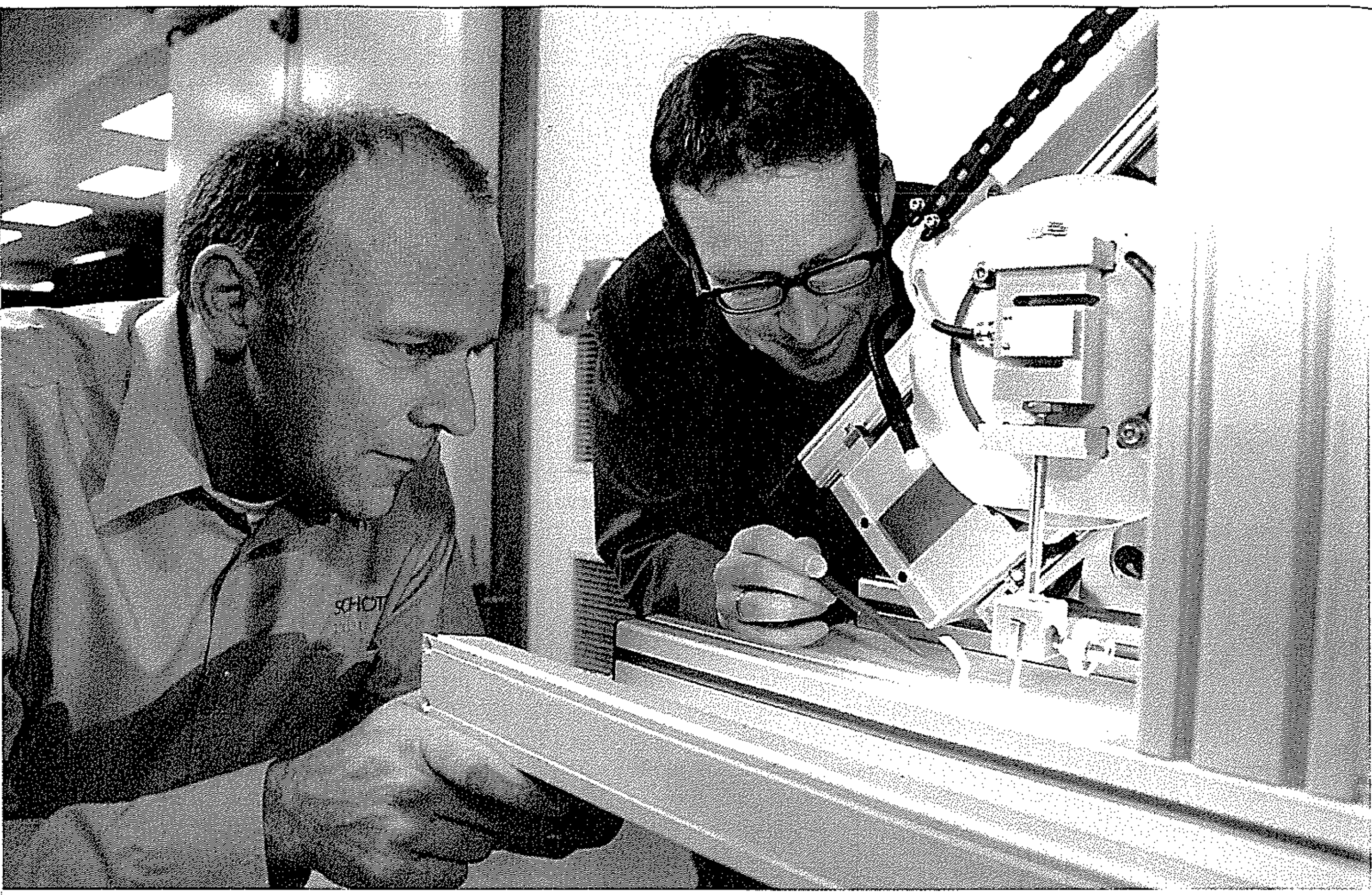


Photos: Solarpraxis AG/Boris Loeffert

A measuring device's quality is not always easily visible. Experts only certify a module's long service life if the back foil holds up.

# Unseen quality

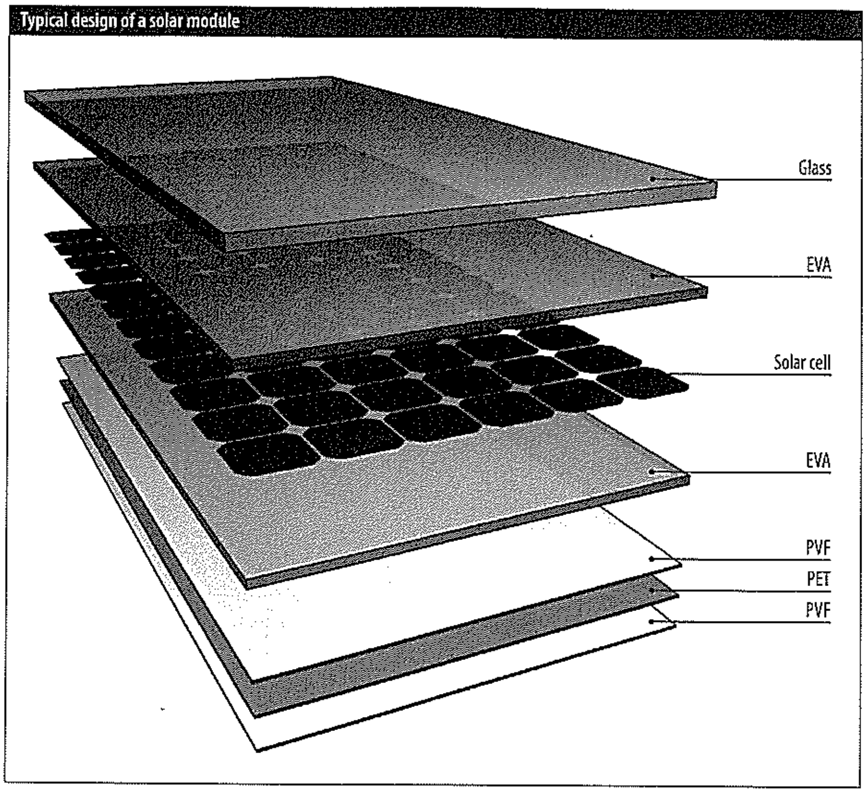
**Module assembly:** Generally, module manufacturers offer a 25-year performance guarantee with certificates and quality labels. But certificates and quality labels do not tell us much about the long-term stability of modules. In reality, tests under harsh conditions discover drastic differences in endurance. The modules are to be tested with the greatest care.

"Look at this," says Uwe Fliedner, "I have no problem reaching through here." The director of module development at Schott Solar picks up the module and has no trouble pushing his hand between the individual layers of the composite foil. He then grabs the edge of the white cover foil and gives it a slight tug. The commonly used TPT (Tedlar/Polyester/Tedlar) composite cover foil can be easily pulled off without tearing. It is clear that the three foils supposed to form a single compound are not properly sticking together. Another module has the same problem to an even greater extent. In this case the back of the module practically falls on Flieder by itself. "This is a typical case - less adhesion than with post-its," as the engineer dryly comments.

The prospect of having such modules on roofs is a nightmare for manufacturers and their customers. After all, if the foils delaminate, the initially tight composite of embedded material and back foils (or individual foil layers) falls apart, allowing water to enter the modules. Yet this is only the start of the problem. "Once the water freezes, it's all over," the development director predicts. "The damage is tremendous."

What Fliedner is demonstrating and describing in words is the results of a systematic series launched by the module manufacturer two to three years ago. The tests show how complicated module construction is, providing one example of the obstacles manufacturers face. Customers cannot tell at a glance whether a manufacturer has solved these problems. The differences between good and poor quality reveal themselves only over years.

The goal of the test series was to find optimal alternatives to existing foil systems, ones which were not sufficiently available at the time of their production. One obvious option was to use a foil composite with similar technical data and product descriptions, a method that proved unrealistic. "The back foil is like the module's skin, and, like the glass on top, protects the module from back damage," Fliedner explains. "We want to make sure that the modules stay in good shape for at least 25 years." Otherwise the modules might turn into distributors of electric shocks.




Back foils protect cells on the back if there is no second pane of glass. The cells are encapsulated on both sides with EVA (ethylene vinyl acetate), which bonds with adjacent layers during lamination. The back foils consist of multiple layers that protect the module, in this case PVF (polyvinyl fluoride, known under the trade name Tedlar) and PET (polyethylene terephthalate). They are already on sale as composites.

## DIY testing for greater safety

Generally technical data or use by other manufacturers do not adequately indicate foil security. Apart from size, the modules may all look quite similar to the layperson. Differences, however, remain. Each manufacturer uses a different combination of components, all of which can vary. From the glass to the cells, the embedding material (such as EVA), the soldering material, and the multi-layer back foil: all of these factors can vary. In such manufacturer-specific systems, synthetic components like EVA and back foils clearly have different reactions to the specific compositions. Then there are the different adhesives used to make the multiple layers (usually three) into the rear composite foil.

If manufacturers want to give their customers the greatest possible security, they have to perform their own tests. Established module manufacturers know this. "The ones we know all conduct their own tests before they choose a specific component," says Karl-Anders Weiss of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg, Germany. Yet they have to do more than test the properties and suitability of components. Module tests including the specific component, such as a particular back foil, are more important. Weiss thinks such tests indispensable. "Even if manufacturers only use certified components in their modules, we still do not know that the module itself will work properly."

Despite the large amount of work involved, Schott Solar decided at the outset that the back foils shortlisted would have to undergo a systematic inspection before a final decision is taken. Staff from module development asked to have sample goods from 21 suppliers for this purpose. Fliedner says there is a good reason why only foil producers from Europe, North America, and Japan were invited: "In our experience, it takes three to five years before manufacturers really know what is important in developing new foil alternatives." East Asian suppliers had less experience and were therefore not asked to provide samples, although that is sure to change.

A total of 65 foil varieties were submitted to the lab. The list was shortened to 52 products for testing. For each of the products a reference sample and five test samples for a component test were created. First the testers applied a common EVA embedding material with each of the foil types on a 30 by 30 centimeter pane of glass. They then tested the laminate's adhesive properties on the reference sample by trying to pull it off. It was left otherwise unchanged so that a visual comparison with the samples could later be made.

The test samples then underwent the initial climate chamber tests. The aim was to separate the wheat from the chaff. The test included 2,000 hours at 85 degrees Celsius and 85 percent humidity (modified damp-heat test), 400 temperature changes from -40 degrees to +90 degrees (modified thermocycle test), and a test combination developed in-house. The latter was basically the humidity freeze test required by IEC; crystalline modules spend ten days at 85 percent humidity and temperatures ranging from -40 degrees to +85 degrees. Scott then upped the ante; the test candidates had to undergo four days of damp heat and three days of thermocycles for 20 weeks.

At regular intervals, the testers took a look at the test samples to see whether and when the foils changed colors, shrank, formed bubbles or tore. They also checked how long the laminate's adhesive properties measured on the reference sample remained. "For instance we took the test samples out of the climate chamber after 500 hours of damp-heat testing to see how much force it would take to pull off the foil." After 1,000, 1,500, and 2,000 hours, test samples once again had to prove their strength. In this way testers could tell when the adhesion of the overall composite and the adhesion between the EVA and the back foil truly began to give way.

All of the materials able to be separated into their individual parts after the three climate chamber tests or that were tearing or becoming brittle were ruled out of the main test. Materials that showed weaknesses had been taken out at each stage. As Fliedner explains, "Delamina-

Graph: Solarpraxis AG/ Harald Schütt

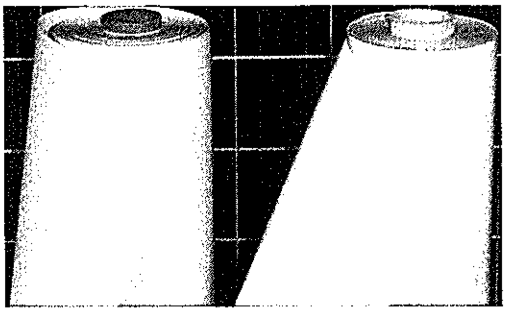
tion, tears, and brittleness are definite exclusion criteria for us, especially when such problems occur halfway through the initial test. This is a clear signal for us that the module's safety is questionable." For instance, in case of tears, contacts can be exposed. Under heavy morning dew or rain, the whole array would then be under current.

Of the 52 foil samples, 23 passed the initial tests in relatively good shape. They were then used on a production line under production conditions to manufacture ten 80 by 200 centimeter modules. Subsequent to this, the 230 test modules in question underwent the test program for IEC certification, a specific series of tests as to electrical, mechanical, environmental, and aging.

The firm then changed the last two of these tests stages considerably. Instead of 1,000 hours of damp-heat testing and 200 temperature cycles as required by IEC 61215, the damp-heat test lasted 2,000 hours, and there were 400 temperature cycles followed by a "combined test." Plus all of this had to cause no damage. Samples from the company's own module lines also all have to regularly undergo such testing.

### IEC standard tests too lax

Understandably enough certain manufacturers wonder whether such harsh testing is really needed. After all, the IEC standards used to certify modules in accredited test labs are far more moderate. Yet some of the certifiers themselves support stricter tests. They have repeatedly found that almost all foil combinations easily pass the IEC's environmental and aging tests. Under harsher testing, however, the result is very different. The certifiers therefore wonder whether the foils may not have been optimized simply to pass the IEC tests. If so the long-term stability needed for the modules would no longer have been the central concern. Fliedner also has a crucial rebuttal for critics: "Over the years, we have seen how much moisture, temperature, and temperature changes affect the long-term stability of modules. The 25-year performance guarantees of IEC specifications do not sufficiently take account of what we need to be safe."



Most back foils look alike. Yet in fact their performance varies greatly.

The success of photovoltaics is one of the main reasons why manufacturers are increasingly focusing on long-term stability. "The market is increasingly becoming an investor market. Investors want security," says Weiss. In addition, the insurance sector is also looking into solar arrays due to the growing demand for them. After all the probability of damage claims is rapidly on the increase. This means additional pressure on module manufacturers.

The IEC standards cannot help cushion that pressure because a guarantee of long-term stability is not their pur-

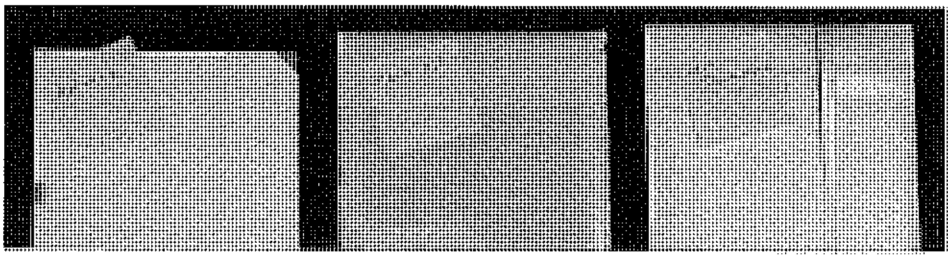
| | | INITIAL TEST (Percent of [illegible] initial test samples) | MAIN TEST (Percent of [illegible] modules) |
|---|---|---|---|
| ASSESSMENT CRITERIA | Relevance | 52 foil systems in environmental and aging tests | 20 foil systems in stricter IEC certification test |
| OUTPUT DEGRADATION | Safety issue | [illegible] | |
| TEARS | Ground for failure, Safety issue | 20 | 30 |
| BRITTLENESS | Ground for failure, Safety issue | [illegible] | [illegible] |
| DELAMINATION OF FOIL SYSTEM | Ground for failure, Safety issue | 20 | 40 |
| DELAMINATION OF EVA/BACK FOIL | Ground for failure, Safety issue | 15 | 20 |
| INSUFFICIENT ADHESION | Crucial, Case-by-case assessment | 50 | 30 |
| BUBBLES IN MODULE | Crucial, Case-by-case assessment | 10 | 20 |
| BUBBLES IN BACK FOIL | Crucial, Case-by-case assessment | 10 | 50 |
| OVERALL FOIL COMPOSITE SHRINKS | Crucial, Case-by-case assessment | 10 | 50 |
| INDIVIDUAL LAYERS OF FOIL COMPOSITE SHRINK | Crucial, Case-by-case assessment | 8 | 50 |
| DISCOLORATION | Crucial, Case-by-case assessment | [illegible] | [illegible] |
| MATERIAL INHOMOGENEITY | Crucial, Case-by-case assessment | 10 | 20 |
| HAIL RESISTANCE | Safety issue | [illegible] | 20 |

Overview of test results: Fewer than half of the foil systems passed the initial tests, and three passed the main test.

pose. "Standards merely ensure a certain level of quality as defined by the standards committee," Weiss explains. "Fulfilling them is necessary but insufficient. Everyone knows that." While the standards are constantly being revised to move them closer to practice, Weiss says there is nonetheless little chance that they will ever be able to clearly test and certify stability for 20 or 25 years. "A standard always specifies a procedure that may apply for a wide range of module types." Uncertainties remain because each type reacts differently to the same standard procedure. And module manufacturers have to deal with these uncertainties. Stricter test routines beyond that prescribed by the standard would at least reduce the level of uncertainty. However, Weiss says that climate and aging tests are mainly useful for comparative tests. "There are products you know to be stable. If a direct comparison is made based on stricter specifications, you can at least tell which one is better. You see which product is more stable." Yet you still do not see how long it would hold up under actual use.

## Success equals poor results

The testers at Schott agree. Their stricter test conditions tell them which way to go if they want to improve the quality of their modules, both now and in future. For instance, their module tests discovered a range of weaknesses in the back foils. The discoloration on the cover foil, originally white, is the element most likely to be considered a cosmetic drawback. Even if pigment distribution became inhomogeneous on the cover layer during the tests, the module's score only lowered slightly.



The first obstacle for the foils. In the initial test, they are inspected on 30 by 30 centimeter glass panes. The reference is on the left, the result after UV exposure in the middle, and after a thermal cycle in a climate chamber on the right. The yellow areas are an alarming indication that the material is becoming brittle.

Bubbles the size of the palm of your hand within the module or on its back proved more critical. They indicated that the foil composite was no longer sticking together. When they peeled apart the composite foil, testers found out the reason why. In some cases, the adhesive no longer worked. In others the foil manufacturer had not applied the adhesive properly. In other there simply was no adhesive, and elsewhere the adhesive was clumped up.

Shrinkage in foils also occasioned a lower score. Although hard to notice in the test samples, it was impossible to overlook on the modules built afterwards. Some of the foils shrank entirely, whereas others only had individual shrinking layers. Interestingly, only half of the foil systems retained their original size; some of the samples even failed the test because they shrank too much. A few millimeters of shrinkage can still be tolerated: the worst case, however, astounded testers. The foil system was a centimeter shorter post-test.

There was also little doubt in cases where it was found that the foil composite, the embedding material, or the back foil was delaminating. Foil systems that easily fell apart failed, as did those that tore or became brittle after the climate tests or the subsequent mechanical tests and aging tests. As Fliedner explains, "We had foils that looked pretty good at first glance after the climate tests. They were so brittle you would only have had to tap on them with a screwdriver and they would have broken like glass." Of course, the testers didn't perform the screwdriver test. The IEC also requires other mechanical tests, such as the hail test.

All in all, the test series was a complete success for module manufacturers. Yet only three of the 23 test candidates passed the IEC test routines with stricter climate tests at a level sufficient to fulfill the module manufacturer's product specifications. The number of winning candidates could expand if foils were to be developed properly.

| COMPONENTS | ADHESION BEFORE DAMP HEAT TEST (Newton/centimeters) | ADHESION AFTER 2,000 HOURS OF DAMP HEAT TEST (Newton/centimeters) |
|---|---|---|
| Glass and EVA | > 100 | > 40 |
| EVA and back foil | > 100 | > 5 |

Adhesives for back foils: An adhesion test on these samples after the initial test shows that foil adhesion is much lower after the damp heat test (average values of all of the foils systems tested).

## Component standards desirable

The question remains: what will be done with the results, material data, and measurements compiled during testing? Fliedner says they will be kept in a database. They will then be available for future tests, which will make testing a bit less complicated. "For instance, we only have to measure water vapor permeability once for each type of foil." Furthermore, the data will be used to find out as much as possible about materials and the interaction of components in the system, i.e. the module. It will then be easier to determine which properties the backside material requires. Developing such properties in cooperation with foil manufacturers will also become easier.

The development director can easily imagine module and foil makers working more closely together. He also thinks it would be good if material manufacturers performed in advance some of the test routines he and his staff conducted when selecting a foil. "The combination of glass, embedded material, and back foil should be something that foil manufacturers always test." For such a division of tasks, standards are needed to clearly specify the scope and type of test program. There are no such standards for back foils, with one exception; the component norm specifies the admissible operating voltage. This is a purely electric test that does not produce any information as to the durability of the foils.

It will take time for national and international efforts to produce standards for the durability of back foils to come into effect. Even if everything goes as planned and standards committees agree their realization will take at least another two years.

Even then, manufacturers will still have to test thoroughly the relevant components of their modules. Customers will simply have to trust that their manufacturer of choice really does conduct with care these complex tests. ◆ Claudia Treffert