from 12,000 to 20,000 units per year, depending on the state of the economy, and average sales growth of a-Si PV in the 1990's approached 30% per year. Equally exciting and important, the market for solar systems in Uganda is now taking off as it did in Kenya, and if properly supported, this pattern could spread to other nations in eastern Africa and, indeed, throughout sub-Saharan Africa.

A typical Kenyan solar system buyer purchases an unsubsidized 12 Wp a-Si PV panel, attaches it to the roof and directly wires it to a car battery or a locally manufactured "solar" battery. (The "solar" batteries made in Kenya are similar to car batteries, but have been modified to have thicker lead plates. This makes them somewhat more robust than car batteries for deep cycling applications.) Common uses of the electricity include lighting, televisions, and radios. A 12 Wp solar system will provide power for a fluorescent lamp or a small black and white television for a few hours per day. The level of service provided by a small solar system is substantially lower than by a connection to the national electrical grid. However, the overwhelming majority of rural Kenyans have little hope of ever receiving grid service. At present, fewer than 2% of rural Kenyans are served by the national grid. Thus, solar panels provide a limited amount of electricity to rural Kenyans who have few other options.

Until very recently, three European based manufacturers accounted for nearly all of the sales of a-Si PV modules in Kenya. The French company, Free Energy Europe (FEE) manufactures 12 Watt panels, while Intersolar in the UK, manufactures 14 Watt rated panels. Koncar, a Croatia-based firm, also manufactures 12Watt panels. The most important reason for the commercial success of these small panels has been their low cost compared to the other types of panels available in the Kenyan PV market. FEE's 12 Watt panel sells in shops for 4,000 KSh ($1 = 78 KSh), which corresponds to 333 KSh per rated Watt, while Intersolar's 14 Watt panel often sells for about 5,000 KSh, or 357 KSh per rated Watt. For comparison, small crystalline PV modules generally sell for 650 KSh per rated Watt.

However, despite their commercial success, there has been much concern in Kenya and around the world about the quality of these small a-Si PV panels. To address this concern, our research group conducted tests in 1999 to assess the performance of PV panels available in Kenya. The collaborative research team included participants from Energy Alternatives Africa (EAA) of Nairobi (Kenya), and the University of California, Berkeley (USA) and Princeton University (USA).

From March to July of 1999 we visited 145 families that used solar PV as a source of household electricity. PV panels tested were owned by families in rural areas near Nanyuki, Nyeri, Chuka, Bungoma, Webuye, and Kisumu. In addition, our research team purchased new a-Si PV panels in Nairobi, which were tested for performance over time at EAA's office in Nairobi as well as at the University of California, Berkeley. A total of 130 working a-Si PV panels were tested. In addition, we found 23 panels in the field that had cracked or failed. Finally, 17 crystalline PV panels in the field in Kenya were examined in order to compare their performance to that of the a-Si panels.

Results from our tests indicate that a-Si panels made by Free Energy Europe and Koncar perform well when compared to crystalline PV panels, but the Intersolar panels performed well below acceptable standards. However, Intersolar has taken a number of steps to improve their panels in the last year. Preliminary tests performed on their new modules recently indicate an improvement over the ones that were tested in 1999. We will continue to test these new Intersolar modules, and will

publish the results in this journal as they become available.

COMPARING a-Si PV AND CRYSTALLINE PV PANELS

There are a number of different types of photovoltaic panels. The two main types available in Kenya are (1) crystalline silicon PV and (2) amorphous silicon PV. The crystalline PV panels can be further divided into monocrystalline and polycrystalline PV types. Amorphous silicon panels are divided into multi-junction and single junction panels. While all of these technologies are used to generate electricity from solar energy, there are some differences that exist in their manufacturing process, and these differences affect their cost as well as the performance of the panels. Our research focused entirely on the performance of the single junction a-Si modules that are available in Kenya, but it is useful to understand how these panels differ from the other PV panels.

Crystalline PV panels were first invented in the 1950's, and the technology now has a well-deserved reputation for high quality performance. Most brands of crystalline PV modules are rugged enough to last 20 years or more. By comparison, amorphous silicon PV panels are newcomers. They were invented in the mid-1970's, and made commercially available by the Chronar Corporation (USA) in the mid-1980's. The a-Si technology has a mixed reputation for performance, although some brands have clearly demonstrated high quality standards. In particular, several brands of multi-junction a-Si panels are regarded as quality products. Examples include the triple junction a-Si modules made by Unisolar, and the double junction "Millennium" a-Si PV modules made by BP-Solarex. The research results present later in this article show that some manufacturers of single junction a-Si modules also make high quality products.

One of the main technical differences between crystalline and amorphous PV technologies is in their efficiency at converting solar energy into electricity. Crystalline PV panels now have efficiencies that range from 8 to 15%, while single junction a-Si modules often have efficiencies that range from 2 to 4%. For most rural consumers, these differences in efficiency are *not* very important. The efficiency of a panel indicates how much electricity can be generated from a given surface area of the panel. This means that an a-Si 12 Watt panel will be larger in size than a crystalline panel with the same 12 Watt rating. Most households in rural Kenya have plenty of space on their roofs to mount PV panels, so the lower efficiency of the a-Si panels is not a significant drawback.

A second difference between a-Si and crystalline PV is in their performance during the first few months after they are purchased. For a given amount of sunlight, the performance of crystalline PV panels remains fairly constant from the time of purchase. In contrast, most a-Si panels lose about 25% of their output during the first few months of use, after which, the performance stabilizes at a constant level. The final "stabilized" performance is supposed to equal the manufacturer's "rated" performance. Thus, a 12 Watt panel should start out at about 15 Watts when new and then drop to 12 Watts over the first few months of use. This initial loss of performance should not be a problem for Kenyan PV system owners, as long as the final "stabilized" performance is equal to the rated performance.

The final important difference between a-Si and crystalline PV panels in Kenya is in their price differences. As noted earlier, a-Si PV panels are more popular in Kenya due to their lower prices compared with crystalline panels.

AMORPHOUS SILICON PV PANELS AVAILABLE IN KENYA

The 12 Watt PV panels made by "Free Energy Europe" (FEE) are known to many in Kenya under the brand name "Neste Advanced Power Systems" (NAPS). FEE acquired the PV manufacturing site of NAPS in 1998. These panels have a thin black plastic frame, with a part number of model 11601. Prior to 1996, NAPS manufactured an 11Watt panel that was widely available in Kenya. This older panel (model number A13R) had a silver aluminum frame, and is similar to in appearance to the Koncar 12 Watt modules (the NAPS panel had a label with the name "Neste", which is the best way to tell this one from the Koncar). In this article, NAPS and FEE will refer to the 11Watt module and the 12 Watt module respectively.

The "Intersolar" 14 Watt panels are known in Kenya under the brand name "Phoenix Gold". These panels (model number B108D) are characterized by their gold frames and black plastic frame corners. Prior to 1998, Intersolar made 11 Watt modules called the "Phoenix" (model number B107W) that are distinguished by their green plastic frame corners.

The "Koncar" 12 Watt panels have silver aluminum frames (see above for the similarity to the old NAPS 11 Watt panels). Many Koncar PV panels sold in Kenya do not have a label from the manufacturer, but often have a "Sollatek" sticker on the back (Sollatek is the name of the Kenya-based importer of Koncar modules).

TESTING PV MODULES IN KENYA

Our research team tested PV modules using a carefully designed and accurate outdoor test method. The result of the test is a "current-voltage" curve (also known as an "I-V" curve) for each panel. The I-V curve is used to estimate the maximum power output for each panel. This maximum power estimated can then be compared to the manufacturer's rated power output in order to assess the performance of the panel.

In confirming the accuracy of our test methods, six panels purchased in Kenya were sent to the National Renewable Energy Laboratory (NREL, USA) for independent analysis. NREL tested the modules using two different methods. A first test was done using a solar simulator similar to the type commonly used by PV manufacturers in rating their panels. A second test used simulator which gave results more accurate than methods used by PV manufacturers. The results of the tests done at NREL indicated that our test results are accurate to within ±5% of the actual performance of the PV panels. Thus we are confident that our results are an accurate representation of the true performance of the modules that we tested.

PERFORMANCE LEVELS OF THE DIFFERENT a-Si PANEL BRANDS

We found large differences in the average performance of different brands of a-Si PV panels sold in Kenya. See Table 1 and Figure 1. Of the brands tested, a-Si PV panels made by NAPS (now FEE) performed best, panels made by Koncar were a close second in performance, and panels made by Intersolar were a distant third.

The average power output from the 12 Watt FEE panel was 10.6 Watts, or 89% of its rated output. The average output of the older 11 Watt NAPS panels was 9.7 Watts, or 88% of rated output. The 12 Watt Koncar panels produced, on average, 10.0 Watts (83% of rated). The average output of the older 11 Watt "Phoenix" panel made by Intersolar was just 6.8 Watts (61% of rated), and the average output of the 14 Watt "Phoenix Gold" panel was 7.7 Watts (55% of rated). Note that these average performance levels do not include any panels which were cracked or which had failed completely.

It is somewhat troubling that, on average, none of the panel brands tested performed at their rated output levels. Nonetheless, the panels made by NAPS / FEE compared favorably with the 17 crystalline panels tested in the field in Kenya (see Figure 1). In fact, tests done by other researchers in the USA in a number of studies published since the 1980's indicate that many brands of crystalline and amorphous PV panels often perform 5-15% below their rated power output. These results suggest that the NAPS and Koncar brands of a-Si modules sold in Kenya perform just as well as many brands of crystalline PV modules in meeting their rated power levels.

FAILURE RATES FOR a-Si PANELS

In addition to their low power output, the Intersolar a-Si modules appear to suffer from high levels of failure (we defined a failed panel as one that was producing less than 10% of its rated power). About 46% of the 11 Watt "Phoenix" panels and 40% of the 14 Watt "Phoenix Gold" panels encountered in the field had failed. In most cases the failure of these modules appeared to be caused by water leakage into the module. We also found cracked glass plates in several cases. In contrast, only 6% of the Koncar and none of the 11 Watt NAPS and 12 Watt FEE panels that we found had failed. The reader should note that these results are likely to underestimate the failure rate for a-Si PV panels in Kenya because many families probably return failed panels on warranty or throw them away. Our results are based on only those failed panels that families had kept around.

LONG TERM PERFORMANCE OF a-Si PANELS

Although 85% of the a-Si PV panels that we found in the field were less than 5 years old, we did find some that were as much as 10 years old. We had sufficient data to make an analysis of the long term performance of the NAPS 11 Watt panels and the Koncar 12 Watt panels. This analysis suggested that the power output for these panels may drop by about 1% per year. It is possible, however, that small improvements in the manufacturing of these PV panels can account for the difference in performance between the older and newer panels.

PVUSA, a research laboratory in the USA, funded by the US government and utility companies, tested PV panels over an eight-year period. Their results indicated that a drop in performance of 1-5% per year may be common for both amorphous and crystalline silicon PV technologies. Results of the PVUSA study, combined with our findings suggest that the power output of the NAPS and Koncar a-Si PV panels are comparable to the long term performance of crystalline PV panels.

WARRANTIES FOR a-Si PV PANELS IN KENYA

All three of the manufacturers of a-Si PV panels sold in Kenya offer, and honor, warranties on their products. Free Energy Europe sells panels in Kenya with a 10-year warranty, while Koncar and Intersolar panels have a 5-year warranty. The terms on these warranties all guarantee that the panels will perform to within 90% of the rated power output for the period of the warranty. Importing agents for all of these panels have historically been cooperative about replacing modules that are returned on warranty.

However, there are some concerns about the practical value of these warranties to protect customers in rural Kenya. The main concern is that most inhabitants of rural Kenya, including local salesmen of PV panels, are unable to accurately measure the power output of PV panels. This means that rural families generally cannot determine if the performance of their panel is above or below 90% of rated power. The first sign of panel failure is battery failure. However this may be misleading as but batteries fail regularly even when used with a panel that is working properly. It is therefore often difficult for families to know whether they should try to return their panel on warranty or not. As a result, many PV users return panels only when they have failed completely. Thus, many Kenyan families currently own a-Si PV panels that are performing below warranty specifications, but few return the panel for a new one.

RECENT STEPS TO IMPROVE THE PERFORMANCE OF a-Si PANELS

Over the past decade, all three a-Si companies in our study have made changes in their manufacturing processes with the goal of improving the performance of their products. The strong performance of the NAPS / FEE PV panels suggests that NAPS and now FEE achieved great success in improving their products.

Although the poor showing of the Intersolar panels that we tested in 1999 is troubling, Intersolar has made some investments in improving the quality of their products over the last year. In September of 1999 (about two months after our field tests) Intersolar introduced a new version of the "Phoenix Gold" 14 Watt PV panel, and this panel is now available in Kenya. These new panels look the same as the older version of the "Phoenix Gold", except that their frame is a brighter color of gold. Our research group is currently testing eight of these panels sent to us by Intersolar. Preliminary results indicate slight improvements in the power output. However, even with these improvements performance of Intersolar panels fall short of the performance of the FEE and Koncar panels. On a promising note, Intersolar has improved the sealing of its panels. Improved seals will help keep water out and reduce panel failures.

a-Si PV PANELS CAN PROVIDE RELIABLE, LOW COST PV TO RURAL KENYAN FAMILIES

The better performing a-Si PV panels sold in Kenya are the lowest cost PV panels available in Kenya in terms of the price per measured peak Watt. See Table 2. Among the panels examined by our research group, panels made by Free Energy Europe are currently the least expensive panel available in Kenya, with a price of 377 KSh (about $4.80) per measured peak Watt.

The high performance of the Free Energy Europe and Koncar panels show that single junction amorphous silicon PV panels can provide a high quality but low cost alternative to crystalline PV panels. However, the differences in performance of the various brands of a-Si PV panels suggests that Kenyan consumers must be careful in choosing PV panel brands.

Figure 1: Average Performance for PV Panels Tested in 1999

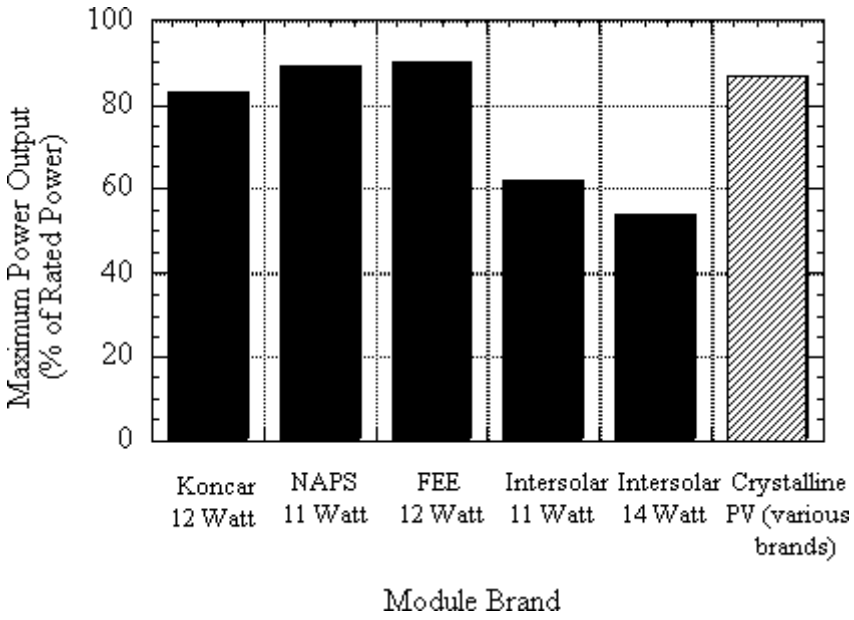

Table 1: Performance Summary for a-Si PV Panels Tested in Kenya During 1999

Panel Type	Rated Max. Power (Watts)	Average Measured Max. Power (Watts)	Percentage of Rated Output	Average Age of Modules (years)	# Modules Tested
Koncar	12	10.0	83%	2.8	31
NAPS	11	9.7	88%	3.1	31
NAPS / FEE	12	10.6	89%	0.9	32
Intersolar "Phoenix"	11	6.8	61%	2.4	5
Intersolar "Phoenix Gold"	14	7.7	55%	1.5	12
APS	25	22.5	90%	5.0	1
Chronar	10	7.2	72%	5.9	4

Table 2: Typical Retail Prices for Some Small PV Panels in Kenya
(note that the price per measured Watt is based on performance results from 1999)

Module Brand	Module Type	Rated Power (Watts)	KSh per rated Watt	KSh per measured Watt
Free Energy Europe	a-Si	12	333	377
Koncar	a-Si	12	417	500
Intersolar "Phoenix Gold"	a-Si	14	357	649
Typical Crystalline PV	x-Si	20	600	686

CONTACTS:

Arne Jacobson and Daniel M. Kammen
Energy and Resources Group (ERG)
310 Barrows Hall, University of California, Berkeley, CA 94720-3050, USA.
E-mail: arne@socrates.berkeley.edu and dkammen@socrates.berkeley.edu

Richard D. Duke
Science, Technology, and Environmental Policy (STEP) Program
Princeton University, 5 Ivy Lane, Princeton, NJ 08544, USA
E-mail: duke@princeton.edu

Note: The research was generously funded by the Dexter Trust of the city of Chicago, Illinois, USA.

Readers who would like more details about our test methods and results, or other information about our research, should contact us at the above addresses to obtain copies of additional reports and scientific papers that we have written.

Go back to the updated ATF site or to the main ATF home page at MIT.