Workshop Proceedings of the 3\textsuperscript{rd} International Workshop

\textbf{Thin Films in the Photovoltaic Industry}

\textbf{22/23 November 2007}

\textbf{Editor: Arnulf Jäger-Waldau}
The Institute for Energy provides scientific and technical support for the conception, development, implementation and monitoring of community policies related to energy. Special emphasis is given to the security of energy supply and to sustainable and safe energy production.

European Commission
Joint Research Centre
Institute for Energy

Contact information
Address: Dr. Arnulf Jäger-Waldau, Via E. Fermi 2749, TP 450, 21027 Ispra (VA), Italy
E-mail: arnulf.jaeger-waldau@ec.europa.eu
Tel.: +39 0332 78 9119
Fax: +39 0332 78 9268

http://ie.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

Legal Notice
Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

Europe Direct is a service to help you find answers to your questions about the European Union

Freephone number (*):
00 800 6 7 8 9 10 11

(*) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server http://europa.eu/

JRC 43566
EUR 23281 EN
ISSN 1018-5593
DOI 10.2790/1269

Luxembourg: Office for Official Publications of the European Communities

© European Communities, 2008

Reproduction is authorised provided the source is acknowledged

Printed in Italy
Workshop Proceedings of the
3rd International Workshop
Thin Films in the Photovoltaic Industry
held at the EC JRC Ispra, 22/23 November 2007

Chairperson: Bernhard Dimmler and Arnulf Jäger-Waldau

Editor: A. Jäger-Waldau

Co-organised by

EUR 23281 EN
This are the minutes of the 3rd International Workshop "Thin Films in the Photovoltaic Industry" held at the European Commission's Joint Research Centre in Ispra, Italy on 22/23 November 2007.

The workshop series was initiated in 2005 by Bernhard Dimmler, Würth Solar, Germany and is supported by EPIA and the JRC's Renewable Energies Unit. In the meantime the workshop has established itself as a discussion and brain storming event for the Thin Film PV Industry.

In the past years, the yearly world market growth rate for Photovoltaics was an average of more than 40%, which makes it one of the fastest growing industries at present. Business analysts predict the market volume to increase to € 40 billion in 2010 and expect rising profit margins and lower prices for consumers at the same time.

Today PV is still dominated by wafer based Crystalline Silicon Technology as the “working horse” in the global market, but thin films are gaining market shares. For 2007 around 12% are expected. The current silicon shortage and high demand has kept prices higher than anticipated from the learning curve experience and has widened the windows of opportunities for thin film solar modules. Current production capacity estimates for thin films vary between 3 and 6 GW in 2010, representing a 20% market share for these technologies.

Despite the higher growth rates for thin film technologies compared with the industry average, Thin Film Photovoltaic Technologies are still facing a number of challenges to maintain this growth and increase market shares. The four main topics which were discussed during the workshop were:

- Potential for cost reduction
- Standardization
- Recycling
- Performance over the lifetime

I would like to thank all participants for their devotion of time to come to this workshop and share their views in open discussions. It is my strong believe that this workshop series with its fruitful exchange of ideas can accelerate the development and manufacturing capabilities of thin film technologies.

Ispra, February 2008

Arnulf Jäger-Waldau
Renewable Energies
European Commission – Joint Research Centre
TABLE OF CONTENT

PREFACE ............................................................................................................................................... 1

TABLE OF CONTENT ......................................................................................................................... 3

LIST OF PARTICIPANTS ................................................................................................................... 5

AGENDA................................................................................................................................................. 7

EXECUTIVE SUMMARY .................................................................................................................... 9

INTRODUCTION ...................................................................................................................................... 9
BACKGROUND ....................................................................................................................................... 9
TOPICS OF THE WORKSHOP ................................................................................................................... 9
EXPECTATION OF THE ORGANIZERS ..................................................................................................... 10

PROCEEDING OF THE WORKSHOP............................................................................................ 11

SUMMARY OF PRESENTATIONS............................................................................................................ 11
SESSION 1: EQUIPMENT MANUFACTURERS .......................................................................................... 12
SESSION 2: MODULES MANUFACTURERS ............................................................................................ 13
SESSION 4: STANDARDIZATION ........................................................................................................... 14
SESSION 5: EC INTEGRATED PROJECT PERFORMANCE ........................................................................ 14

ANNEX: WORKSHOP PRESENTATIONS..................................................................................... 16

Bernhard Dimmler  Introduction  17
Arnulf Jäger-Waldau  Overview of Thin Film Photovoltaics Worldwide  24
Christoph Daube  Aspects of Cost Reduction with Large Area Production of a-Si Based Thin Film Modules  34
Fachri Atamny  Solar Technology Drivers: Costs / Standardisation  51
Michael Liehr  Challenges for Vacuum System Manufacturers in the PV Industry  59
Udo Wilkommen and Martin Diemer  Thin film Photovoltaic Production Technology  67
Karl-Heinz Stegmann  Glass & Module Size for Thin Film Solar  89
Hermann Maurus  Thin Film Silicon Technology @ Schott Solar  94
Thorsten Brammert  Si Thin Film Module Production at Q-Cells  110
Markus Beck  CIGS based Thin Film PV  114
Paul Mogensen  AVANCIS  116
Axel Neisser  Manufacturing CuInS₂ Solar Modules  123
David Eaglesham  First Solar Company Overview  130
Ch. Protogeropoulos  Thin-Film PV Industry Development in Greece  132
Hans Linden  Sunrise Solar Cells  135
Gert Jan Jongerden  Heliantos Solar Cell Laminates  138
Bernhard Dimmler  Manufacturing and Performance of CIS Modules Large Production Volume at Würth Solar  149
<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daniel Fraile Moronto</td>
<td>EPIA-SEMI PV Standards Technical Committee</td>
<td>152</td>
</tr>
<tr>
<td>Werner Bergholz</td>
<td>How can a New and Emerging technology as Thin Film PV Profit from Standardisation</td>
<td>159</td>
</tr>
<tr>
<td>Daniel Fraile Moronto</td>
<td>PV CYCLE – Motivation, Objectives and Benefits</td>
<td>172</td>
</tr>
<tr>
<td>Raymund Schäffler</td>
<td>PV CYCLE – Technical Issues</td>
<td>189</td>
</tr>
<tr>
<td>Daniel Fraile Moronto</td>
<td>IP Performance Project</td>
<td>198</td>
</tr>
<tr>
<td>Ewan Dunlop</td>
<td>The Current Situation of International PV Standards</td>
<td>208</td>
</tr>
</tbody>
</table>
LIST OF PARTICIPANTS

- **FACHRI ATAMNY**
  OC Oerlikon Balzers AG; Iramali 18; 9496 BALZERS (Liechtenstein)
  tel: +4233884309; fax: +4233885421; E-mail: fachri.atamny@oerlikon.com

- **MARKUS BECK**
  Solyndra, Inc.; 47700 Kato Road; 94538 FREMONT (United States of America)
  tel: +1-510-440-2555; fax: +1-510-440-8342; E-mail: markus.beck@solyndra.com

- **WERNER BERGHOHLZ**
  E-mail: w.bergholz@jacobs-university.de

- **TORSTEN BRAMMER**
  Brilliant 234. GmbH; Sonnenallee 7-11; 06766 THALHEIM (Germany)
  tel: +49 3494 66 99 92100; fax: +49 3494 383470; E-mail: j.rott@q-cells.com

- **CHRISTOPH DAUBE**
  Solar Business Group; Siemensstrasse 100; 63755 ALZENAU (Germany)
  E-mail: christoph_daube@amat.com

- **BERNHARD DIMMLER**
  Würth Solar; Alfred-Leikam Str. 25; 74523 SCHWÄBISCH HALL (Germany)
  tel: +49 791 94600-301; fax: -109; E-mail: bernhard.dimmler@we-online.de

- **EWAN DUNLOP**
  European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
  tel: +39 0332 789090; fax: +39 0332 789268; E-mail: ewan.dunlop@ec.europa.eu

- **DAVID EAGLESHAM**
  First Solar, Inc.; 28101 Cedar Park Blvd.; 43551 PERRYSBURG (United States of America)
  tel: 4196628500; fax: 4196628525; E-mail: rafoore@firstsolar.com

- **DIEGO FISCHER**
  VHF-Technologies SA; Av. du Sport 26; 1400 YVERDON (Switzerland)
  E-mail: diego.fischer@flexcell.ch

- **DANIEL FRAILE**
  EPIA; Rue d'arlon 65; 1040 BRUSSELS (Belgium)
  tel: +3224001062; E-mail: pol@epia.org

- **ARNULF JAEGGER-WALDAU**
  European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
  tel: +39 0332 789119; fax: +39 0332 789268; E-mail: arnulf.jaeger-waldau@ec.europa.eu

- **GERT JAN JONGERDEN**
  Helianthos; Velpwerweg 76; 6828 BM ARNHEM (Netherlands)
  tel: +31 26 366 2265; fax: +31 26 366 5464; E-mail: gertjan.jongerden@nuon.com

- **DR. MICHAEL LIEHR**
  Leybold Optics Dresden GmbH; Zur Wetterwarte 50 Haus 303; 01109 DRESDEN (Germany)
  tel: 00493518669558; fax: 00493518669517; E-mail: michael.liehr@leyboldoptics.com

- **HANS LINDEN**
  Scheuten R&D BV; P.O. Box 22; 5900 AA VENLO (Netherlands)
  tel: +31(0)773599222; fax: +31(0)773247505; E-mail: hlinden@scheuten.com
• HERMANN MAURUS
SCHOTT Solar; Hermann-Oberth-Str. 11; D-85640 PUTZBRUNN (Germany)
tel: +49 89 46 264 201; fax: +49 89 46 264 209; E-mail: hermann.maurus@schott.com

• PAUL MOGENSEN
Avancis.GmbH; Otto Hahn Ring 6; 81739 MUNICH (Germany)
tel: +49 89 219620 544; fax: +49 89 219620 503; E-mail: paul.mogensen@avancis.de

• HARALD MUELLEJANS
European Commission, DG JRC, IE: Via E. Fermi, 2749; 21027 ISPRA (Italy)
tel: +39 0332 789301; fax: +39 0332 789268; E-mail: harald.muellejans@ec.europa.eu

• AXEL NEISSER
Sulfurcell Solartechnik GmbH; Barbara-McClintock Straße 11; 12489 BERLIN (Germany)
tel: +49 30 6392 3823; fax: +49 30 6392 3844; E-mail: neisser@sulfurcell.de

• HEINZ OSSENBRINK
European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
tel: +39 0332 789196; fax: +39 0332 789268; E-mail: heinz.ossenbrink@ec.europa.eu

• CHRISTOS PROTOGEROPOULOS
RENI - Renewable Energy Innovations; 170, Sygrou Av.; 176 71 ATHENS (Greece)
tel: +30 21 09516201; fax: +30 21 09537084; E-mail: c.protogeropoulos@reni.gr

• TONY SAMPLE
European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
tel: +39 0332 789062; fax: +39 0332 789268; E-mail: tony.sample@jrc.it

• PETER SCHNEIDEWIND
ersol Solar Energy AG; Wilhelm-Wolff-Str. 23; 99099 ERFURT (Germany)
tel: 0361-21951101; E-mail: peter.schneidewind@ersol.de

• RAYMUND SCHÄFFLER
Würth Solar GmbH & Co KG; Alfred-Leikam-Str. 25; 74523 SCHWÄBISCH HALL (Germany)
tel: +49 (0)791 94600 308; fax: +49 (0)791 94600 309; E-mail: raymund.schaeffler@we-online.de

• KARL-HEINZ STEGEMANN
Signet Solar GmbH; Hermann-Reichelt-Str. 3; 01109 DRESDEN (Germany)
tel: +49(0)3518923156; fax: +49(0)3518923151; E-mail: khstegemann@signetsolar.com

• RALF WENDT
Calyxo GmbH; OT Thalheim, Sonnenallee 1a; 06766 BITTERFELD-WOLFEN (Germany)
tel: +49 3494 368 980 130; E-mail: A.Mueller@calyxosolar.com

• UDO WILLKOMMEN
VON ARDENNE Photovoltaik GmbH&Co.KG; Plattleite 19/29; 01324 DRESDEN (Germany)
tel: +493512637800; fax: +493512637786; E-mail: willkommen.udo@vonardenne.biz

• WILLEM ZAAIMAN
European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
tel: +39 0332 785750; fax: +39 0332 789268; E-mail: willem.zaaiman@jrc.it
AGENDA

22 November 2007

10:00 – 12:00 Optional Laboratory visit of the European Solar Test Installation (ESTI)

14:00 – 14:10 Welcome, Heinz Ossenbrink, European Commission; DG JRC
14:10 – 14:20 Introduction, Bernhard Dimmler, Würth Solar GmbH&Co. KG
14:20 – 14:40 Overview about Thin Film Photovoltaics Worldwide, Arnulf Jäger-Waldau, European Commission; DG JRC
14:40 – 15:10 Aspects of Cost Reduction with Large Area Production of a-Si Based Thin Film Modules, Christoph Daube, AMAT
15:10 – 15:40 Solar Technology Drivers: Costs / Standardisation, Fachri Atamny, Oerlikon Solar
15:40 – 16:10 Challenges for Vacuum System Manufacturers in the PV Industry, Michael Liehr, Leybold Optics
16:10 – 16:30 Coffee Break
16:30 – 17:00 Thin Film Photovoltaic Production Technology, Udo Willkommen, von Ardenne Photovoltaik
17:00 – 19:00 short presentations of each manufacturing company
20:00 Dinner

23 November 2007

08:30 – 09:30 continuation of company presentations
09:30 – 10:00 PV Cycle – Introduction, Daniel Fraile Moronto, EPIA
10:00 – 10:30 PV Cycle – Technical Issues, Raymund Schäffler, Würth Solar
10:30 – 11:00 Coffee Break
11:00 – 11:15 Standardization: what have been already and what should be done from the sight of EPIA, Daniel Fraile Moronto, EPIA
11:15 – 12:30 How can a New and Emerging technology as Thin Film PV Profit from Standardisation, Werner Bergholz, Jacobs University, Bremen
12:30 – 14:00 Lunch
14:00 – 14:30 IP-Performance Project, Daniel Fraile Moronto, EPIA
14:30 – 15:30 Current Situation of International PV Standards, Ewan Dunlop, European Commission – DG JRC
15:30 – 16:00 Conclusion and Close of the Workshop
EXECUTIVE SUMMARY

Introduction
After the success of the two previous workshops on Thin Films in the Photovoltaic sector, in November 2005 and November 2006 respectively there was a big demand for the follow-up. Therefore, the 3rd International workshop on Thin Films in the Photovoltaic sector was held in Ispra, Italy, the 22nd & 23rd November 2007. The workshop was chaired by Bernhard Dimmler of Würth Solar and Arnulf Jäger-Waldau of the European Commission, DG JRC. The organization was supported by EPIA (European Photovoltaic Industry Association) and hosted by JRC Ispra, Italy.

The results of this workshop are an important input for the Working Group “Science, technology, industry and application” of the PV Technology Platform, as well as for the EU Integrated project Performance and the recently founded association PV CYCLE which aims to create an European PV waste management system in order to collect and recycle PV modules.

Due to the fact that the Thin Film Industry is growing rapidly and a large number of new players are entering the field with announcements of new factories which are targeted to double in capacity each year, a targeted discussion workshop is needed.

Background
Photovoltaic solar electricity systems do have the potential to deliver electricity on a large scale at competitive cost in the near future. One of the main obstacle of PV today to serve as an important energy source is the high production cost of the PV module. Today PV is dominated by wafer-based Crystalline Silicon Technology as the “working horse” in the global market (more than 90% share of the market in 2006). Thin Film technologies have the highest cost reduction potentials of all PV technologies in the mid and long term. The currently used thin film materials are amorphous / microcrystalline Silicon and the compound polycrystalline semiconductors CdTe and CIS (CIS holds for the material family of Cu(In,Ga)(Se,S)₂). All of them are developing fast and are already in the status from small startups to large scale productions.

The disadvantage of Thin Films Technologies in comparison to Crystalline Silicon Technologies is still the lack of fundamental material property data (at least for CdTe and CIS) and the missing maturity in production technology.

This workshop was aimed to increase the support to concentrate efforts on a common level. The aim was to strengthen and increase the share and the role of thin films technologies in the worldwide PV market for the future.

Topics of the Workshop
The topics which are of high interest for the Thin Film manufacturers were addressed during the workshop; these are mainly the reduction of production cost and the performance and reliability of the product over a long lifetime. Besides other topics of high relevance that have gained importance during the last years were addresses and are also presented in the next list:
Potential to reduction cost:

- Consumption of materials
- Increase of the module efficiency
- Bigger deposition areas
- Economies of scale

Standardization:

- of the final product (size, materials, etc.)
- Manufacturing process (sputtering techniques, substrates used, equipment interfaces, etc.)
- Integration in building.

Recycling:

- Adaptation to the European legislation.
- Introduction of a take back and recovery system of PV modules in Europe.
- Different techniques for recycling.
- Cost of collection and recycling of thin films modules vs. crystalline silicon modules

Performance over the lifetime:

- taking advantage of the c-Si technology long experience.
- Behavior and degradation of materials.
- Characterized of the thin film module by measuring the electric performance in simulated sun light compared to outdoor behavior.

Further scientific R&D with respect to PV quality and stability and the establishment of professional and standardized characterization equipment and methods under industrial circumstances is highly needed.

The final aim of the workshop was to strength the PV thin film technology and to establish it as a leading technology in the incoming years through minimizing investment and material costs and maximizing product quality and productivity.

For the 3rd International Workshop on Thin Films in the Photovoltaic sector representatives from the emerging Thin Film companies, which are already producing or will start next year, representatives for equipment manufacturers of in-line productions as well as experts in the field of standardization, testing and certification and recycling were invited to participate.

**Expectation of the organizers**

For the further support and to enable Thin Films to become a leading technology in Photovoltaics in general the workshop was designed in order to find answer to the following questions:

- What is the status of Thin films PV?
- What is the status of and which are the technical roadmaps of the vacuum equipment and/or process suppliers?
- What are the technological achievements?
- Are there synergies in fields like glass coating or FPD production?
- What are the potential ways to reduce production cost and how to overcome them?
Summary of Presentations
Bernard Dimmler, member of the Steering Committee of the EU PV Technology Platform and chairman of the workshop started the meeting with an overview of the Thin Films technology in the PV sector, presenting how the sector has grown in the last few years and the perspective for the coming years, in which the Thin Films Photovoltaic may share around 20% of the global PV market in 2010. The current market situation is very favorable for Thin Films Photovoltaic and this fact is reflected in the fact that not only new market players are choosing this technology as their technology to invest, but that an increasing number of established solar cell producers with previous focus on wafer based solar cells are broadening their solar cell production basis with thin films technology.

The capacity of the Thin Films is rapidly increasing and by the end of the decade roughly 2 to 3 GW of production capacities for various thin films technologies are expected.

Today there are still some weak points that must be address in the Thin Films technology:

- No sufficient knowledge in basic material (at least for CdTe and CIS)
- Maturity of production technology still low, prototype equipment
- No standards in manufacturing and product up to now
- Not sufficient knowledge in how to measure the different thin films technologies with the same accuracy than for crystalline silicon modules

Nevertheless, the Thin Films PV technology presents several advantages as for example:

- high product quality, and a potential module efficiency of 15-20% in the mid/long term
- low material consumption with a solar cell thickness of about 2-5 µm
- Huge flexibility in module design (material costs)
- low energy needs with an energy pay back time ≤ 1.5 years today and ≤ 0.5 year for the long term
- high energy ratings in application
- High production depth (from raw material to end product)

Furthermore, the Thin films PV have the highest cost reduction potential of all PV technologies. This reduction will be achieved by:

- reduction of material consumption (the 50% of the final module cost is due to the material cost)
- Introduction of new standards for manufacturing and products
- Increase of the deposition areas (in both glass and rolled foils)
- Recycling of the module materials (glass represent from 75%-90% of material of whole module)

The next presentation was given by Arnulf Jäger-Waldau, of the EU DG JRC, in which a status and perspectives of Thin Film solar cell production was presented. With a production of cell/modules of 2.5GW in 2006, the announced capacity by the PV companies for 2010 is 23GW, of which Thin Films PV are 6GW (note that this figures may differ about 50% with the real capacity). Within Thin films, a-Si seems to be the most deployed technology followed by CIS and CdTe. Europe is leading and will lead the deployment of the Thin Films technologies during the next years, followed by USA (focused
more in CIS), Japan and China (where more than the 95% of the production will be of a-Si). If production volume is ramped up according to plans, Thin Film PV has the potential to reach the 1 €/Wp cost target at the end of this decade.

The system’s component costs were analyzed in order to identify how is the best way to reduce the whole cost of the system:

- Planning &financing: 15%
- Inverter: 9-10%
- BOS &installation: 10-30%
- Modules: 40-66%

An increase or decrease of the efficiency of the module implies an increment or a reduction of the BOS &installation costs respectively. Nevertheless, the financing and inverter cost remain always the same. Therefore, a way to reduce cost would be the use of lower efficiency modules in those cases in which the value of the installed area is not relevant.

Then, the event was divided in five sessions:

- Equipment manufacturers
- Thin Films module manufacturers
- Recycling (PV CYCLE)
- Standardization
- IP Performance

**Session 1: Equipment manufacturers**

Four presentations were given during this session. Each company (Applied Materials, Oerlikon, Leybold Optics, VonArdenne) presented their own products, technologies, roadmaps and arguments on how the production cost could be reduced. The presentations can be found in the annex.

The discussions of these presentations were focus mainly on:

- Reduction of the production cost by:
  - Reducing the cost/m²: increasing the substrate area (following the experience of the LCD industry) from 0.6m² to 10m². These big areas may give an added value to PV from the architects’ point of view (increasing the BIPV market and applications).
  - Increasing W/m²: using high efficiency technologies like the tandem μc-Si/a-Si.
  - Reducing the number of steps in the manufacturing process and the number of this process. There are too many processes established or still under development: PECVD, MOCVD, (co)-Sputtering, (co)-Evaporation, Paste, Inkjet, Electroplating, Nanoparticle/Sol-Gel etc.
  - Reducing energy consumption in the factories.
  - Increasing the capacity of the factories (mass production)

- Standardization of glass substrate size: while some equipment manufacturers and module manufacturers find the increment of the substrate size as a driver for reduction of cost production, others affirm that the use a standardized size would help to reduce this cost. The discussion comes when defining which the most appropriate size is.

- The use of a (dual) Cylindrical Sputter Magnetron instead of a Planar Sputter Magnetron will increase the utilization of the target material (from ≤ 45% to ≤ 80%) and therefore, will reduce
material costs in about 40%. And, although the price of the cylindrical sputter magnetron is almost the double than the planar one, the lifetime is longer (up to 3 times more)

**Session 2: Modules Manufacturers**

For this session 13 Thin Films PV companies (Solyndra, Brilliant, Würth Solar, First Solar, Helianthos/NUON, Scheuten, Schott Solar, Avancis, Sulfurcell, Solar cells Hellas Group, Ersol, Signet Solar, Calyxo) which are already producing or will start next year and represent the different Thin Film technologies as silicon based, CIS and CdTe gave a short presentation. Each company presented (with and without slides) their current and expected production capacity, the manufacturing process, product characteristics as efficiency, sizes, power, and technological roadmaps. See presentations in the Annex.

The outcome of this session can be summarized in the following:

- Glass substrate size and module size don’t need to be the same. And depend on each module manufacturer how to use this substrate (how many modules per substrate are necessary in order to avoid material losses)
- It is not clear the benefit of G8.5 versus G5 (while bigger substrates will reduce production cost, the cost for packaging, transportation and the difficulty in the installation will increase). For the previous reasons, it isn’t clear neither the benefit of big modules for BIPV.
- The reduction of €/W has to be addressed at the same time by increasing the production capacity and increasing the efficiency.
- The Standardization of Thin Film Processes and equipment is also required to allow the reduction of production cost. Nevertheless, the current existence of many different modules sizes and many substrates sizes will not help to this standardization process.

**Session 3: Recycling**

The main topic of this session was the recently creation of PV CYCLE and the activities that association is carrying out. Two presentations were given (See presentation in the Annex), the first one by Daniel Fraile, EPIA, to present the current European policy on waste and the possibility of inclusion PV modules under the scope of the WEEE directive during its revision next year. This, together with the aim of becoming a responsible industry which tackle the climate change and others environmental issues have been the motivations to found the PV CYCLE association. The main objective of PV CYCLE, lead by EPIA, BSW and the main international PV companies, is to introduce a Take Back and Recovery system for PV modules in Europe by the end of 2008.

Raymund Schäffler from Würth Solar and also member of PVCYCLE, presented mainly which would be the costs for the PV industry in to possible three scenarios: Business as usual, introduction of the Take back and recovery system with PV under the scope of the WEE directive and without it (intermediate results of a study carried out by Ökopol).

Different studies from NREL, NBL, ZSW and others centers estimate the cost recycling in the range of 5 – 10 c€/Wp. It is important to note that they also estimate that the cost of non-recycling will be much higher due to the disposal of hazardous substances in landfills.

Some weak points related to the cost of recycling of Thin Film PV modules are:

- The highest cost of recycling is the crashing and separation of the active layer from the glass.
- Each Thin Film technology presents different cost of recycling due the material used.
- The current cost of recycling is based in certain assumption, but this cost will decrease with the experience (learning curve).
- With an industry based in the economies of scale in order to reduce the production cost, the quantities of PV waste will increase implying an increase of the cost of Collection & transportation of PV modules.
- The cost of Thin Film PV modules is still more expensive that for c-Si technologies.

**Session 4: Standardization**

A session was dedicated specially to understand the benefits of the Standardization and how the Thin Film PV and the PV industry in general can profit from it. Two presentations were given during this session. See presentation in the Annex.

Daniel Fraile from EPIA presented the recently created EPIA-SEMI PV Standards Technical Committee which objectives are to identify, develop and implement standards or specifications by the industry for the industry, especially in those fields where other bodies like IEC or CENELEC are not involved, like materials, equipment and processes.

Werner Bergholz from the University of Bremen and also member of SEMI gave a presentation on how the standardization of products, materials, equipment and processes helps to the industry to reduce production and product costs, and how it lowers the entry barriers for competition. Real cases from the Semiconductor and nanotechnology industry were given as good examples on how the standardization can reduce dramatically the production cost in emerging technologies.

**Session 5: EC Integrated Project Performance**

For the last session of the event, as in the previous edition of the International workshop on Thin Films, the EU IC Performance was presented. Two presentations were given (See presentations in the Annex).

Daniel Fraile, EPIA reported on the objectives, structure and fields of work within the project. The project aims to improve the general understanding of:

- PV device testing methods,
- PV module and systems performance,
- PV module and systems stability.

Ewan Dunlop, EU DG JRC, gave and overview of the IEC TC82 activities and their relation to the Performance Project and its results.

An inter comparability Round Robin among the main European Test Laboratories has been done for PV c-Si modules with the following conclusions:

- Good results regarding comparability: The spread for reported P_{MAX} lies in the range ±2%. High or systematic discrepancies for laboratories could be either explained by deficits of the measuring equipment or measurement procedures.
- PV Industry expressed the need for additional information on calibration data of reference modules. Test reports shall go beyond STC and state how modules shall be measured to ensure an optimal transfer of calibration.

Thin Round Robin is being performed now for Thin Films PV modules and result will be available for spring 2008.
The lifetime and degradation of 204 c-Si modules have been analyzed for 23 years in the JRC; some of the results are the following:

- High power losses (>20%) are attributed generally to FF losses (interconnections resistance increase), while moderate modules degradation is caused by $I_{sc}$ loss due optical properties degradation and photon induced semiconductor degradation,
- There is no statistically significant difference in the performance of the modules with mono-crystalline and poly-crystalline cells (average degradation rate 0.7 % per year),
- There is difference between groups of modules with the glass back substrate (average 23% degradation) and polymer substrate (average 14%),
- The visual appearance of field–aged modules is often not correlated with their electrical performance and state of electrical insulation,
- Of the 204 modules studied in this work 82.4% have been verified to have the final maximum power greater than 80% of the initial power i.e. meeting the manufacturers warranty criteria,
- Furthermore two thirds of modules have the final maximum power verified to be more than 90% of the initial power value after 25 years of outdoor exposure.

Finally B. Dimmler asked the participants to give feedback to the workshop and proposals for topics and areas of interest for possible future workshops. Active support to realize these further activities is highly welcome.
ANNEX: WORKSHOP PRESENTATIONS

The Presentations are also available on the Web-Page of:

http://www.epia.org

3rd International Photovoltaic Industry Workshop on Thin Films

“Introduction”

Bernhard Dimmler
Würth Elektronik Research GmbH

Schwäbisch Hall
bernhard.dimmler@we-online.de

www.wuerth-solar.de

Thin Films are taking off in PV

“Thin Film production capacities are increasing rapidly“

due to:

• After 25 years of development Thin Films have gained enough technological maturity and proven quality with calculable risk

• performance and life time expectations proven

• High cost reduction potential, just starting learning curve

Additionally accelerated by
PV market volume increase and Silicon shortage
Thin Films in PV

Thin films PV have the highest cost reduction potential of all PV technologies today.

The emerging materials are:
- amorphous / microcrystalline Silicon
- CadmiumTelluride (CdTe)
- CIS: Cu(In,Ga)(Se,S)₂

All are starting with several large volume factories with good prospects to reduce costs of PV modules

Lacks of thin Film Technologies:
- Material knowledge (at least for CdTe and CIS) still low
- maturity of production technology still low, prototype equipment
- no standards in manufacturing and product up to now

Advantages of Thin Films

- **high product quality, efficiency**: outstanding CIS
  - CIS: cell max. 19.9 %; module 11 up to 14% today,
    - potential module efficiency 15-17% in mid/long term
  - CdTe and a-Si: 2 – 4 % less respectively

- **low material consumption**: solar cell thickness 2 - 5 µm
  - further huge potential esp. in module design (material costs)

- **low energy needs**: energy pay back time: today ≤ 1.5 years,
  - long term ≤ 0.5 year

- **high energy ratings in application**
Module Efficiency
Expectation of maximum values

Actual aperture area module efficiencies in production in average:
- a-Si: 3 – 7 %
- CdTe: 6 – 9 %
- CIS: 6 – 12 %

Source: PV Technology Platform experts Thin Films

Advantages of Thin Films in production
“large area production technology”

- in-line continuous and large area deposition
  - glass: 0.6 x 1.2 \rightarrow 1.4 \times 1.4 \rightarrow 3.2 \times 6.0 \text{ m}^2
    synergies with architectural glass coating and FlatPanelDisplay technologies
  - rolled foils (metal and polymer) of 30cm x km: synergies packaging ind.
- low process temperatures: \sim 500^\circ\text{C} for CIS/CdTe, all other processes < 200^\circ\text{C}
- Integrated electrical interconnects
- High production depth: from the raw material to the final product
  high grade of automation, high yield

\rightarrow high cost reduction potentials
3rd International Photovoltaic Industry Workshop
on Thin Films

Module Production

Source:
c-Si, Thin Film as estimated by end of 2006

Possible Total Production [MWp]

<table>
<thead>
<tr>
<th>Year</th>
<th>c-Si</th>
<th>Thin Film / New concepts / New players</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>774</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>1,250</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>1,418</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>1,750</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>2,089</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>3,088</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>3,825</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>5,000</td>
<td></td>
</tr>
</tbody>
</table>

Share of Thin Film of total

- 3.8%
- 4.0%
- 7.1%
- 8.6%
- 9.6%
- 16.2%
- 18.3%
- 20%

Estimation: 2020 thin films 7.5 GW (=22%) of total 34 GW,
2030 thin films 133 GW (= 28.6% = new concepts) of total 380 GW

Expected Evolution of Thin Film Module Production Capacities (as of Oct. 2007)
counting existing, announced and expected* productions worldwide

- CdTe
- a-Si/rel.
- CIS
- total thin films

*expected: assessment of technological maturity by the author
Manufacturing costs: Driven by production volume

Source: PV Technology Platform experts Thin Films

Manufacturing costs: Driven by innovations

Source: PV Technology Platform

Increase of production volumes
Learning effects: process yield, cycle times, up-time, availability of equipment
Increase of efficiency
Reduction of material costs

Improvement of productivity
Innovative processes
Innovations: foils, barriers
Increase of efficiency
Reduction of material costs (modified materials)
Thin Films: cost compete with quality
Two main routes of development

In the mid future there will be 2 types of products of Thin Films:

1) Very low cost, low quality:
   • Very large substrates based on glass:
     from square-meter to 20 m² (see FPD or architectural glass)
   • Foils of km’s length, roll-to-roll coating + sealing barriers
   • Innovative deposition processes vacuum less like electrodeposition and printing of nanoparticles, glass beads, etc.

2) Mid cost, very high quality:
   • Larger area, high productivity
   • Application and transfer of in laboratory already proven technologies
   • Monolithic integration, series interconnect, hermetic sealing
   • New concepts: multijunction, spectrum conversion, modified materials

Improvements in Production
Technological Roadmap

COST REDUCTION

Product quality: average module efficiency
   by continuous process optimization, stabilization and innovations

Productivity: - improvement of overall process yield:
   by continuous process optimization and improved process control
   
   - reduction of cycle time,
   
   - increasing product area in production
   
   - standardization in production

Materials: reduction amount of material (yield, thickness),
   recycling of production waste, EOL module recycling
   longer term: new module concepts (foils)
### 3rd International Photovoltaic Industry Workshop on Thin Films

#### Thursday 2007-11-22

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:00</td>
<td>Welcome</td>
<td>Ibc Heinz Ossenbrink</td>
</tr>
<tr>
<td>14:10</td>
<td>Introduction</td>
<td>Bernhard Dimmler</td>
</tr>
<tr>
<td>14:20</td>
<td>TF International overview</td>
<td>Arnulf Jäger-Waltau</td>
</tr>
</tbody>
</table>

**Topic 1:**

~ 14:30-18:30h

**Scaling Effects on ROI, Glass (foil) size in production**

- How are the status and the technical roadmaps of the vacuum equipment and/or process suppliers? Are there synergies from the glass coating or FPD production or other fields? What are feasible sizes? With what steps of glass (foil) size would there be an optimum in gain of ROI and low productivity risk? How yield and availability could be influenced? Etc.

30min.
- Applied Materials

30min.
- Oerlikon

30min.
- Leybold Optics

30min.
- vonArdenne

5-10min. each
- short presentations of each manufacturing company if possible with roadmaps with respect to scaling, glass size, state of the art and future, etc.

19:30 | Dinner organized by EPIA |

---

#### Friday 2005-11-23

**Topic 2**

~ 9-10.30h

**PV-Cycle**

- Presentation of the activities going on in this topic, ongoing plans
- PV Cycle: history and political background, further steps, message to new players
- PV Cycle: the technical view
- Other short notes and discussion

Daniel Fraile
Raymund Schäffler
all

**Topic 3**

~10.30-12.30h

**Standardization**

- EPIA together with SEMI is trying to support and install standardization in PV manufacturing; can that support thin film PV? How could the roadmap on standardization be?

10 min.
- Standardization: what have been already and what should be done from the sight of EPIA

45 min.
- “How can a new and emerging technology as Thin Film PV profit from Standardization?”

Daniel Fraile
Prof. W. Bergholz, Univ. Bremen
all

**Topic 4**

~14.00-16.00h

**EC Integrated Project PERFORMANCE**

- Presentation of the project and already done results of work, further plans; lifetime and module certification; offer to all thin film manufactures to participate

- Project Structure

- Results, actual status and further work to be done of the subprojects

- Other short notes and discussion

Daniel Fraile
Ewan Dunlop
all

16 h | End of workshop |
Status and Perspectives of Thin Film Solar Cell Production

Arnulf Jäger-Waldau

European Commission, DG JRC, Ispra
Institute for Environment and Sustainability
Renewable Energies

Disclaimer

• The capacity numbers were collected from Press Announcements of the different companies with a cut-off date End of October 2007.
• There is a sometimes quite high uncertainty in the overall figure as well as the time lines. As I pointed out in the presentation I consider 50% to be realistic in the given time frame.
• On slide 10 and 11 the 4.5 and 2€/Wp are possible system prices – not project costs - for the customer. Therefore, possible costs for the acquisition or lease of land is not included.
  - The actual BOS/installation costs might vary from project to project. Therefore, I added the case of a 50% BOS and a 100% BOS penalty in the case of 6% modules.
  - The figures for the modules represent the possible selling price of the module.
• The use of the material is permitted as long as the sources are acknowledged.
• Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use, which might be made of the following information.
• Photovoltaics Overview
• Industry
• Cost Reduction and Learning Curves
• Markets
• Conclusions

World-wide PV Cell/Module Production

Data source: PV News

- Rest of World
- United States
- China & Taiwan
- Europe
- Japan
Announced Capacity Increases

Thin Film Industry

- more than 130 companies worldwide (range: research to production)
- 21 companies have produced thin film PV in 2006
- 82 companies have announced plans to increase their production capacities
- 32 in Europe, 14 China, 19 USA, 9 Japan, 8 ROW
- 50 silicon based
- 19 Cu(In,Ga)2(Se,S)2
- 8 CdTe
- 5 Dye & others
Announced Production Capacities by Technology

Announced Capacity Increases: Regional Differentiation by Technologies
PV Technology Learning Curve since `76

"78% Line". Doubling of cumulative production reduces costs by 22%

Cost Relevance of Module Efficiency

Module efficiency

\[ \eta_M = \text{12\%} \quad \eta_M = \text{6\%} \quad \eta_M = \text{6\%} \quad \eta_M = \text{9\%} \quad \eta_M = \text{24\%} \]

<table>
<thead>
<tr>
<th>Module Efficiency</th>
<th>( \eta_M = 12% )</th>
<th>( \eta_M = 6% )</th>
<th>( \eta_M = 6% )</th>
<th>( \eta_M = 9% )</th>
<th>( \eta_M = 24% )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning + Financing</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>Inverter</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>BOS + Installation</td>
<td>10%</td>
<td>20%</td>
<td>11.5%</td>
<td>15%</td>
<td>7%</td>
</tr>
<tr>
<td>Modules</td>
<td>66%</td>
<td>51%</td>
<td>64.5%</td>
<td>69%</td>
<td>50%</td>
</tr>
<tr>
<td>Inverter</td>
<td>61%</td>
<td>51%</td>
<td>64.5%</td>
<td>69%</td>
<td>50%</td>
</tr>
<tr>
<td>Installation</td>
<td>2.75 €/W</td>
<td>2.29 €/W</td>
<td>2.9 €/W</td>
<td>3.1 €/W</td>
<td>3.1 €/W</td>
</tr>
<tr>
<td>BOS addition</td>
<td>50%</td>
<td>100%</td>
<td>15%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>BOS reduction</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
</tr>
</tbody>
</table>
Cost Relevance of Module Efficiency

Module efficiency

- $\eta_M = 12\%$
- $\eta_M = 6\%$
- $\eta_M = 9\%$
- $\eta_M = 24\%$

2 €/Wp

- 20% Planning + Financing
- 10% Inverter
- 15% BOS + Installation
- 55% Modules
- 1.1 €/W

55% Modules
- 47.5%
- 1.1 €/W

50% BOS addition
- 1.05 €/W

10% BOS addition
- 1.05 €/W

15% BOS addition
- 1.05 €/W

30% BOS reduction
- 1.05 €/W

Average Thin Film Cost Structure

Technology dependent Drivers
- Deposition Process: Dominates Energy
- Deposition Materials: Dominates Depreciation
- Package/Assembly: Dominates Materials

Common Drivers
- Material Cost: Volume, Efficiency
- Depreciation: Throughput, Efficiency
- Labour: Throughput, Automation, Efficiency
- Energy: Throughput, Efficiency
Thin Film Cost Reduction Potentials

**Current:**
- Active Layers: 20 – 98 €/m²
- Inactive Parts: 19 – 26 €/m²
- Total: 39 – 124 €/m²

**Optimised:**
- Active Layers: 5.5 – 23 €/m²
- Inactive Parts: 8 – 11 €/m²
- Total: 13.5 – 34 €/m²

Data: K. Zweibel
Learning Curve Scenarios

- **Thin Film 2006**
  - Slow decrease of improvements (1%)
  - 83%

- **Wafer Silicon**
  - 1990
  - 2000
  - 2006

Advanced Concepts

Cumulative Production [MW]

European Installations

- White Book Target: 3 MW
- 45% Growth: 15,100 MW
- > 50% Growth
- 35% Growth: 11,350 MW

Cumulative Installed Capacity [MWp]

**Market Estimates**

<table>
<thead>
<tr>
<th>PV News</th>
<th>Europe + Japan + USA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35% Growth</td>
</tr>
<tr>
<td>2006: 2,500 MW</td>
<td>1,680 MW</td>
</tr>
<tr>
<td>2010: 7,140 MW</td>
<td>5,200 MW</td>
</tr>
<tr>
<td>2011: 9,300 MW</td>
<td>7,000 MW</td>
</tr>
</tbody>
</table>

**Conclusions**

- Thin Film PV Production Capacities grow faster than the already high PV growth rates
- High uncertainty about time schedule of about 50% of the announced capacity increases
- If production volume is ramped up according to plans, Thin Film PV has the potential to reach the 1 €/Wp cost target at the end of this decade
- Markets for the next decade will still depend on public support
Thank you for your attention!
Aspekte der Kostenreduktion bei der großflächigen Herstellung a-Si basierter Dünnschichtmodule

Ch. Daube
Director Global Product Management Solar

Contents

- INTRODUCTION APPLIED MATERIALS
- SCALE OF MANUFACTURING
  - Market growth
- PRODUCT COST REDUCTION
  - Cost per m²
    - Glass/display
    - Size
    - Process
  - Watts per m²
    - Materials science
    - Yield & control
    - IC know-how & leverage
- THIN FILM LINE CONCEPT
  - Configuration
  - Products
- Summary
Applied Materials’ Vision
We apply nanomanufacturing technology™
to improve the way people live

Safe Harbor Statement
This presentation contains forward-looking statements, including those relating to Applied’s product capabilities, technology leadership, strategy to reduce solar production costs, growth opportunities, served available market; customers’ plans; and the solar industry outlook. These statements are subject to known and unknown risks and uncertainties that could cause actual results to differ materially from those expressed or implied by such statements, including without limitation: (a) broadening of demand in the solar industry, which is subject to many factors, including global economic conditions, the cost-effectiveness and performance of photovoltaic (PV) products compared to conventional and other alternative energy sources, technological innovations, availability and cost of raw materials such as silicon, evolving industry standards, changing customer and end-user requirements, government subsidies and economic incentives for alternative energy development, and geopolitical uncertainties; (b) customers’ capacity requirements and timing, rate and amount of capital spending for new technology; (c) Applied’s ability to: (i) accurately predict the characteristics of, and capitalize on opportunities in, the emerging PV market, (ii) successfully adapt its existing products and develop and commercialize new products that enable increased solar cell efficiency and performance at a lower cost, (iii) recruit, incent and retain key employees, (iv) obtain and protect intellectual property rights in key technologies, (v) develop, deliver and support a broad range of products, and (v) integrate acquired businesses; and (d) other risks described in Applied’s SEC filings. All forward-looking statements are based on management’s estimates, projections and assumptions as of February 27, 2007, and Applied undertakes no obligation to update any such statements.
Applied Materials’ Overview

- Revenue (Last 4 Quarters): Approx. $9.1 Billion
- Worldwide Employees: Approx. 14,000
- Worldwide Locations: 14 countries
  Manufacturing in North America, Germany, Israel, Taiwan, U.K.
  Development in North America, Asia, Europe and Israel
- RD&E Investment (FY'01 – FY'05): $1 Billion/Year
- Service: 3,300 field engineers
- Installed Base:
  > 19,000 Silicon IC systems
  > 500 Flat Panel Display systems
  > 500 Glass and Web Coating Systems
- World Wide Locations: Approx. 14,000
- World Wide Employees: Approx. $9.1 Billion
- Revenue (Last 4 Quarters): $1,500 / m²
- Cost per transistor
- Cost per area
- Cost per watt

Applied Materials Enables Industry Growth by Driving Cost Reduction....

FIRST
1974 2004
4 trillion 1,400,000 trillion
10 cents 5 nano-dollars
20,000,000x Cost Reduction
Source: SIA, IC Knowledge LLC

THEN
1995 2005
0.3 million m² 20 million m²
$30,000 / m² $1,500 / m²
20x Cost Reduction
Source: Display Search, Nikkei BP, Applied Materials

NEXT
Cost per watt
Contents

- INTRODUCTION
- APPLIED MATERIALS
- SCALE OF MANUFACTURING
  - Market growth
- PRODUCT COST REDUCTION
  - Cost per m²
    - Glass/display
    - Size
    - Process
  - Watts per m²
    - Materials science
    - Yield & control
    - IC know-how & leverage
- THIN FILM LINE CONCEPT
  - Configuration
  - Products
- Summary

World PV Market Size and Application Segmentation

40 % p.a.

63%

18%

Market Size in MWp


Off-Grid & Consumer on-Grid
Different World PV Market Projections until 2010 (Status: 2006/2007)

- LBBW (PV Market Model Version 2.0, LBBW Research, Febr. 2007)
- EPIA (Pessimistic Scenario, PV Med Athens, Apr. 2007)
- EPIA (Policy driven Estimate, PV Med, Athens, Apr, 2007)

World Electricity Production Forecast

1 assuming 1.4% increase per year (source: IEA WEO 2004, "World Alternative Policy Scenario") and starting at 17.400 TWh world electricity production in 2004 (source: BMWi "Zahlen und Fakten - Energiedaten", 2006)
2 assuming average of 1200 kWh yearly electricity production per installed kWp module power (own estimate)
3 TWh = Terrawatt-hour = 1 billion Kilowatt-hours
**Price Experience Curve for PV Solar Modules**

**History**
- 20% price decrease by doubling cumulative volume

**Forecast**
- Experience factor
  - 15%
  - 18%
- 1.3 GWp/a in 2005
- 6 GWp/a in 2010
- 70 GWp/a in 2020
- 340 GWp/a in 2030

**Future Growth of the Global PV Solar Electricity Market in GWp and bn€ turnover**

- Range depending on experience factor (15% - 18%)
General drivers of the price experience curve

- Market growth

- **Learning by R&D** (improving the know why)
- **Learning by doing** (improving the know how)
- **Learning by using** (optimized interacting of the individual components)
- **Learning by interacting** (transfer of knowledge between users, manufacturers research and policy)

Worldwide R&D capabilities
PV-Lab Alzenau established

Several 5,7 m² lines sold

Complete line approach

Cooperations, funded projects

Two Primary Photovoltaic Technologies

**Crystalline Silicon “c-Si”** (wafer-based)
- Front contacts
- Passivation & anti-reflection layer
- N-type dopants
- Silicon wafer (absorber)
- Back reflector
- Back contacts

2010F: ~$1.25 – $1.50 cost/watt
(14% - 23% efficient)

**Thin Film “TF” Silicon** (glass-based)
- Glass substrate
- Transparent conductor
- Thin film silicon
- Back contact

2010F: ~$0.90 – $1.30 cost/watt
(8% - >10% efficient)
a-Si based Thin Film Technologies have…

a) **low cost (price) per m²** (BIPV) at lower eta (4-6%)
   - deposition area: 0.6 → 1.4 → 3 → 5 → 10 m²
   - utilize technology development in TFT technology (e.g. ASI)
   - creation of semi transparency

b) **low cost (price) per Wp**
   - a-Si/µc-Si
   - efficiency 8% today, up to 10 % in 2010 and 14 % in 2030

c) **no polysilicon supply constraint**

---

Contents

- INTRODUCTION APPLIED MATERIALS
- SCALE OF MANUFACTURING
  - Market growth
- PRODUCT COST REDUCTION
  - Cost per m²
    - Glass/display
      - Size
      - Process
  - Watts per m²
    - Materials science
    - Yield & control
    - IC know-how & leverage
- THIN FILM LINE CONCEPT
  - Configuration
  - Products
- Summary
Scale of manufacturing
Example: TFT Display Technology Development

in 2005 more than
500 production / R&D machines

Experience Reducing Unit Production Costs

Experience from LCD Manufacturing
Applied’s Capabilities

Large Area Platforms
- ATON™
- AKT50K PECVD
- MULTIWEB

Integration

Automation

Service & Support

Process Technology

Tandem & control
- IC, integration & know how

Applied’s Capabilities

Materials science (cell architecture)

Thin Film

a-Si:H/μ c-Si:H Cell Spectral Response

Wavelength, microns

Cost / m²
Watt / m²

Tandem Junction
Increases Voltage
Collects More Light
Enhances Stability
a-Si:H/μc-Si:H Tandem Cells

**General Advantages**
- Silicon technology
- Real thin-film concept
- Ideal combination of materials for tandem cells
- High efficiencies demonstrated

μc-Si:H compared to a-Si:H
- Improved red/NIR-response
- High stability

Potential
- TCO/light trapping
- High deposition rates necessary
- Large area deposition

Material Science: Light-trapping

**Absorption Coefficient**
- a-Si:H @ 500 nm: 10,000 cm⁻¹
- μc-Si:H @ 700 nm: 3000 cm⁻¹
- μc-Si:H @ 900 nm: 260 cm⁻¹

**Current Density (mA/cm²)**
- a-Si:H/μc-Si:H cell:
  - Max. 26 – 27 mA today
  - Potential 41.5 mA
Requirements

**Physical:**
- High transparency (VIS and near IR)
- High conductivity
- Optimized light scattering

**Technological:**
- Low costs
- Large areas
- High rates

Industry (standard): SnO$_2$ : F (but high quality @ low costs not yet available)

Approach followed @ FZJ:
- Magnetron sputtered and texture-etched Zinc Oxide (ZnO)

Surface Texture and Optical Properties

Textured-etched RF-sputtered ZnO:Al shows:
- $\delta_{rms}$ up to 150 nm for optimised films
- Excellent transparency: VIS and near IR
- Low sheet resistance (typically < 10 $\Omega$)
Contents

- INTRODUCTION
- APPLIED MATERIALS
- SCALE OF MANUFACTURING
  - Market growth
- PRODUCT COST REDUCTION
  - Cost per m²
    - Glass/display
    - Size
    - Process
  - Watts per m²
    - Materials science
    - Yield & control
    - IC know-how & leverage
- THIN FILM LINE CONCEPT
  - Configuration
  - Products
- Summary

Introducing SunFab™ Thin Film Line
SunFab PECVD 5.7 System for Thin Film Si

Processes glass at 4 times the size of Applied Materials’ nearest competitor

Scale-Up of Deposition to 5.7m² Glass Size

Demonstration of first 5.7 m² deposited a-Si material for solar. Visually shows the size of the substrate and engineer.
Module Sizes available from the SunFab Line

1.1 meters

Best for Roof Top
- Standard size for easy handling
- Tandem junction best to save area
- Weight is ~25kg

2.2 meters

Best for Solar Farm
- Large module size to save BOS costs
- Single junction already gives high power
- Weight is ~50kg
- Convenient near drop in solution for BOS

2.6 meters

Best for BIPV + Solar Utilities
- Single piece of see-through window gives maximum use of area & saves lamination costs
- See-through results in less conv efficiency
- Weight is ~100kg

Modules can be ¼ size, ½ size or full size to address various market segments

Fact Sheet SunFab™

- Up to 75MW per production line
- ¼ size, ½ size and full size modules
- 6% for single junction (>340 Wp on full size)
- 8% with path to 10% for tandem junction (>450 Wp → 570 Wp)
- Glass-PVB-glass is lowest cost / highest reliability; mass production approach adapted from automobile and architectural glass markets
- Dimensions SunFab™ – 80m x 140m
- Employees – Approximately 130, including operations, engineering and management
Contents

- INTRODUCTION APPLIED MATERIALS
- SCALE OF MANUFACTURING
  - Market growth
- PRODUCT COST REDUCTION
  - Cost per m²
    - Glass/display
    - Size
    - Process
  - Watts per m²
    - Materials science
    - Yield & control
    - IC know-how & leverage
- THIN FILM LINE CONCEPT
  - Configuration
  - Products
- Summary

Summary SunFab™

- Go Large
  - Enables 5.7 m² – 4x larger than today’s largest thin film modules
  - Reduce production costs (labor, j-box, capital, overhead)
  - Reduce installation costs (labor, cabling, mounting)
  - Technology / toolset to enable GW-scale production
  - The transition is well underway
- Proven
  - Based on large-area PECVD tool with nearly 600 installed systems
  - PVD for back contact from leading glass coating platform: >190 systems
- Mass production
  - All other tools sourced from established leaders in their respective platforms / technologies
  - All elements necessary to produce a world class product – integrated production line from glass in to panel out; process integration; factory automation software and global service and support relationship
Thank you for your attention
Solar Technology Drivers: Costs / Standardization

November 22, 2007

Fachri Atamny

Agenda

- Oerlikon Overview
- Oerlikon Solar as Technology and Market Leader
- PV-Solar Driver: Cost Reduction
Six areas of high tech competencies

<table>
<thead>
<tr>
<th>Oerlikon Solar</th>
<th>Oerlikon Coating</th>
<th>Oerlikon Vacuum</th>
<th>Oerlikon Textile</th>
<th>Oerlikon Drive Systems</th>
<th>Oerlikon Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>Coating</td>
<td>Vacuum</td>
<td>Textile</td>
<td>Drive Systems</td>
<td>Components</td>
</tr>
<tr>
<td>Thin Film</td>
<td></td>
<td>Laser</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechatronics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Oerlikon at a glance – 170 locations around the world

- 5 Billion CHF sales in 2007
- 35 Countries
- >6700 Living Patents
- 19500 employees Worldwide – and Growing
  - >1500 Scientists and Engineers
  - >2500 Global Support
Sustainable EBIT improvement since 1HY 2005

(in CHF m)

<table>
<thead>
<tr>
<th></th>
<th>1HY 04</th>
<th>2HY 04</th>
<th>1HY 05</th>
<th>2HY 05 (1)</th>
<th>1HY 06</th>
<th>2HY 06</th>
<th>1HY 07</th>
<th>2HY 07</th>
<th>plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-annual EBIT development</td>
<td>69</td>
<td>77</td>
<td>126</td>
<td>202</td>
<td>231</td>
<td>&gt;270</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Strong 2nd half year 2007 expected

(1) EBIT 2005 w/o sale of Inficon
Double digit growth in the first 9 months of 2007 (1)

(1) Oerlikon incl. former Saurer Group on a pro-forma basis January – September 2006

<table>
<thead>
<tr>
<th></th>
<th>Q1 -Q3 2006</th>
<th>Q1 -Q3 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orders received</strong></td>
<td>3,846</td>
<td>4,524</td>
</tr>
<tr>
<td><strong>Orders on hand</strong></td>
<td>1,461</td>
<td>1,648</td>
</tr>
<tr>
<td><strong>Sales</strong></td>
<td>4,136</td>
<td>4,136</td>
</tr>
<tr>
<td><strong>EBIT</strong></td>
<td>305</td>
<td>342</td>
</tr>
</tbody>
</table>

(1) Oerlikon incl. former Saurer Group on a pro-forma basis January – September 2006

---

### Agenda

- Oerlikon Overview
- Oerlikon Solar as Technology and Market Leader
- PV-Solar Driver: Cost Reduction
Our Mission

To be the leading supplier of product and fab solutions for the PV manufacturing industry
- Equipment and processes
- Building and infrastructure
- Products and warranties

Oerlikon as First Mover

Milestones

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept 03</td>
<td>Oerlikon Solar R&amp;D Lab with Dr. J. Meier and Dr. U. Kroll, cooperation with IMT</td>
</tr>
<tr>
<td>June 04</td>
<td>First 1.4m² a-Si thin-film module presented</td>
</tr>
<tr>
<td>Dec 04</td>
<td>Research facility delivered to SCHOTT Solar, start of joint development</td>
</tr>
<tr>
<td>May 06</td>
<td>TÜV Rheinland 1.4m² module tests passed</td>
</tr>
<tr>
<td>Dec 06</td>
<td>40 MW facility delivered to Ersol Thin Film</td>
</tr>
<tr>
<td>July 07</td>
<td>Start of ramp-up of the ersol Thin Film line first modules reach nominal power on-time</td>
</tr>
<tr>
<td>Sept 07</td>
<td>Introducing Micromorph Tandem (9+% stab.)</td>
</tr>
<tr>
<td>Oct 07</td>
<td>40 MWp ramp-up at SCHOTT Solar</td>
</tr>
</tbody>
</table>
Strong and Highly Motivated Team

Dec 2003  20 employees
Dec 2004  28 employees
Dec 2005  82 employees
Dec 2006  140 employees
Dec 2007  200 employees

Agenda

- Oerlikon Overview
- Oerlikon Solar as Technology and Market Leader
- PV-Solar Driver: Cost Reduction
Solar Technology Driving Force: Cost Reduction

Cost Reduction  →  Productivity Up
Glass size

Performance Up
Standardization

Investment Down

Glass size

Q-Efficiency Up

Nr.-Junction Up

Light Trapping Up
Interfaces Adjustment Up

Equipment $ Down

Consumable Down*

Footprint Down

Utilization Up

Solar Technology Driving Force: Cost Reduction

Solar Technology Driving Force:

Cost Reduction

Productivity Up

Up-time Up

Yield Up

Throughput Up

Automation Up

Manuf. Steps Down

MP Complexity Down

Glass size

Performance Up

Q-Efficiency Up

Nr.-Junction Up

Light Trapping Up
Interfaces Adjustment Up

Equipment $ Down

Consumable Down*

Footprint Down

Utilization Up

Solar Technology Driving Force:

Cost Reduction

Productivity Up

Up-time Up

Yield Up

Throughput Up

Automation Up

Manuf. Steps Down

MP Complexity Down

Glass size

Performance Up

Q-Efficiency Up

Nr.-Junction Up

Light Trapping Up
Interfaces Adjustment Up

Equipment $ Down

Consumable Down*

Footprint Down

Utilization Up

Cost of Ownership Development to Grid Parity

Amorph 2007 to micromorph tandem 2010

<table>
<thead>
<tr>
<th>Cost of Ownership Development to Grid Parity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current small fabs</td>
</tr>
<tr>
<td>2007 for 20 MWp fabs</td>
</tr>
<tr>
<td>2010 large fabs</td>
</tr>
</tbody>
</table>

Driver is not necessarily glass size.

New application would require bigger glasses (architecture glass vs. TV)
Solar - Achieving Grid Parity

**Fab nominal capacity**

- 2006: 1 GWp
- 2007: 2 GWp
- 2008: 3 GWp
- 2009: 4 GWp
- 2010: 5 GWp

**Module efficiency**

- 2006: 7%
- 2007: 8%
- 2008: 9%
- 2009: 10%
- 2010: 10%

**Cost of ownership**

- 2006: $1.5/Wp
- 2007: $1.0/Wp
- 2008: $0.7/Wp

*yield, uptime, tact time, efficiency improvements

---

FAB 1200 – End-to-End Turnkey Production Solutions

- All thin-film production systems and processes from Oerlikon

Front-End

- TCO FC
- Laser
- Clean

Line Automation

- PECVD
- Laser
- TCO BC
- Laser

Back-End

- Contacted Tested device
- Encapsulation-Lamination
- Cross Contact
- Lamination
- Flasher
- Flasher
Challenges for Vacuum Systems Manufacturers in the PV Industry

Michael Liehr
Leybold Optics Dresden

Trends & Motivation

- Unrivaled market growth over the past years
- Subsidised markets, growing prices for fossil fuels
- Global warming becoming focus of politics
- Growing market share for thin film technologies
- Thin film PV needs high percentage of vacuum based technologies

M. Liehr, EPIA Workshop, 23-24 Nov. 2007
Market Development

Further market growth only by significant cost reductions

Reductions of EBIT/_margin seems inevitable

Thin film PV will take the same course as wafer based PV

Photovoltaics:
- The price problem
  - PV market will continue to be artificial for the time being
  - Price increase for fossil and nuclear fuels may be helpful for PV
  - Thin film PV has higher potential for cost reductions
  - Thin film solar cells have shorter energy payback cycles
Market Development

High efficiency branch:
- smaller part of the market
- efficiency is technology driver
- some thin film technologies may be competitive

BIPV (building integrated photovoltaics) branch:
- larger part of the market
- Wp costs are technology driver
- large sized cells in flexible modules (or cheap conventional type modules)

Market saturation

BIPV
- cheap Si TF cells
- cheap CIGS cells
- cheap ... in cheap modules

High efficiency
- crystalline cells
- tandem/triple Si tf cells
- CIGS cells
... in conventional modules

2007
All types of solar cells in conventional modules

$%

Challenges

Three Challenges

- „Turnkey“ Solutions (f. thin film solar cells)
- Reduction of production costs
- New solar cell/module concepts
Silicon thin film has the longest history but lowest potential for high efficiency.

CIGS has the highest efficiency potential. Indium price problems/shortage may only be of a speculative nature.

CdTe suffers from a bad reputation (Cd cancerogenic) but now leads the race for the lowest price per Wp (First Solar).

<table>
<thead>
<tr>
<th>TF solar cell type</th>
<th>Module efficiency range</th>
<th>Capacity 2006 approx</th>
<th>Module/Cell Makers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$-Si(BC:Si)</td>
<td>6.7% (6.9%)</td>
<td>193 MWp</td>
<td>Panasonic, Mitsubishi H.I, Sharp, Schott Solar, Free Energy Europe</td>
</tr>
<tr>
<td>CIGS</td>
<td>9.11%</td>
<td>74 MWp</td>
<td></td>
</tr>
</tbody>
</table>

Source: ZSW, Stuttgart

(Vacuum) systems manufacturers do not have sufficient know-how in highly efficient "Turnkey" factories.

Research institutions often offer only lab processes which have not been tested sufficiently in production environments.

The dynamics of the thin film PV market does not give much time to develop new technologies thoroughly.

"Experienced" solar cell maker
Know how: Line integration, optimisation

Example

Component supplier
(e.g. Power Supplies)

Consumable supplier
(e.g. Sputter Targets)
There are almost no worldwide accepted standards in substrate size (rigid and flexible)
Glass: 910x910 mm², 455x910 mm², 1400x1100 mm², 600x1200 mm², 800x1300 mm², 300x1200 mm², 600x900 mm², 650x1250 mm²,...
Web: 10 mm Cu web, 300 and 600 mm steel web & polymer...

Too many competing processes for making thin film solar cells
Established or still under development: PECVD, MOCVD, (co)-Sputtering, (co)-Evaporation, Paste, Inkjet, Electroplating, Nanoparticle/Sol-Gel etc.

TCO performance is crucial for the struggle towards higher solar cell efficiencies
Magnetron Sputtering

Cost Reduction

Planar Sputter Magnetron
- with ZnO:Al2O3 target
- mature technology
- no moving parts

Cylindrical Sputter Magnetron
- with ZnO:Al2O3 target
- much higher target utilisation
- much higher sputter rates
- no re-deposition zones
- TCO resistivity not subject to target lifetime

Cylindrical Target
Planar Target

Cooling water
Magnets & Iron yoke
Target-carrier
Target Material
“Racetrack” Plasma
“Redeposition zones”

> Cylindrical magnetron sputtering cathodes have reached mature stage
> Rotation of target, power transfer and cooling are industrially viable
> Target manufacturers have understood the significance of this technology
> Not every material is suitable as cylindrical targets
Cost Reduction

- Using cylindrical ZnO:Al2O3 targets reduces material costs about 40% (as of 01/07)
- 2-3 times higher deposition rates saves investment costs

<table>
<thead>
<tr>
<th>Cylindrical Sputter Cathode</th>
<th>Planar Sputter Cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ZnO : Al2O3 2%)</td>
<td></td>
</tr>
<tr>
<td>Layer thickness: 500 nm</td>
<td>Layer thickness: 600 nm</td>
</tr>
<tr>
<td>Target length: 750 mm</td>
<td>Target length: 750 mm</td>
</tr>
<tr>
<td>Backing tube ID: 5&quot;</td>
<td>Backing tube ID:</td>
</tr>
<tr>
<td>Target thickness: 14 mm</td>
<td>Target thickness: 14 mm</td>
</tr>
<tr>
<td>Target utilisation: 75%</td>
<td>Target utilisation: 25%</td>
</tr>
<tr>
<td>Dynamic dep. rate: &lt; 150 mm/min</td>
<td>Dynamic dep. rate: &lt; 140 mm/min</td>
</tr>
<tr>
<td>Collection efficiency 90%</td>
<td>Collection efficiency 80%</td>
</tr>
<tr>
<td>Power 15 kW</td>
<td>Power 15 kW</td>
</tr>
</tbody>
</table>

Cost Reduction

- Costs for magnetron and targets, accumulated for 1, 2 and 3 years of operation respectively
- Significant reduction of investment and consumable costs for cylindrical magnetron cathodes within one year
New Solar Cell/Module Concepts

Concept for CIGS solar cells on metal strips

- "All-in-one" solution for CIGS on flexible substrates
- No monolithic series connection
- Length of substrate 1000-4000 m
- Change of substrate without venting entire machine

New Solar Cell/Module Concepts

- Mo, NaF, Cu(InGa)Se₂, Buffer layer, i-ZnO, AZO
- Heating module

Conclusions

- There are still some efforts necessary to bring all major thin film solar cell production know-how to the vacuum systems manufacturer community
- It is imperative to cut the costs for solar cell production equipment (~30% by 2010)
- New solar cell and module concepts will be needed to establish PV as a lucrative supplier of electrical energy
Thin Film Photovoltaic Production Technology

Udo Willkommen
Martin Dimer

VON ARDENNE Photovoltaik GmbH & Co. KG

Outline

• Brief company portray
• Different kinds of equipment
• Driver of cost's for a thin film production
• Advantages of rotatable magnetrons
• Example for metal or TCO coating
  ▶ Different sizes of substrates
  ▶ The effort of substrate scaling
• Conclusions
Corporate Expertise

Technologies

- Plasma
- Electron Beam

Industrial Vacuum Processes

- Customized Equipment for
  - Production
  - Pilot
  - R&D
### Strategic Business Fields

- Architectural Glass
- Photovoltaics
- Metal Strip

### Applications

- Architectural Glass
- Photovoltaics
- Automotive
- Display
- HR Mirror
- Solar Absorbers
Business 2006

Characteristic Differences between wafer based and thin film Solar Cells

<table>
<thead>
<tr>
<th></th>
<th>Wafer based solar cells</th>
<th>Thin film solar cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate size [m²]</td>
<td>0.024</td>
<td>0.72...5.7</td>
</tr>
<tr>
<td>Cycle time per substrate [sec]</td>
<td>2...4</td>
<td>60...600</td>
</tr>
<tr>
<td>Efficiencies [%]</td>
<td>14...20</td>
<td>5...13</td>
</tr>
<tr>
<td>Contact layers</td>
<td>screen print plating</td>
<td>vacuum coating</td>
</tr>
<tr>
<td>Absorber</td>
<td>thermal and chemical processes</td>
<td>mainly vacuum coating</td>
</tr>
<tr>
<td>Passivation- and antireflexion layer</td>
<td>vacuum coating</td>
<td></td>
</tr>
<tr>
<td>Modul concept</td>
<td>connection in series</td>
<td>integrated connection in series</td>
</tr>
</tbody>
</table>
### Vacuum Process Technology

<table>
<thead>
<tr>
<th>Electrical contacts</th>
<th>Absorber</th>
<th>Passivation</th>
<th>Antireflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al, Ag, NiV, Mo, Sb₂Te₃, ITO, ZnO:Al, i-ZnO</td>
<td>a-Si:H, μc-Si:H, CuGa, In, Se, S, CdTe</td>
<td>Si₃N₄:H</td>
<td>PECVD (Sputtering)</td>
</tr>
<tr>
<td>Sputtering, Evaporation</td>
<td>PECVD, Evaporation, Sputtering</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Different kinds of equipment

**Examples of glass coating machines**
Clustersystem CS 730 for R&D

Substrate 10x10cm²

VISS 300 for R&D

Substrate 30x30cm²
Glass Coater GC 60 H for pilot line production

Substrate 60x120 cm²

Glass Coater GC 60 V

Substrate 60x120 cm²
Glass Coater GC 60 V

Substrate 60x120 cm²

Glass Coater GC 120V

Substrate 120x120 cm²
GC 120 H for pilot line production

Substrate size: 120x120cm²

GC 175 V production tool

Substrate size: 175x175cm²
Architectural Glass Coater GC 321 H

Substrate size: 3,20 x 6,00 m²

Architectural low-E Coater GC 321 H
Driver of cost's for a thin film production

- 60 to 70% target material
- Consumption of high purity medias
  - Clean room area
  - DI water
  - Process gases
- High skilled people
- Maintenance of coating machines

What can we do to reduce the operational cost`s?

- Increasing of utilization of the target material
- Longer campaign time without interruption
- Bigger substrate formates
- Carrier free transport
- Low maintainance times
- High availibilty of the coater
Dual Magnetron Sputtering

WSM 900 with Zn:Al Metal Targets
DC-DC mode, after 1.500 kWh
WSM 900 with ZAO Ceramic Target
DC-DC mode, Targets 240 x 900 mm²

Large Area WSM-type Magnetron
for Glass Coating applied
Sputter Process with Planar Magnetron

Utilization: \( \leq 45\% \)

Usable width up to 4m

WSM Magnetron
Target Erosion

app. 45\%
Dual Rotatable Magnetron Process

Dual Rotatable Magnetron for Large Area Coatings
Dual Rotatable Magnetron
Reactive Sputtering with Cr Target

ZnO:Al Ceramic Tube Target (2%-Al₂O₃)

Advantages with Rotatable Magnetrons
• Large material stock for long campaign durations
• High power density for high deposition rates
• No compound debris / flaking from target surface
• Very high target utilization (80%)
RSM/RSM 1300 Rotatable Magnetron mit Mo-Rohrtarget

RSM/RSM 1300 Rotatable Magnetron with DAS and ZAO-Target
Sputter Process with Rotatable Magnetron

Utilization: \( \leq 80\% \)

Usable width up to 4m

Utilization of target material

<table>
<thead>
<tr>
<th></th>
<th>Tube</th>
<th>Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80%</td>
<td>45%</td>
</tr>
</tbody>
</table>
Reservoir of target material

**Tube**

![Diagram showing the circumference formula](image)

Circumference = \(3.14 \times \text{diameter}\)

In reality, 3.5 times more

Comparison planar Magnetron and Tube Magnetron

Ceramic ZnO:Al\(_2\)O\(_3\) Target

- Tube cathode: high pool of material and high utilization of the target (70...80%) lead to high cost reduction compared to the planar target
Scale of Production Processes on large Surfaces
Development of Costs

Example: deposition of ZnO:Al from ceramic tube target

- **Process:** sputtering with tube magnetrons in horizontal systems
- **Substrates:** 1,4m² (Gen 5) \( \rightarrow \) 5,7m² (Gen 8.5)
  \( \rightarrow \) 19,8m² („Jumbo-Format“ in architectural glass coating)
- **Layer thickness:** 1000nm
- **Cycle time:** 60sec
- **Substrate temperature:** 200°C
- **Investment write-off:** linear, 7 years
- **10% efficiency** for estimation of annual production capacity (MWp)
- **Target cost reduction** by using large quantities in mass production is not considered

Cost Reduction by Extension of Substrate Surfaces
Sputtering of ZnO:Al

- **30% cost reduction** by scaling on large surfaces
- **60 – 70% costs for Targets**
- **10 - 15% investment costs** in vacuum coating system
- possibility of further cost reduction via thicker ceramic or metallic targets

![Cost Reduction Graph](image-url)
## Summary

- Scaling of large substrate formats shows a further possibility to cut production costs (if the technologies allow it)
- Example: production technology to deposit transparent conductible contact layers basing on ZnO:Al
  - In mass production operating costs (targets) define production costs up to 60 to 70% (CoO)
  - Scaling of large surfaces allow cost savings of more than 30%
  - Sputtering of thicker ceramic targets or metallic ZnAl-Targets could lead to further cost reductions
- Scalable, quick and in consumables well-priced production technologies can make an important contribution to further cost reduction in the mass production of solar cells

## Substrate Sizes

<table>
<thead>
<tr>
<th>Substrate Size</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>330 × 600 cm²</td>
<td>„Jumbo-Format“</td>
</tr>
<tr>
<td>220 × 260 cm²</td>
<td>Gen 8.5</td>
</tr>
<tr>
<td>110 × 130 cm²</td>
<td>Gen 5</td>
</tr>
<tr>
<td>60 × 120 cm²</td>
<td></td>
</tr>
<tr>
<td>30 × 30 cm²</td>
<td></td>
</tr>
<tr>
<td>10 × 10 cm²</td>
<td></td>
</tr>
<tr>
<td>Company</td>
<td>Technology</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Antec Solar Energy</td>
<td>CdTe</td>
</tr>
<tr>
<td>Calysso</td>
<td>CdTe</td>
</tr>
<tr>
<td>First Solar</td>
<td>CdTe</td>
</tr>
<tr>
<td>CSG</td>
<td>TF-c-Si</td>
</tr>
<tr>
<td>ErSol Thin Film</td>
<td>a-Si</td>
</tr>
<tr>
<td>Brilliant 234</td>
<td>a-Si</td>
</tr>
<tr>
<td>NUON</td>
<td>a-Si</td>
</tr>
<tr>
<td>Schott Solar</td>
<td>a-Si</td>
</tr>
<tr>
<td>Signet solar</td>
<td>a-Si</td>
</tr>
<tr>
<td>VHF Technologies GmbH</td>
<td>a-Si</td>
</tr>
<tr>
<td>Avancis</td>
<td>CIS</td>
</tr>
<tr>
<td>Johanna Solar</td>
<td>CIS</td>
</tr>
<tr>
<td>Odersun</td>
<td>CIS</td>
</tr>
<tr>
<td>Scheuten Solar</td>
<td>CIS</td>
</tr>
<tr>
<td>Solibros GmbH</td>
<td>CIS</td>
</tr>
<tr>
<td>Sulfurcell Solartechnik GmbH</td>
<td>CIS</td>
</tr>
<tr>
<td>Würth Solar</td>
<td>CIS</td>
</tr>
</tbody>
</table>
Glass & Module Size for Thin Film Solar

K.-H. Stegemann
VP Technology
EPIA 3rd “Thin Film Workshop”
November 22 & 23 / 2007

Glass & Module Size Thin Film

- Glass size
- Equipment up-scaling
- Module size
Economy of Scale for LCD Technology

- Glass Thickness 0.7mm
- G5 1.10mx1.30m
- G7 1.87mx2.20m
- G8 2.20mx2.50m
- G9 2.40mx2.80m
- G10 2.85mx3.05m
- Status
  - G8 production
  - G10 planning Sharp

Summary for LCD displays
- Specific glass size & production (no loss)
- On side glass production (Corning)
- Specific equipment market
- Cost reduction by up-scaling

Conclusion for Si thin film PV
- Si Thin film is connected to LCD market
- More and larger PV modules per substrate
Status Thin Film

- Status module production

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a-Si</td>
<td>a-Si</td>
<td>a-Si/µ-Si Tandem</td>
<td>a-Si/µ-Si Tandem</td>
<td>a-Si/µ-Si Tandem</td>
<td>a-Si/µ-Si Tandem</td>
<td>a-Si/µ-Si Tandem</td>
</tr>
<tr>
<td>ASI-F90</td>
<td>G-EA060</td>
<td>NA-901WP</td>
<td>CSG 100</td>
<td>WS 11007/80</td>
<td>FS-272</td>
<td>AT1 50</td>
</tr>
<tr>
<td>1.1mx1.3m</td>
<td>0.95mx1.3m</td>
<td>1.13mx1.3m</td>
<td>1.25mx1.3m</td>
<td>1.27mx1.5m</td>
<td>1.27mx1.5m</td>
<td>1.27mx1.5m</td>
</tr>
</tbody>
</table>

- Status equipment for a-Si/µ-Si thin film

<table>
<thead>
<tr>
<th>Oerlikon</th>
<th>AMAT</th>
<th>Ulvac</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-Si/µ-Si Tandem</td>
<td>a-Si/µ-Si Tandem</td>
<td>a-Si</td>
</tr>
<tr>
<td>1.1mx1.3m</td>
<td>2.2mx1.6m</td>
<td>1.1mx1.4m</td>
</tr>
<tr>
<td>G5</td>
<td>G8.5</td>
<td>G5.5</td>
</tr>
</tbody>
</table>

- Equipment from LCD

Substrate Size Roadmap for TFPV

- Si Wafer versus Glass Size (Generation 1 to 9 Flat Panel Industry)
**Float Glass Size**

- Architecture glass size (Europe)
  - 3.21 m x 6.00 m

  ![Diagram](image)

- Back Glass ~ 40% glass loss for G8.5; 25% for G5
- NSG TCO Glass ~ 20% loss

**Optimal Module Size**

- Cost Reduction by up-scaling for 60MW line

<table>
<thead>
<tr>
<th>Glass Size</th>
<th>1.2x0.6m</th>
<th>1.1x1.3m</th>
<th>2.2x2.6m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical strength</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting strength</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cables, j-boxes</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>12</td>
<td>25</td>
<td>99</td>
</tr>
<tr>
<td>Mounting frames</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting effort</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Signet Solar Company Confidential
Summary

- Detailed calculation are necessary
- Production cost per Wp
- BOS cost per Wp
- Mechanical and mounting issues?
- Specific glass production for PV
- Optimal glass size for production G8.5?
- Optimal module size for BOS G5?
Silicon Thin Film PV Technology @ Schott Solar

Hermann Maurus
Schott Solar GmbH
http://www.schott.com/solar

Outline

- Introduction to SCHOTT AG and SCHOTT Solar GmbH
- Thin film Production at Schott Solar
- Future developments
- Market segments and product size
- Keyword is “cost”
SCHOTT AG at a glance

- 2 Billion Euro Sales worldwide
- 17,000 Employees in 37 Countries
- Founded: 1884
- Owner: Carl-Zeiss-Stiftung

SCHOTT Solar GmbH

SCHOTT Solar, Inc.
Billerica (MA) USA
Vollintegrierte Fertigung von Wafern, Zellen und Modulen

SCHOTT Solar Inc.
Roseville (CA) USA
System Integration
Vertrieb von Modulen und Systemen

SCHOTT Solar CR
Valasske Mezirici, CR
Produktion von Solarmodulen

Alzenau, Hauptsitz
R&D c-Si
Fertigung von Wafern und Zellen

Putzbrunn
R&D Thin film
Produktion von Dünnenschicht-Modulen: OEM, BIPV

Jena
Produktion von Dünnenschicht-Modulen: Standard-Module
Outline

- Introduction to SCHOTT AG and SCHOTT Solar GmbH
- Thin film Production at Schott Solar
- Future developments
- Market segments and product size
- Keyword is “cost”

Thin film production at SCHOTT Solar

3 MW pilot production line in Putzbrunn

- operation since 1992
- 7/24
- equipment uptime 90%
- yield beyond 90%
- OEM, BIPV, Standard PV modules developed
Thin film production of SCHOTT Solar

>30 MW production line in Jena

- SOP September 2007
- full production begin of 2008

Improvements from Pilot to Production

<table>
<thead>
<tr>
<th>Pilot module</th>
<th>Production module</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASI F-32</td>
<td>ASI F-90</td>
</tr>
</tbody>
</table>

- Module power
  - 32W
  - 86 to 100W
- Module size
  - 0.6m²
  - 1.4m²
Improvements from Pilot to Production

Pilot module
ASI F-32

Production module
ASI F-90

Module power
32W

86 to 100W

Module size
0.6m²

1.4m²

Capacity
3 MW

>30 MW

Footprint PECVD
1

2

Laser eff. speed
1

8

Outline

- Introduction to SCHOTT AG and SCHOTT Solar GmbH
- Thin film Production at Schott Solar
- Future developments
- Market segments and product size
- Keyword is “cost”
Future development of efficiency is a “must”, because it offers strongest cost decrease!

**Roadmap**
Demonstrator-Module with 1.4m² (Gen5)

Future substrate size?

- Production module
  ASI F-90
- Pilot module
  ASI F-32
  Future Size?
  „ASI F-360“?

**Module power**
- 32W
- 86W to 100W
- 350W to 500W?

**Module size**
- 0,6m²
- 1,4m²
- 5,7m²?
Key features of thin-film Si technology

- Synergy from large area TFT-display PECVD production equipment
  - cluster, batch, in-line
  - up to 5.7m² (Gen 8.5)

Outline

- Introduction to SCHOTT AG and SCHOTT Solar GmbH
- Thin film Production at Schott Solar
- Future developments
- Market segments and product size
- Keyword is “cost”
ASI products: Standard Modules

Market: Roof Top PV

Probably no profit from very large size product?
ASI products: Standard modules

Market: On Grid-Industrial

Eventually profit from very large size product?

Market: On Grid-Industrial
ASI products: Standard Modules

Market: Field installations

Will profit from very large size product!
ASI products: OEM

Market: Off-Grid Consumer

No profit from very large size product.

Market: Off-Grid Consumer
ASI products: BIPV elements

Market: Facades

Probably no profit from very large size product?

Market: Facades
ASI products: BIPV elements

5000m² BIPV roof, Stillwell Train Station, Brooklyn, NYC

This project would probably have had profit from very large product size!
Outline

- Introduction to SCHOTT AG and SCHOTT Solar GmbH
- Thin film Production at Schott Solar
- Future developments
- Market segments and product size
- Keyword is “cost”

Keyword is “cost”

- Some market segments profit from larger plate size,
  but more important is
- Productivity has to be enhanced !
- Prize per Watt has to come down !!
Keyword is “cost”

Following questions have to be answered:

- Reduction on investment cost per W(capacity) ?
- Limits to efficiency, when going to very large dep size ?
- Adequate machines for all other production steps ?
- Availability and efficient usage of high quality TCO ?
- Stability of very large size products ?
  ...
  ...
- Cost per Watt of very large size products ?
Thank you!
Brilliant 234. GmbH
Si Thin Film Module
Production at Q-Cells

Group Organisation

<table>
<thead>
<tr>
<th>Wafer-Based Technology</th>
<th>Core Business</th>
<th>Thin-Film Business</th>
</tr>
</thead>
<tbody>
<tr>
<td>REC</td>
<td>17.18%</td>
<td></td>
</tr>
<tr>
<td>- Strategic partner and main supplier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Technology leader in polycrystalline silicon production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EverQ</td>
<td>33.3%</td>
<td></td>
</tr>
<tr>
<td>- String Ribbon technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Joint Venture with Evergreen Solar and REC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>flexcell</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>- Low-concentration PV technology</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- No. 1 independent cell player and No. 2 worldwide
- Poly- and monocrystalline solar cells
- Next generation high-efficiency cell concepts in development

Flexible Substrates (Glass)

- Cadmium telluride technology
- CIGS technology
- CIGS technology
- Crystalline silicon on glass
- Amorphous silicon on plastic film (“flexcell”)

Leader in core business with a strong focus on new technologies
Strategy: Thin-Film Technologies

Laboratory <1 MWp
- Almost ready to rumble

Pilot factory 10-30 MWp
- Early Pilot Production
- Under Construction
- Under construction

Scaling Up >50-100 MWp per unit
- Prolonged Test production

Decisions to be taken by end 2007/2008 based upon operational results

Overview Solar Valley
- Area: approx. 77 hectare
- Number of companies (today): 9
- Number of employees until 2010 (in total): > 5,000

Q-Cells today

PAGE 3
3rd Intl. PV Industry Workshop on Thin Films, Ispra, 2007

PAGE 4
3rd Intl. PV Industry Workshop on Thin Films, Ispra, 2007
BRILLIANT 234.

- Best efficiency in lab: 12%
- Efficiency: short-term target: 8%, mid-term target 10%
- Employees as of now: 75

Thank you.
Solyndra Introduction

- Location: Fremont, California, USA
- Technology: CIGS
  - vacuum deposition: CIGS, Mo back contact, i-ZnO/Al:ZnO window
  - wet chemical CdS junction partner
  - monolithic cell interconnect
- Substrate: Glass; 1.1m width
- Non-standard cell form-factor and packaging
- System Design Approach to lower total installed cost and lower cost of photovoltaic electricity
- Market Target: low slope rooftops
Technology Co-Operations

- Recycling and Environmental Aspects (joined PV-CYCLE)
  - LCA
  - Process waste material reclamation
  - End-of-use module collection & recycling
- Raw Material Sourcing Aspects
  - Evaporation feedstock supply chain and purity (Cu, In, Ga, Se)
  - Sputter target supply and quality; rotary targets (Mo, i-ZnO, Al:ZnO)
  - Glass substrate supply, potentially Mo-coated glass
- Cd-free buffer
- TCO optimization
- IEC standards (member of IEC TC82)
  - Performance
  - Reliability
  - Safety
  - Reference cells
- Employee sourcing
  - develop university PV programs
CIS Marketing & Production History

1981 Thin film development program initiated Arco Solar (a-Si. CIS, CdTe)
1993 CIS selected to continue in pilot plant
1998 1st Generation commercial CIS production (10 W module)
2000 Introduction of 40W module
2003 13.1% champion efficiency on 0.5m²
2005 Introduction of 80 Wp CIS module
2006 AVANCIS Joint venture formed for 2nd Generation CIS production
2007 Construction of 2nd Generation production facility
2008 Planned start of production of 120 Wp CIS module
Avancis aims to have

- High Quality
- High Performance products comparable to Si
- High Stability long lifetime products (tests modules have withstood 4000h DH)

And to be competitive with Si based modules
AVANCIS Module Efficiency will be in Ballpark Range of Poly Si Modules

Photon Magazin Market Survey Modules 2003

Target for AVANCIS in 2008

AVANCIS product Roadmap

New product opportunities
AVANCIS product sizing

3210mm

6000 mm

Based on Standard European float glass size

AVANCIS product sizing

3210mm

6000 mm

Sputtered Molybdenum coating

Avancis pre-product is coated on standard glass coater and then cut to size
18 substrates cut from a standard Jumbo glass size with an optimised yield of 98%

- Product will be competitive with wafer based Si modules and to be suitable for large arrays.
- Aim to move towards larger substrate sizes
  - fewer pieces from a Jumbo Format?
- Long term idea would be to keep substrate size as large as possible as far as possible in the module process.
  - We therefore require appropriate production and measurement equipment
AVANCIS supports Equipment standardisation

- **Standard Product Size**
  - Module size, mother substrate size
  - Enables standard size for chambers and std automation design
  - Lower equipment cost
  - Product size roadmaps

- **Standard Process Steps**
  - PVD-CIG, PVD-ZnO, Patterning, Assembly
  - Enables robust process developments and CoO optimization
  - Lower CoO and less process develop. cost
  - Technology roadmaps

- **Standard Platforms**
  - Sub-line concepts
  - Enables mature design for cost and reliability
  - Lower equipment cost
  - Equipment roadmaps

Compelling evidence from FPD Industry: Standardization of thin film processes and equipments allows significant cost reductions and more effective R&D programs.

AVANCIS-Facilities

1st Production facility in Torgau - on glass industry site
STATUS

• Facilities completed
• Equipment move in starting
• Production planned for Mid 2008
• Recruitment of key personnel completed
  ▪ 100 employees by end of 2008

• Planning started for additional 80MW capacity on Torgau site
Manufacturing CuInS₂ solar modules
Sulfurcell Solartechnik GmbH, Berlin

A. Neisser
Sulfurcell Solartechnik GmbH
Barbara-McClintock-Str. 11, D-12489 Berlin, Germany

neisser@sulfurcell.de, Phone: +49-30-63923823, Fax: +49-30-63923800

Sulfurcell - More than 5 years of experience in CuInS₂ technology

Snapshot
• Based on new technology from Europe's largest research institute for thin-film PV (HMI Berlin)
• Erected in 2003
• Currently employing 100 people (12 specialists, 80 operators, technical/administrational staff)

Objectives of the pilot production
✓ Scale-up from 5 cm x 5 cm to 125 cm x 65 cm
✓ Prove feasibility of manufacturing
✓ Develop 50 MW capable processes
✓ Check out market perception
Now: Learning by manufacturing

Sulfurcell developed its technology in an industrial environment in order to optimise processes for mass production.
Steady increase of production output
Continuous improvement of best and average module efficiency

Key figures of Sulfurcell production
Cumulative power reaches ≈ 0.5 MW end of Q3-07
Continuous 7-days operation will start in Q4 → run rate of 2 MW in Q1/08

Introduction – Technology

- Architectural glass coating techniques
- Sputtering techniques for all thickness defining process steps
- Sputtering allows low capital expenditure for large production capacities

A simplified cell structure enhances process stability and robustness

- A high level of stability inherent in the production process is due to:
  - Simple cell structure
  - Sequential preparation of the compound CIS
- High productivity is driven by:
  - Use of highly reactive Sulfur instead of Se
  - Rapid thermal processing
  - Absorber formation in less than 5 minutes
- Cost saving materials
Introduction – Production process

A lean production process involving five deposition steps

Gap between lab and production further reduced

Comparison of small area and module efficiency

<table>
<thead>
<tr>
<th>Type</th>
<th>Cell</th>
<th>Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacture</td>
<td>Lab (HMI)</td>
<td>Prod. (SC)</td>
</tr>
<tr>
<td>Area [sqcm]</td>
<td>0.5</td>
<td>5 x 5</td>
</tr>
<tr>
<td>Status</td>
<td>certified [1]</td>
<td>06.06</td>
</tr>
<tr>
<td>Eff [%]</td>
<td>11.4</td>
<td>9.2</td>
</tr>
<tr>
<td>Voc [mV/cell]</td>
<td>729</td>
<td>680</td>
</tr>
<tr>
<td>FF [%]</td>
<td>71.7</td>
<td>69.5</td>
</tr>
<tr>
<td>Jsc [mA/cm²]</td>
<td>21.8</td>
<td>19.4</td>
</tr>
</tbody>
</table>

Substrate size - scale-up 2003-2004

The scale-up was successfully completed in 2004

Pictures of 125 cm x 65 cm sized CIS layers after sulfurisation

Initial process

Advanced process

Process: Rapid thermal processing of copper/indium layers under sulfur vapor (top-temperature: 500 °C)

Key scale-up challenge: Homogeneous, adhesive CIS
### Substrate size – some remarks

<table>
<thead>
<tr>
<th>Market – customer feedback</th>
<th>Manufacturing of large area substrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof installation</td>
<td>Processing / handling</td>
</tr>
<tr>
<td>• require for rather flexible montage zones - there is no standard roof yet</td>
<td></td>
</tr>
<tr>
<td>• Substrate size is limited by what a single workman can handle wrt. size and weight (1m², 30kg)</td>
<td></td>
</tr>
<tr>
<td>BPV - Facade integration</td>
<td>Layer deposition</td>
</tr>
<tr>
<td>• 2,5m seems to be common unique length for elements - BIPV products should be multiples of this</td>
<td></td>
</tr>
<tr>
<td>Large installation / power plants</td>
<td>• 6 x 3 m² glass substrates are common practice in glass industry</td>
</tr>
<tr>
<td>• high acceptance of 1m² format</td>
<td></td>
</tr>
<tr>
<td>• (highly automated installation might ask for large module sizes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Sputtering technology: is available</td>
</tr>
<tr>
<td></td>
<td>• Patterning: should not be a problem, although precise position of substrate and laser ±5µm challenging</td>
</tr>
<tr>
<td></td>
<td>• Rapid thermal processing: lateral homogeneous fast temperature and pressure ramps at area &gt;1m² still challenging, will require more R&amp;D efforts</td>
</tr>
<tr>
<td></td>
<td>Module finishing</td>
</tr>
<tr>
<td></td>
<td>• no problem</td>
</tr>
</tbody>
</table>

Sulfurcell sees a high acceptance of its current substrate size of 125 x 65 cm² at the market

### Marketing strategy – Focus on individual solutions such as BIPV

- **Roof top system**
  - Private house in France applying Sulfurcell's RI modules
  - Conventional roof-top systems

**Thin films offers excellent solutions for solar architecture**
Sulfurcell's approach in BIPV

Sulfurcell's guidelines in developing new products for solar architecture

- Solar modules should fit high aesthetic expectation in order to be attractive as building material
- Prices per square meter should not be higher than those of passive premium materials
- Installation of modules and installation system must be easy and standardised

Sulfurcell's products for BIPV

- Homogeneous, black
- High aesthetics at reasonable price
- Specialized frames

PV facade at the Ferdinand Braun Institut Berlin

Substrate size – Jumbo Module

The Jumbo Module

- Sulfurcell has designed a 3m² demonstrator for a 200W module suited for roof and facade integration (in cooperation with partner)
- Compatible in size with thermal solar collector
- Large size laminate of 3½ standard PV modules
- Presented at the PV conference in Dresden in Sept. 06
Summary

- Targets of pilot production – scale-up, feasibility, product development – fulfilled
- Targets in pilot line 2008
  - Drive continuous KPI improvement before next ramp-up step
  - Build-up knowledge about relevant technological and manufacturing issues (“make errors now, not later”)
- High acceptance of 125 x 65 cm² module size at the market
- Next step
  - Planning phase of ramp up to 50MW has already started
  - Product size will be same as in pilot
First Solar Company Overview

November 2007

Dave Eaglesham

Manufacturing ramp

- Proven replication at Base Plant
- Continuous improvement methodologies
- "Copy Smart" replication

<table>
<thead>
<tr>
<th>Year</th>
<th>25 MW</th>
<th>~100 MW</th>
<th>277 MW</th>
<th>435 MW</th>
<th>910 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>22</td>
<td>67</td>
<td>76</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>2006</td>
<td>24</td>
<td>67</td>
<td>76</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>2007</td>
<td>20</td>
<td>67</td>
<td>76</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>2008</td>
<td>20</td>
<td>67</td>
<td>76</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>2009</td>
<td>20</td>
<td>67</td>
<td>76</td>
<td>73</td>
<td>73</td>
</tr>
</tbody>
</table>

- Ohio Base Plant
- Ohio Expansion
- German Facility
- Malaysia 1
- Malaysia 2
- Malaysia 3
- Malaysia 4
Company Overview

910MW of Capacity in Operation or Under Construction [1]

Perrysburg, Ohio
- Scaled first module production line in the U.S. to steady state volume in 2005, added two production lines in 2006

Frankfurt (Oder), Germany
- Four production lines (158MW) constructed in Frankfurt (Oder), Germany which reached full production during second half of 2007

Kedah, Malaysia (under construction)
- Four, four-line plants (158 MW each) are under construction with full production targeted by second half of 2009
  - Plant 1 will reach full production during second half of 2008
  - Plant 2 & 3 will reach full production during the first half of 2009
  - Plant 4 will reach full production in second half of 2009

In November 2007 we increased the nameplate capacity from 30MW to 39.6MW per line

[1] Based on Q3ST run rate
Thin-film PV Industry Development in Greece

C Protogeropoulos
Solar Cells Hellas Group

Solar Cells Hellas Group of Companies

1. Production of Wafers, Solar Cells and PV Modules
   Solar Cells Hellas, SolTech and Energy Solutions

2. Design, Trading of Components and Construction of PV Systems
   RENI – Renewable Energy Innovations

3. Development of PV Stations
   Solar Datum, 4E Energy, Solar Concept, Spes Solaris etc.
Solar Cells Hellas SA – General

- Company founded in 2005.
- Factory now under development in the industrial zone of Patras.
- Production of crystalline silicon wafers, cells and modules.
- Final annual capacity 60MW.

Facilities: buildings 14.000m², land 37.000m².
- Working Positions: 230
- Member of EPIA.
- www.schellas.gr

Solar Cells Hellas SA – Patras Factory

- September 2006
- June 2007
- February 2007
Energy Solutions SA – General

- Company founded in December 2003.
- Located at Pernik industrial complex, 30km SW of Sofia, Bulgaria.
- Member of EPIA.
- [www.energysolutions.gr](http://www.energysolutions.gr)

Thin Film Fabrication Hellas SA

- Development of new facility for thin-film production in the Industrial Area of Patras.
- Building area 15,000m², land 47,000m².
- Tandem thin-film technology: a-Si(0.3μm)/μc-Si(1.5μm).
- Module dimensions: 1.3m×1.1m (area 1.43m²).
- Module nominal power and efficiency: 120Wp, η=8.4%.
- Envisaged annual production capacity: 30MW (250,000 modules)
- Collaboration with Oerlikon.
Sunrise solar cells

Side view of cell

ZnO
Absorber
Molybdenum
metal film
insulating polymer

$I_{ZnO}$

$I_{Mo}$
Proces steps:

1. Glass beads
2. Mo / CuIn
3. H$_2$S
4. Etch / Buffer
5. Glass beads
6. TCO
7. Polymers
8. Back contact
Helianthos solar cell laminates

Outline

- **Introduction**
  - Helianthos roll-to-roll solar cell laminate manufacturing
  - Pilot line
  - Flexible tandem PV laminates
  - Up scaling
Nuon, a leading energy company

Nuon is active in the generation, marketing, sale and transportation of (renewable) energy.

- Vertically integrated Dutch utility company
- Private company owned by provinces & municipalities
- Founded in 1998 from merger of regional Dutch utility companies
- Net turnover of ~ €5.6 bln,
- Total assets of ~ €10.8Bn; 9,700 employees
- 3,500 Mw power generation capacity
- Innovative company with sustainable business and financial profile; frontrunner in Renewable Energy (2006, 0.6 TWh)
- Core countries: The Netherlands, Germany & Belgium

Nuon Helianthos: Objective

Solar cell laminate products:
- Roll-to-Roll production technology
- Flexible & lightweight modules
- Si technology: abundant + eco-efficient

Structure solar cell laminate

- substrate
- back contact
- active layer
- TCO – transparent front contact
- protective layer
- electron
- hole
From pilot line to large scale production

Feasibility study lab cells

**Industrial piloting:**
- Roll-to-Roll Pilot Line
- Test marketing

**Large scale production**

- 1 km²/yr unit (~ 75 MWp)
- Gradual build up

Starting development with ‘integrators’, e.g. building (element) parties

- 1997-2000
- 2001 – 2008
- 2009 - ...

Roll-to-Roll Pilot Line

- 35 cm wide foil
- a-Si:H p-i-n single junction
- Monolithic series integration

**Objective:**
- Test industrial feasibility
- Process R & D
- Market development
Temporary ‘superstrate’: schematic processing sequence

- Al foil
- TCO deposition (SnO₂:F)
- a-Si:H deposition (/μc-Si)
- Back contact deposition
- Patterning
- Carrier lamination
- Temporary carrier removal
- Connection point / Cutting / Encapsulation
- [QC]

Helianthos process sequence

- TCO deposition: APCVD
- Si deposition: PECVD
- Back contact: sputtering
- Series connection
- Lamination of carrier foil
- Etching of temporary foil
- Contacting and cutting
- Encapsulation of modules
Efficiency pilot line PV laminates (apert. area stab.)

Damp Heat

Damp Heat test
Thermal cycling

Thermal Cycling-test

Tandem modules
Know How Partners

Utrecht University

FZ Jülich (IPV)

Delft University of Technology

TU/e

Eindhoven University of Technology

Netherlands Organization
for Applied Scientific Research

ECN

Energie Centrum Nederland

a-Si/μc-Si tandem module: increasing efficiency in lab line with know how partners

Stabilized eff. 8%
Large area modules

1 X 0.3 m²
Init. efficiency 6 %

Larger area modules

6 X 0.3 m²
Init. efficiency ~6%

Up scaling

- Substrate size
  From 0.3 m (pilot) to 1 – 1.5 m wide (production)
- Roll length
  1 km (pilot) to 3 – 5 km (production)
- Annual capacity
  From 0.001 – 0.01 km²/yr (pilot) to 1 – 10 km²/yr (production)
- Efficiency
  Single a-Si (6 - 7% a.a.s.) - tandem a-Si/nc-Si (9 - 11 %) - third gen (15 – 20 %)
- High throughput active layer deposition incl. efficient duty cycle
- Abundant, eco-efficient materials
- Improved materials functionality and utilization e.g. foils, resins
From roll-to-roll process to electricity production on the skin of buildings

In the Netherlands 70 m² a-Si laminate produces the electricity for average household (3500 kWh /yr)

Conclusions

- Development proceeding rapidly
  - Pilot line running for 30 cm wide a-Si solar cell laminates
  - Performance and reproducibility increasing
  - Larger modules produced (up to 6 meter long)
  - Field testing started
  - Up scaling starting

- New pilot facility – under construction

- Good progress towards affordable solar electricity
Manufacturing and Performance of CIS Modules
Large Volume Production of Würth Solar

Bernhard Dimmler
Würth Solar GmbH & Co. KG
Schwäbisch Hall
Germany
bernhard.dimmler@we-online.de

www.wuerth-solar.de

Outline: - company
- development of thin film PV
- Würth Solar: status and prospects
- products and performance

Wurth Solar
New production facility

worldwide first CIS module
Volume Production

1999 – 2006:
pilot production with 1.5 MW/a
Proof of concept
• CIS with high quality
• high productivity

2005/2006: 18 month from ground Breaking to full capacity running

2007: 15 MW running

Further scaling until spring 2008
Up to 30 MW/a
Würth Solar
New production facility

- Capital investment: 55 million €
- Total facility area: 22,000 sqm. incl. administration and warehouse
- Annual output: 15 MW (200,000 CIS-Modules), 30 MW already included in planning
- Employees: 140 (as of 2007), continuous shift operation

The CIS Thin Film Module

Series connection of two CIGS cells:
- active cell width: 3 – 8 mm
- connection width: 0.3 – 0.4 mm
- number of cells in product: 1 - 75 (- 500)
CIS Technology Roadmap

ZSW laboratory line: 30 x 30 cm²
Würth Solar production: 60 x 120 cm²

Improvements in Production
Technological Roadmap

Product quality: average module efficiency: > 14 %
by continuous process optimization, stabilization and innovations

Productivity: - improvement of overall process yield: > 90 %
by continuous process optimization and improved process control
- reduction of cycle time, mainly CIS by technological improvements and innovations <<10min.
- longer term: increasing product area in production

Materials: reduction amount of material (yield, thickness),
recycling of production waste,
longer term: new module concepts (foils)
Why a EPIA-SEMI PV Standards Technical Committee?

1. European procedures are too complicated to follow and too low (confusion and chaos)

2. No control from the Industry on what the standard institutions are developing

3. Unclear added value for the end-user

4. Develop only useful standards for the industry
Benefits of EPIA-SEMI PV Standards Technical Committee

1. SEMI Standards have an excellent development time when compared with other Standards Developing Organizations.

2. The Standards will be developed by the industry for the industry (volunteers assigned by their companies):
   > Integration of the Industry inside the standardisation process will achieve the Development of the ‘right’ standards

3. Global Scope

4. Easy Participation (most communication is electronic with increased usage of teleconference and web-based applications)

Benefits for the Industry

New or improved standards will contribute to:

- Reduce costs in design, production and deployment
- Foster fair and transparent competition
EPIA-SEMI PV Standards Technical Committee

- **Aim:** Implementation of new standards (Quality & Performance) and update of the existing ones.
- **Scope:** Cover the whole value chain from feedstock to BOS

- **Co-Chairs:**
  - Dr. Hubert Aulich (Crystalox Solar)
  - Dr. Laszlo Fabry (Wacker chemie)

- **Current Activities:**
  - Defining the Structure of the Committee (by products, by markets, by specific request from the Industry, etc.)
  - Gathering the industry needs (questionnaires)
  - Creating the first Taskforces

Possible Structure by Products

---

SEMI-EPIA PV Standards Technical Committee, ISPRA 23th November 2007
Possible structure by Markets

<table>
<thead>
<tr>
<th>Material used</th>
<th>Components</th>
<th>Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminates</td>
<td>III-V</td>
<td>Org</td>
</tr>
<tr>
<td>Glass</td>
<td>Si, Ga, Ge</td>
<td>TF</td>
</tr>
<tr>
<td>Paste</td>
<td>mc, mc</td>
<td>mc, mc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OIS</td>
</tr>
<tr>
<td></td>
<td>Vector</td>
<td></td>
</tr>
<tr>
<td>Cell Mod.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PECVD</td>
<td></td>
</tr>
</tbody>
</table>

First Task Force on EIS (Equipment Interface Specifications)

1. Creation of the Task Force and nomination of the leadership (Milan, 7th September 2008)
2. Definition of structure, working group and participant (Stuttgart, 10th October)
3. Expected publication of the Standards (October 2008)
PV-EIS Task Force - Structure

CORE GROUP
Working Group

Manufacturers
(materials, cells, modules, …)

Equipment Manufacturers

Solution Providers & Integrators

Institutes & Others

Task Force

Survey of Rules

Organization

Editing of Results

CO-CHAIR(s)
ISE
Solarworld
Manz

Technical Editor
Acp-IP

Coach
ISE
IPA

Working Group: Scope and structure

Working group 1
- Specification of EI requirements
- Evaluation of existing EI standards

Working group 2
- Evaluation of EI existing in PV
- Specification of PV EI Standard
**Work Group 1 – Sign Up / Lead**

**Task:** “Specification of EI requirements”  
**Lead:** M. Boltz, acp-IT

**Equipment Manufacturers:**  
- Oerlikon  
- Manz

**Manufacturers (material, cells, modules):**  
- Ersol  
- DC  
- Conergy  
- Q-Cells

**Solution Providers / Integrators:**  
- AIS  
- Camline  
- acp-IT  
- Cimetrix

**Institutes and Others:**  
- IPA  
- ISE

SEM-IPIA PV Standards Technical Committee, ISPRA 23th November 2007

---

**Work Group 2 – Sign Up / Lead**

**Task:** “Evaluation of existing interfaces and standards”  
**Lead:** M. Glaser, Manz

**Equipment Manufacturers:**  
- Centrotherm  
- Manz  
- Rofin SINA  
- R&R

**Manufacturers (material, cells, modules):**  
- Siemens  
- acp-IT  
- AIS

**Solution Providers / Integrators:**  
- Siemens  
- acp-IT  
- AIS  
- Cimetrix

**Institutes and Others:**  
- IPA  
- ISE

SEM-IPIA PV Standards Technical Committee, ISPRA 23th November 2007
Thanks for your attention

All of you are welcomed to participate in the SEMI-EPIA program for PV standards
How can a new and emerging technology as Thin Film PV profit from Standardization?

Werner Bergholz

Outline

• What is standardization?

• What is the benefit?

• How?
What is standardization?

- **What it is not:** Static $\rightarrow$ block progress

- **A standard is a „living“ dynamic document**
  - Regular reviews
  - At the latest after 5 years
  - Takes into account technical progress
  - Enables improvement
  - Enables elimination of mistakes

What is standardization?

- **Examples for standards:**
  - A4 paper, USB computer accessories
  - generic purchasing specification(s) for equipment or materials
  - A standardized characterization method
  - A standardized equipment or PV cell assessment

- **What kind of systematics can we find for standardization?**

- **Common factor:** an element of the supply chain
What is standardization?

- **PV Supply chain**

  - Materials
  - Cell Process
  - Product Assessmt
  - Assembly Service
  - equipment

What is standardization?

- **PV Supply chain: standards at interfaces**

  - Materials
  - Cell Process
  - Product Assessmt
  - Assembly Service
  - equipment
What is standardization?

• **PV Supply chain:** standards along the complete value chain

![Diagram showing the PV supply chain with stages: Materials, Cell Process, Product Assessment, Assembly, Service.]

What is standardization?

• **Examples: Assessment**
  – Standard for measurement of material parameters
  – Standard for assessment of uptime, productivity, safety of equipment
  – Standard for assessment of certain product properties, such as efficiency, durability, reliability
  – ....
What is standardization?

- **Examples: enabling technology**
  - Standards for mechanical interfaces between equipment – transport containers
  - Standards for electronic interfaces between
    - Equipments
    - Equipment and Manufacturing Execution system
    - Equipment and data warehouse
  - Standards for production logistics interfaces

Outline

- **What is standardization?**
- **What is the benefit?**
- **How?**
Benefits

• **DIN study: general advantages**
  - *Multiple sources decrease cost and increase security of supply*
  - *Standardization lowers the entry barrier for competition*
  - *VW: standardized components: 40 – 60% cost reduction*
  - *Airbus: factor of 15 reduction of cost for standardized components, A320: 18 million savings in reduction of storage costs*

Benefits

• **SEMI examples**
  - **1973: Si wafer shortage**
    - *due to “inflation” of Si wafer specifications*
    - *First SEMI M1 standard quickly adopted by 80%*
    - *higher productivity \( \rightarrow \) enough Si wafers*
  
  - **1990s: EHS standard S2**
    - *Reduction of start up time for each tool: 2 weeks*
    - *Total cost savings: 6 Million \$ = 1\% of total cost*
Benefits

• **SEMI examples**
  – **SEMI GEM SECS software standard**
    • Interface between equipment and MES system
    • Before: “Tower of Bable”
    • After: plug and play

  ➔ **reduction of IT cost for host site software by 80%**

Benefits

• **More „knowledge-management“ Benefits**
Outline

• What is standardization?

• What is the benefit?

• How?

How

Standard Development Organisations

• SEMI: Semiconductor Equipment and Materials International
  • Industry Association of Microelectonics and FPD suppliers
  • > 750 standards for
    – Wafers, chemical, gases, other materials
    – Equipment assessment stds (uptime, EHS,...)
    – Mechanical and software interface standards
  • Worldwide standards (North America, Europe, Japan, Korea, Taiwan, China, Russia)
  • Consensus process: votes by companies
  • Cycle time: 12 – 18 months
How

- IEC (International Electrotechnical Commission)
  - National standardisation bodies contribute, not individual companies (DKE, BSI, ANSI,...)
  - > 8000 standards for all sorts of electrotechnical applications
    - Photovoltaics
    - Nanoelectronics
  - Worldwide standards
  - Consensus process: votes by country
  - Cycle time: 36 months

How

- Which SDO should do what?
  - SEMI → early parts of supply chain
  - IEC → later parts of supply chain
How

• Standards and emerging technology?

• Example 1: Chip industry transition from 200mm to 300mm wafers

• Example 2: Nanoelectronics

How

200mm $\rightarrow$ 300mm

– Consortium of 14 companies: I300I
– Development of a whole suit of anticipative standards
– Results: Best practice generic process for
  • Si wafers specifications including wafer mark
  • Wafer carriers and mechanical interfaces
  • Software and performance standards

– Saved many million dollars per 300mm fab!
How

200mm → 300mm: Usage of standards

Has the Availability of 300 mm Standards Increased or Decreased Your Use of SEMI Standards Over the Last Four Years?

Figure 2a – Increase in use of standards (300 mm standards have significantly increased the use of standards in the semiconductor industry)

How

200mm → 300mm: Usage of standards

Do Companies Customers and/or Suppliers Cite or Reference SEMI Standards

(All Respondents)

Yes 70%

Do Not Know 14%

No 7%
How

300mm → 450mm:
standards work starts now, production in 2014

Example 2: Nanotechnology
- ISO TC 229 started up in 2006
- IEC TC 113 started up in March 2007
- Several (joint) working groups on
  - Terminology
  - Characterization
  - Environment, Health, Safety
  - Performance assessment (for nano-enable electronic feature)

- PV: cells based on TiO2 and Carbon Nano Tubes are on offer already now!
How

Example 2: Nanotechnology

Take Home Message

- Standards as a „best practice“ Supply Chain elements
- Based on voluntary cooperation between industry volunteers and other stakeholders
- SEMI: Materials, Equipment, Process
- IEC: Product and Product performance
- It is never too early for standardization
- Microelectronics: Guestimate 10-30% savings 200mm → 300mm
PV CYCLE

Motivation, Objective and Benefits

3rd International Thin Films workshop

Daniel Fraile

European Union Waste Policy

Principle: The industry must be responsible for its products

- RoHS: Directive 2002/95/EC on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment

- Both directives entered into force on 13 February 2003 and require Member States to transpose their provisions into national law by 13 August 2004
WEEE Directive

- Objectives: The priority of this directive is the prevention of production of wastes from electrical and electronic equipment (WEEE) and their reuse, recycling and recovery of such wastes so as to reduce disposal.
- Each producer is responsible for financing the collection, treatment, recovery and disposal of its own products
- The scope of the Directive is defined in Annex IA/IB: PV modules are not listed in Annex IA/IB
- Legal basis: Article 175 EC Treaty

Revision of the WEEE Directive

- Two studies have been organized by the EC in order to prepare the revision of the WEEE directive (2008):
  - The producer responsibility principle of Directive 2002/96/EC WEEE
    Contractor - ÖKOPOL – Institut für Ökologie und Politik GmbH - on December 2006
ROHS Directive

RoHS: Directive 2002/95/EC on the Restriction on the Use of Certain Hazardous Substances in Electrical and Electronic Equipment

- Member States shall ensure that, from 1 July 2006, new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).
- Legal Basis: Art. 95 of the Treaty

Review of the ROHs Directive

Possible objects of the review: scope of the directive, substances covered

- May 2007: Consultation with stakeholders- end of the first stage.
- 2008: Consultation with stakeholders on options for the revision of the Directive
- Late 2008: expected presentation of the legislative proposal for the review of the ROHs directive
Motivation to found PVCYCLE

- EU legislation and transposition to the national laws
- Environmental producer responsibility
- Maturity of the industry

Waste Forecast By Weight

<table>
<thead>
<tr>
<th>Year</th>
<th>Germany</th>
<th>Total Europe</th>
<th>USA</th>
<th>Japan</th>
<th>Rest of World</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2008e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2009e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2010e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2011e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2012e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2013e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2014e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2015e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2016e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2017e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2018e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2019e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2020e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2021e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2022e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2023e</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

35,397 t 132,750 t
Environmental targets

As a renewable energy source, PV industry must contribute with convincing solutions to the protection of the environment by promoting increased use and sustainability of PV technology.

The PV industry must meet the global climate protection requirements.

Necessary:
- Sustainable solutions along the whole value chain
- General waste management and recycling policy
- Guaranty the highest economically feasible collection and recovery rates
- Appropriate treatment of waste PV modules
PV CYCLE Association

• Founding of PV CYCLE Association 2007-07-05 in Brussels

  (EPIA & BSW with the support of 6 PV companies at the beginning)

• The association is established as a nonprofit international management system

• Organized under private law

• financed by the fees of its members

Aims

• Structuring of best paths and methodologies for waste management of PV modules under consideration of national and international legislation

• Elaborate immediately a voluntary take back and recovery system for PV modules

• Evaluation of best practice standards for logistic structures

• Support of research projects (e.g. IEA PVPS Task 12)

• Ensure regularly monitoring

• Public relations in the field of sustainable production and PV waste treatment

• Collection and publication of environmental relevant data
Benefits

- Secure the positive image of PV and therefore the public support of the PV market
- Avoid unfavorable and expensive waste regulations

Revision object of two studies, results have been published on 15th November 2007:

None of these two studies suggest the inclusion of PV modules in the scope of the WEEE Directive.

Tasks

**Short term tasks**
- Establishment of a voluntary take back and recovery system for PV modules

1 – 2 years

**Long term tasks**
- Operation of take back system
- Provide solution for possible environment, health and safety issues
Long term tasks

• Clearly competitive advantage in the market for PV CYCLE members
• Preparation of verifiable databases of PV issues
• Realization of highest collection and recovering rates (example):

Next Activities

Fill the position of the general secretary 2007-end
Formation of working groups 2007-end
Establishment of the take back system 2008
Start of collection 2008
Members

All PV companies with accountability for photovoltaic waste, (e.g. manufacturers, importers and suppliers along the entire value chain of PV products) can become members of the association.

Current Members:
• Avancis
• BP Solar
• Conergy
• First Solar
• Isofoton
• Kyocera
• Q-Cells
• Sanyo
• Schott Solar
• Scheuten Solar

High market share of PV manufacturers:
• Sharp
• Solarfabrik
• Solarworld
• Solon AG
• Solyndra
• Sulfurcell
• Sunways
• Würth Solar
• EPIA
• BSW
• ECN

Thanks for your Attention

Further information: www.pvcycle.org
History

2003  First publications on waste treatment, WEEE, life cycle issues voluntary take back systems with kind support of JRC, IES and EPIA Ökopol Study on waste treatment of modules

2004  Workshops on waste, LCA, WEEE and take back systems Ongoing work in SP6 of EU project “CRYSTAL CLEAR”

2005  First PV CYCLE initiative supported by EPIA and BSW, creation of working group PV CYCLE First initiatives for IEA PVPS Task 12

2006  Drafts of Statutes and Business Plans

2007  Study PVCYCLE supported by BMU, Germany Foundation of PV CYCLE Association
WEEE Directive

- Most important provisions
- Art. 2: scope of the directive
- Annex I A: categories of EEE that fall within the scope of the directive
- Annex I B: list of products belonging to categories in Annex IA to which the Directive applies
- Art. 5: rate of separate collection of at least four kilograms on average per inhabitant per year of WEEE from private households
- Art. 6: treatment
- Art. 9 financing of WEEE collection and treatment

Structure

The association is established as a nonprofit international management system which is organised under private law and financed by the fees of its members.
PV CYCLE

• Collection/Recycling Targets (Collection Rate)

Collection

PV CYCLE

• Collection/Recycling Targets (Recovery Rate- Example)
Founding members

- Avancis
- Conergy
- Isofoton
- Schott Solar
- Solarworld
- Sulfurcell
- EPIA
- BSW

Objectives

- Promote the protection of the climate and the environment in enhancing increased and sustainable use of PV technology.

- Create a positive environment for the ongoing growth of the PV industry

- Install an overall waste management policy
  - guarantees highest economically feasible collection and recovery rates
  - appropriate treatment of waste PV modules.
Next Tasks

- Implementation of the take-back system
  - Concept development and implementation
  - Call for tenders, selection of the service providers
- Operation of the take-back system
  - System management
  - Scheduling and controlling the take-back volumes and waste volumes
  - Controlling the service provider
  - User support
  - Auditing and certification of the system
  - Continuous enhancement of the system

WEEE Directive

Current development

WEEE will be revised in 2008

- Possible object of the revision: scope
- Procedure: codecision.
- Key actors: Parliament, Commission, Council
ROHS Directive

- Current Developments
- Review of the Directive
- Possible objects of the review: scope of the directive, substances covered

Current Activities

Commun agreement of EPIA-BSW members to do:

- Assessment to identify which are the most appropriate solution for the PV industry for waste treatment (take back system).
- Lobbying Activities
Survey Status

- Co-financed by EPIA, BSW and BMU

START
20th May 2007

FIRST OUTCOMES
mid of July 2007

END
End of October 2007

Survey Structure

1. Background and framework.
   - PV Market, technologies, industry, Policy framework, WEEE&RoHs,
     take back systems, possible reaction
2. Recycling processes and techniques
   - Cristalline cells, thin film, perspective
3. Option: Voluntary system
   - Take back system, recovery system, carrier organization, legal and
     juridical aspects
4. Option: WEEE
   - Legal consequences, etc.
5. Options
   - Business as usual with WEEE and without WEEE
6. Overall summary and recomendations (30/10/07)
Survey Partners

- EPIA
- BSW
- Ökopol
- Dörte Fouquet
- ZSW

- Deutsche Solar
- Sharp
- Isofotón
- First Solar
- Würth Solar

Revision object of two studies, results have been published on 15th November 2007:

None of these two studies suggest the inclusion of PV modules in the scope of the WEEE Directive.
PV-Cycle: Overview Thin Film

- PV-Cycle Association
- PV-Cycle Study
- Recycling Technologies for Thin Film PV
- Summary

PV-Cycle Association: Statutes

- Statutes:

  Section 2: Purpose and Principles:

  ...

  (8) The Association wants to ensure non discriminatory take back and recycling systems which guarantee best possible solutions at best cost- and technology-efficient level for all PV technologies, non regarding their market share.
PV-Cycle Association: Bye laws

1. Membership fee

1.1. The fiscal year of the Association shall be the calendar year. The payment of the membership fee shall be due on 31 March each year.

1.2. The annual membership fee of the members of the Association shall be calculated as follows according to their respective category:

<table>
<thead>
<tr>
<th>Membership category</th>
<th>Turnover in the PV module business in Europe of the member in the previous calendar year</th>
<th>Annual fee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full member category I</td>
<td>&gt;100 Mio €/a</td>
<td>25,000 €</td>
</tr>
<tr>
<td>Full member category II</td>
<td>10-100 Mio €/a</td>
<td>12,500 €</td>
</tr>
<tr>
<td>Full member category III</td>
<td>&lt;10 Mio €</td>
<td>5,000 €</td>
</tr>
<tr>
<td>Associated members</td>
<td>Minimum 1,000 €</td>
<td></td>
</tr>
</tbody>
</table>

In the founding year 2007, a full annual fee has to be paid in order to build up the association. If a company becomes a member during the following years it has to pay the full annual membership fee.

---

2. Voting rights in the General Assembly

2.1. Only full members are entitled to vote.

2.2. The voting rights for full members are allocated as follows, according to their category as defined in article 1.2. above:

<table>
<thead>
<tr>
<th>Category</th>
<th>Voting rights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full member category I</td>
<td>3</td>
</tr>
<tr>
<td>Full member category II</td>
<td>2</td>
</tr>
<tr>
<td>Full member category III</td>
<td>1</td>
</tr>
</tbody>
</table>
PV Cycle, general assembly

goals / time schedule / first cost estimates

Data: general assembly, K. Wambach, Deutsche Solar

no transport of single modules
suites not included

© 3rd Int. PV-Industry Workshop on Thin Films, 22/23 Nov 2007 R. Schäffler
Plans for 2008:

- Individual recycling on company level
  - Figures (recycling path, amounts, cost) have to be made transparent to PV-Cycle
- PV-Cycle Association will charge a professional company to setup a recycling system (solution for collection place, boxes, labelling, system monitoring, ....)

PV-Cycle: Study

- Study shall be finalized by 30.11.2007
- Study will be distributed
- Few Preliminary results
Structure Study

1 Introduction

2 Background and framework
   2.1 PV market
   2.2 PV technologies
   2.3 PV industry
   2.4 Political Framework
   2.5 WEEE RoHS
   2.6 Take back systems
   2.7 Possible reactions
   2.8 Summary and recommendations

3 Recycling processes and techniques
   3.1 Recycling crystalline cells
   3.2 Recycling thin film
   3.3 REACH and recycling
   3.4 Perspective
   3.5 Summary and recommendations

4 Option: Voluntary system
   4.1 Voluntary take back system
   4.2 Voluntary recovery system
   4.3 Carrier organisation
   4.4 Legal and juridical aspects
   4.5 Summary and recommendations

5 Option: WEEE
   5.1 Legal consequences
   5.2 PV part of WEEE recovery system
   5.3 Other possibilities
   5.4 Summary and recommendations

6 Options
   6.1 a Business as usual and no WEEE
   6.1 b Business as usual + WEEE
   6.2 Action option
   6.3 Summary and recommendations

7 Overall summary and recommendations

PV-Cycle Study: Scenarios and their costs

Business as Usual (BAU)
Waste treatment of PV modules by the existing waste systems, financed by the user

WEEE
Waste treatment of PV modules organized and financed by the producer

Voluntary Agreement (VA)
Waste treatment of PV modules organized and financed by the producer (collected share) but: share of not collected waste has to be financed by the user with its waste fee

(not an option)
Recycling Technology: Outline of the recycling process for CIS TF modules (mainly developed in “SENSE”)

- Metal-rich CIS Manufacturing Waste
- EoL Modules and poor manufacturing waste
  - Thermal treatment
  - Mechanical separation
  - Crushing, milling, screening

Metallurgical Treatment: Options
a) Hydro metallurgical Treatment (Sense, e.g. Umicore)
   - Indium
   - Gallium
   - Selenium
   - Glass
b) Pyrometallurgical Treatment (e.g. PPM)
   - Residual wastes

Dr. J. Springer, ZSW
First Solar will open its recycling system for other companies (announcement Pierre Yves Le Borgn at general assembly)

Recycling Technology: a-Si

- Recycling technology for a-Si, a-Si/μ-Si?
- Recycling for a-Si on foil?
  ⇒ Input to PV-Cycle
Recycling Costs and Avoidable Costs

CdTe and CIS Recycling costs (Zweibel, BNL)

Cost of Recycling vs Disposal

Dr. J. Springer, ZSW
Summary

• improve participation of thin film industry in the PV-Cycle association
  ⇒ get member of PV-Cycle

• Use Recycling as marketing instrument
  ⇒ PV is a real green technology

• Improve / set up recycling technology
  ⇒ use test phase 2008
IP PERFORMANE PROJECT

A science base on PV performance for increased market transparency and customer confidence

ISPRA, 23 November 2007
Daniel Fraile

PERFORMANCE
PV Modules and Systems – Measurements, Quality, Standardization

is an EU co-funded project with

<table>
<thead>
<tr>
<th>Total Budget</th>
<th>11.8 Mio €</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of partners</td>
<td>28</td>
</tr>
<tr>
<td>Start date</td>
<td>01 January 2006</td>
</tr>
<tr>
<td>Duration</td>
<td>4 years</td>
</tr>
</tbody>
</table>
Project partners: Research

- Fraunhofer ISE, Freiburg, DE
- PSE, Freiburg, DE
- CIEMAT, Madrid, ES
- WrUT, Wroclaw, PL
- Joint Research Centre, Ispra, IT
- TÜV, Cologne, DE
- ECN, Petten, NL
- CREST, Loughborough University, UK
- CEA-GENEC, Cadarache, FR
- SUPSI-TISO, Canobbio, CH
- UNN-NPAC, Newcastle, UK
- ZSW, Stuttgart, DE
- Arsenal, Wien, AT
- Ben Gurion Univ., Beer Sheva, IL
- Tallin Univ., Tallin, EE
- FH Magdeburg, Magdeburg, DE
- SP, Boras, SE
- PCCL, Leoben, AT
- Ecofys, Utrecht, NL

Project partners: Industry

- EPIA, Brussels, BE
- Isofotón, Malaga, ES
- Würth Solar, DE
- Phönix Sonnenstrom, Sulzemoos, DE
- Conergy, Hamburg, DE
- RWE Schott Solar, Alzenau, DE
- Scheuten Solar Systems, Venlo, NL
- MeteoControl, Augsburg, DE
- IT Power, Basingstoke, UK
Why do We need PERFORMANCE?

- Comparability of cell and module measurements?
- Annual yields and yield predictions?
- Module lifetime?
- Degradation?
- New technologies (a-Si, CdTe, CuInSe, CuInS...)?

Justification

There is much knowledge on measurement and testing procedures as well as PV PERFORMANCE prediction and assessment, but

- it is not integrated from production to application
- it is not implemented in real life
- it is often not helpful in the daily life
- there is not sufficient knowledge concerning thin-film technologies
- thereby it is not sufficient for industry and market needs in a multi gigawatt market
**Approach**

PERFORMANCE provides the necessary knowledge and methods to fulfil the market’s needs for transparency and planning safety

- Improvement of yield predictions
- Harmonising of measurements and tests
- Considering new (thin-film) technologies
- Life-time and Quality
- Modules and System

**8 Subprojects:**

1: Traceable performance measurements of PV devices
2: Energy delivery of PV devices
3: Performance assessment and evaluation of PV systems
4: Modelling and analysis
5: Service life assessment of PV modules
6: PV as a building product
7: Industry interaction and dissemination
8: Standardization processes
Subproject 1: Traceable performance measurements of PV devices

• Improvement of measuring and calibration methods
• Harmonising of measuring methods between test labs and industry
• Development of guidelines for power characterisation of PV cells and modules
• Adaptation of measurement procedures for new and emerging technologies (thin film cells, multijunction cells, back contact silicon cells, etc.)

Subproject 2: Energy delivery of PV devices

• Bridge the gap between indoor STC measurements and outdoor ‘real world’ measurements for any place in Europe
• Determination of annual module energy yield from a minimum set of measured parameters
Subproject 3: Performance assessment and evaluation of PV systems

• Analysis of system performance data towards an understanding of yields and losses
• Analysis of system performance data towards an understanding of long term stability
• Harmonisation / adaptation of guidelines for plant monitoring and operation surveillance
• Assessment of different approaches towards ‘guaranteed results’

Subproject 4: Modelling and analysis

• Development of a coherent set of models of PV module and system performance
• These models will translate PV module data and PV component data into system performance figures and link to long term data sets of ambient conditions
Subproject 5: Service life assessment of PV modules

- Develop ageing models based on ‘real life’ stress factors
- Develop new accelerated ageing procedures
- Facilitate innovation in module technology
- Provide manufacturers with service life data for setting their guarantee specifications
- Increase planning reliability

Subproject 6: PV as a building product

- Assessment of standards and performance requirements for building integrated PV modules towards
  (a) mechanical stability,
  (b) electrical safety,
  (c) fire safety

- Suggestions for module technologies which fit into the existing codes of the building industry
Subproject 7: Industry interaction and dissemination

- Identify the needs of PV markets, producers, installers, customers and investors
- Accelerate feedback loops between industry and standardisation processes
- Communicate project results to industry, politics and users in a rapidly growing market

Industry interaction

- EPIA is full consortium member
- EPIA appointed one company as industry contact for each technical SP

SP1: Isofotón
SP2: Shell Solar / Würth Solar
SP3: Phönix Sonnenstrom
SP4: Conergy
SP5: Schott Solar
SP6: Scheuten Solar Systems
Subproject 8: Standardisation processes

- Contribute to revision of standards
- Initiate new standards
- Develop a long term vision for European standardisation
Upcoming Workshop

- Topic: Energy Rating and Performance Standards of PV Modules
- Place & Date: 12th December 2007, Berlin
- Further information: 
  - www.pv-performance.org
  - www.epia.org

Thanks for your attention!
The Current Situation of International PV Standards

Dr. Ewan D. Dunlop
European Commission JRC

IEC Origins, St. Louis Declaration, 1904

• “That steps should be taken to secure the co-operation of the technical Societies of the world by the appointment of a representative Commission to consider the question of the standardization of the Nomenclature and Ratings of Electrical Apparatus and Machinery.”
  • IEC Statutes drawn up London 1906
  • Lord Kelvin, 1st President
 “…it is actually the ancient EEC that raised, for the first time, the idea and need to coordinate and harmonize standards in all EEC member countries in order to achieve a common market for electrotechnical goods…” This principle is reflected in the Treaty of Rome itself, where Article 100 is of capital importance: "Member States resolved unanimously to abolish existing trade barriers created through legislation and standardization".

By the end of 1959, some principles, which are still valid today, had already been drawn up:
- Priority to IEC work wherever possible
- Mutual information on new national work
- Technical co-operation in technical groups
- Cooperation in testing and certification

IEC TC 82 and CENELEC TC 82

- Established 1981,
- WG 1, WG 2, WG 3
- WG 4
- WG 5, WG 6, - WG 4,
  - - WG 5, WG 7
- More than 60 Standards Published (2.5 per year)
- CENELEC TC 82 have published, adopted some 30 documents
Scope of IEC TC 82

- To prepare international standards for systems of photovoltaic conversion of solar energy into electrical energy and for all the elements in the entire photovoltaic energy system.
- In this context, the concept "photovoltaic energy system" includes the entire field from light input to a solar cell to and including the interface with the electrical system(s) to which energy is supplied.

In particular:

- characteristics of the radiation input
- solar electric conversion devices
- energy storage and power conditioners
- the interface with the electrical system(s)
- the interconnection equipment and materials
- system integration and project management.
TC82 and the last 25 years

- 2006:
  - 1700 MWp (31%/yr)
  - 5000 MWp Total
  - 5 \$2002 / Wp (-6.5%/yr)

- 1981:
  - 18 MWp
  - 30 MWp Total
  - 25 \$2002 / Wp

TC82 and the PV Future

- 2010: 10 GWp / yr (40%/yr)
- 2020: 100 GWp / yr (26%/yr)

- Major Markets:
  - Professional Grid for Peak Demand
  - Rural Electrification
Anticipate Needs from IEC Chairman Presentation 2007

- Lifetime Energy Production
  How many years to pay back investment?
- Reliable Electricity Delivery in Rural Regions
  How to Design Complex Hybrids?
- Reduce Costs of Building Integration
  How to avoid the trap of labour costs?
- Meet Environmental Standards
  How to meet the expectations for clean energy?

Lifetime Energy Production

- Global Market Value of Calibration:
- ± 2% equivalent to ± 500 Mio$ revenue in 2010, when 10 GW are produced

<table>
<thead>
<tr>
<th>Today</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power</td>
<td>(± 2%) Calibration</td>
</tr>
<tr>
<td>Yearly Yield</td>
<td>(± 10%) Energy Rating</td>
</tr>
<tr>
<td>Equivalent Lifetime</td>
<td>(± 30%) EoL testing?</td>
</tr>
</tbody>
</table>
Trade Barriers

- Global/European Markets:
  - Wafers, Cells, Modules, BOS, Systems
  - Building Integrated components
- Major Technical Barriers Do Exist:
  - Inverters (2006 sales: ~ 600 Mio$)
  - Grid interface
  - Safety
  - EMC, Recycling/Disposal, Env.friendly Mat.
  - Project Management / Design Quality

International Schemes

IECEE

Worldwide System for Conformity Testing and Certification of Electrical Equipment and Components (IECEE)

“The Scheme is intended to reduce obstacles to international trade which arise from having to meet different national certification or approval criteria. Participation of the various NCBs within the Scheme is intended to facilitate certification or approval according to IEC standards.”

“mutual recognition”
Calibration Traceability and Power Determination

Work in progress by TC 82

IP Performance sub Project link in order of importance

IEC 60904-2 Ed. 2.0 SP1, SP2, SP3
Photovoltaic devices - Part 2: Requirements for reference solar devices

IEC 60904-3 Ed. 2.0 SP1,SP2, SP4, SP3
Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data

IEC 60904-4 Ed. 1.0 SP1,
Photovoltaic devices - Part 4: Procedures for establishing the traceability of the calibration of photovoltaic reference devices

Calibration Traceability and Power Determination (2)

Work in progress by TC 82

IP Performance sub Project link in order of importance

IEC 60904-7 Ed. 3.0 SP1,SP2, SP4, SP3
Photovoltaic devices - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices

IEC 60904-9 Ed. 2.0 SP1,SP2, SP4,
Photovoltaic devices - Part 9: Solar simulator performance requirements

IEC 60904-10 Ed. 2.0 SP1,SP2, SP4,
Photovoltaic devices - Part 10: Methods for linearity measurements

214
## Performance Measurement and Energy Rating

<table>
<thead>
<tr>
<th>Standard</th>
<th>Edition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 6091</td>
<td>Ed. 2.0</td>
<td>SP2, SP1, SP3, SP4, SP5, SP6</td>
</tr>
<tr>
<td>IEC 61853</td>
<td>Ed. 1.0</td>
<td>SP2, SP1, SP3, SP4, SP6</td>
</tr>
</tbody>
</table>

Description:
- Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices
- Performance testing and energy rating of terrestrial photovoltaic (PV) modules

## Lifetime Type Approval and Product Quality

<table>
<thead>
<tr>
<th>Standard</th>
<th>Edition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61646</td>
<td>Ed. 2.0</td>
<td>SP5, SP1, SP2, SP4, SP6</td>
</tr>
<tr>
<td>IEC 62108</td>
<td>Ed. 1.0</td>
<td>SP5</td>
</tr>
<tr>
<td>IEC 62145</td>
<td>Ed. 1.0</td>
<td>SP5, SP1, SP2</td>
</tr>
<tr>
<td>IEC 62234</td>
<td>Ed. 1.0</td>
<td>SP6, SP5</td>
</tr>
</tbody>
</table>

Description:
- Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval
- Concentrator photovoltaic (CPV) modules and assemblies - Design qualification and type approval (IEC 62108 Ed. 1)
- Crystalline silicon terrestrial photovoltaic (PV) modules - Blank detail specification
- Safety guidelines for grid connected photovoltaic (PV) systems mounted on buildings
### Integration and System Performance Issues

<table>
<thead>
<tr>
<th>Standard</th>
<th>Reference</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61829 Ed. 2.0</td>
<td>SP2, SP3, SP4</td>
<td></td>
</tr>
<tr>
<td>Crystalline silicon photovoltaic (PV) array - On-site measurement of I-V characteristics</td>
<td>IEC 62109-1 Ed. 1.0</td>
<td>SP3, SP6, SP5</td>
</tr>
<tr>
<td>Safety of power converters for use in photovoltaic power systems - Part 1: General requirements</td>
<td>IEC 62109-2 Ed. 1.0</td>
<td>SP3, SP6, SP5</td>
</tr>
<tr>
<td>Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters</td>
<td>IEC 62109-3 Ed. 1.0</td>
<td>SP3, SP6, SP5</td>
</tr>
<tr>
<td>Safety of power converters for use in photovoltaic power systems - Part 3: Controllers</td>
<td>IEC 62116 Ed. 1.0</td>
<td>SP3, SP6,</td>
</tr>
<tr>
<td>Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

### Selected Highlights of on going activities

Ewan D Dunlop

European Commission JRC

---

216
Research objectives in SP1

- Set up traceability chains of indoor characterisation of PV module in both test labs and PV industry
- Improvement of the comparability of measurement results between test labs (ultimate goal ±1% for c-Si modules)
- Development of technology specific measurement/calibration procedures (high efficiency c-Si, thin film, multi-junction PV devices)
- Translation of research results into best practice and labelling guidelines for PV industry (5% tolerance for output power labelling of c-Si PV modules)
Work Packages in SP1

WP 1.1 Round-robin tests (TUV Rheinland)
WP 1.2 Solar simulator performance assessment (TUV Rheinland)
WP 1.3 Thin-film, multi-junction and novel devices (Fraunhofer-ISE)
WP 1.4 Measurement accuracy and traceability chain (EU Joint Research Centre)

WP1.1/WP1.2 Research Approach

Round robin test with commercially available PV modules covering the range of current PV technologies (1. crystalline silicon, 2. thin-film):
- Identification of cell types
- Manufacture of test samples
- Definition of test programmes

Inventory of measuring equipment and documentation of measurement practices in test laboratories:
- Performance evaluation of solar simulators (on-site measurements)
- Questionnaires

Creation of experimental common data basis for analyses

Upgrade of measuring equipment for meeting the requirements of PV technologies
Development of technology specific measurement techniques
Translation to guidelines for PV industry and input to standardisation
### WP1.1 Round Robin Test (c-Si modules)

<table>
<thead>
<tr>
<th>Cell manufacturer</th>
<th>Cell type</th>
<th>Cell dimensions / Efficiency</th>
<th>Cell inter-connection circuit of the module</th>
</tr>
</thead>
<tbody>
<tr>
<td>SunPower Corporation</td>
<td>A-300 back contact</td>
<td>125 x 125 mm (psq) Up to 21.5%</td>
<td>72s1p and 36s2p</td>
</tr>
<tr>
<td>Sanyo Electric Co. Ltd.</td>
<td>HIT Heterojunction with Intrinsic Thin layer</td>
<td>125 x 125 mm (psq) 18.7% (Module)</td>
<td>72s1p</td>
</tr>
<tr>
<td>Microsol International LL Fze.</td>
<td>MONO 156 MPSQ</td>
<td>156 x 156 mm (psq) Up to 15.7%</td>
<td>36s1p</td>
</tr>
<tr>
<td>Q CELLS AG</td>
<td>Q8T3-1580</td>
<td>210 x 210 mm 15.8%</td>
<td>36s1p</td>
</tr>
<tr>
<td>SCHOTT Solar</td>
<td>EFG 12530 Edge defined Film-fed Growth</td>
<td>125 x 125 mm 14.5%</td>
<td>72s1p</td>
</tr>
</tbody>
</table>

### Participating test laboratories

- arsenal research
- CIOMAT
- ESTI
- Fraunhofer Institut Solare Energiesysteme
- SUPSI
- TÜV Rheinland

---

219
WP1.1 Round Robin Test (c-Si modules)

Test results

![Spread of Maximum Output Power](image)

Lab 1 Lab 2 Lab 3 Lab 4 Lab 5 Lab6

WP1.1 Round Robin Test (c-Si modules)

Major Conclusions

- **Good results regarding comparability**: The spread for reported $P_{\text{MAX}}$ lies in the range ±2%. High or systematic discrepancies for laboratories could be either explained by deficits of the measuring equipment or measurement procedures.

- PV Industry expressed the need for additional information on calibration data of reference modules. **Test reports shall go beyond STC** and state how modules shall be measured to ensure an optimal transfer of calibration.

- There is **space for improvement**: The round-robin test together with solar simulator performance data provided a **comprehensive data basis and information source for labs** that can now be used for upgrading hardware and software regarding new technical requirements.
### WP1.1 Round Robin Test (Thin-film modules) ⇒ Ongoing (March 2008)

<table>
<thead>
<tr>
<th>Module/cell technology</th>
<th>Manufacturer</th>
<th>Module type</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-Si</td>
<td>Kaneka</td>
<td>K60 (990 x 960 mm)</td>
</tr>
<tr>
<td>a-Si/a-Si</td>
<td>SCHOTT Solar</td>
<td>ASI-F32/12 (762 x 605 mm)</td>
</tr>
<tr>
<td>a-Si/a-Si/a-Si</td>
<td>Unisolar</td>
<td>US-64 (1366 x 741 mm)</td>
</tr>
<tr>
<td>a-Si/μ-Si hybrid</td>
<td>Sharp Corporation</td>
<td>NA-850 WP (1130 x 935 mm)</td>
</tr>
<tr>
<td>CIS</td>
<td>Würth Solar GmbH</td>
<td>WS 3110075 (1205 x 605 mm)</td>
</tr>
<tr>
<td>CIS</td>
<td>Shell Solar GmbH</td>
<td>Eclipse 80-C (1311 x 656 mm)</td>
</tr>
<tr>
<td>CdTe</td>
<td>First Solar</td>
<td>FS-50 (1200 x 600 mm)</td>
</tr>
</tbody>
</table>

### WP1.2 Solar simulator performance assessment

Variety of test equipment and measurement practices

- **Solar simulator equipment**: 1 steady-state, 5 pulsed (4 different types)
- 3 labs use a combined indoor / outdoor measurement procedure
- The electronic equipment for tracing the I-V curve is different in all labs
- **Multiflash measurement techniques** are available in 3 labs:
  - 2 labs ⇒ measurement of I-V segments, 1 lab ⇒ one I-V data point per flash
- **Variation of I-V data acquisition parameters**: All labs can measure both sweep directions. Preferred sweep direction is Isc ⇒ Voc (4 labs)
- Simulator suppliers use different filtering techniques to get a good spectral match to AM1.5G ⇒ Great variety in spectral irradiance distribution
- **Time for acquiring the I-V curve** ranges from 1.5 to 10 ms (pulsed systems)
- **Non-uniformity of irradiance** fulfils in all cases class A requirements of IEC 60904-9 for module sizes used in the round robin test (<2%)
WP1.3 Thin-film, multi-junction and novel devices

- **General**: Reference devices?

- **CdTe**:  
  Main problem: How to establish stable state? Long-term storage in the dark may require a long period of light exposure to recover.

- **a-Si**:  
  Performance depends on actual history (temperature, irradiation)  
  Energy rating issues

- **Cu(In,Ga)S**:  
  Preconditioning important – technology specific procedures, relaxation time may depend on module efficiency

- **Multi-junction**:  
  Dependence of IV-parameters on spectral distribution requires advanced measurement and calibration methods (current mismatch)

---

WP1.4 Measurement accuracy and traceability chain

- **Survey of actual practice of PV calibration traceability in labs available**

- **Principles of uncertainty analysis and evaluation of the traceability chain**

  - Guide and Spreadsheet for calculation of uncertainty analysis developed

  - Wide range in final uncertainties for Pmax: 1.6% - 16%, 2.5% typical
Experimental SP 2

- Location: outdoor test facility of INES/CEA, (Cadarache, in south of France).
- 13 pyranometers and 19 reference cells
- Same plane outdoors.
- Sampling rate: 2 s
- Direct incidence

Spectral dependence

Response of photovoltaic sensors as a function of air mass
« Original » Calibration

Width of the 95 % confidence interval for the measurement of the solar irradiance:

► Pyranometers: 3.7 %  ► reference cells: 4.2 %

<table>
<thead>
<tr>
<th>Pyranometer</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM11 CEA vented</td>
<td>100.5%</td>
</tr>
<tr>
<td>CM11 ZSW vented</td>
<td>101.3%</td>
</tr>
<tr>
<td>CM11 TUV</td>
<td>101.0%</td>
</tr>
<tr>
<td>CM11 ISE</td>
<td>100.1%</td>
</tr>
<tr>
<td>CM21 CEA vented</td>
<td>99.6%</td>
</tr>
<tr>
<td>CM11 WrUT</td>
<td>100.4%</td>
</tr>
<tr>
<td>CMP11 ISAAC</td>
<td>98.7%</td>
</tr>
<tr>
<td>CMP11 TUT</td>
<td>97.2%</td>
</tr>
<tr>
<td>CM22 CEMAT</td>
<td>101.9%</td>
</tr>
<tr>
<td>CM22 CREST</td>
<td>98.4%</td>
</tr>
<tr>
<td>CM22 CEA vented</td>
<td>101.0%</td>
</tr>
<tr>
<td>PSP BGU</td>
<td>98.5%</td>
</tr>
</tbody>
</table>

Recalibration at 1 sun

Width of the 95 % confidence interval for the measurement of the solar irradiance:

Pyranometers: 2.0 %  reference cells: 1.9 %
Conclusions

• Spread:
  – Pyranometers: 3.7 % after recalibration: 2.0%
  – Reference cells: 4.2 % after recalibration: 1.9%
• Intrinsic discrepancies remain!
  – Different temperature coefficients,
  – Dome effect for the pyranometers
  – Angle of incidence effects
  – Spectral dependence
• Recommendations
  – PV system monitoring should be based on cell of the same technology
  – Best solution: use device of the same manufacturing process

SP3 – PV System Performance Evaluation
SP Lead N Pearsall

• Developing modernised and harmonised European guidelines for the monitoring of PV systems of all kinds
• The guidelines will be web based and constructed from building blocks of instructions relating to different aspects of the system
• Work to date has included the development of the delivery concept, the commencement of drafting of the central building blocks (PV array, inverter etc.) and the definition of the nature and importance of fault mechanisms
• The new guidelines will incorporate the best practice of current monitoring services, whilst providing a framework for the development of enhanced monitoring activities
Characteristics of the tested PV modules

- 204 crystalline silicon-wafer based photovoltaic modules (53 module types originating from 20 different producers)
- Modules are rated from about 8 Wp up to 117 Wp, (average of 40 Wp)
- Encapsulants used: Ethylene-Vinyl Acetate (EVA) – 29 types, Polyvinyl butyral (PVB) – 14 types, Polysiloxanes (Silicone) – 8 types.
- Back substrate used: Polyvinyl fluoride (Tedlar) – 21 cases, Glass – 17 types, Silicone – 5 types, Polyester / aluminum – 4 types, Polyethylene – 1 type.
- 31 mono and 22 polycrystalline based cells module types (123 and 81 modules respectively)
Overall results from electrical performance measurements

Histogram of P_{MAX} losses of all 204 weathered modules

<table>
<thead>
<tr>
<th>Percentage of modules</th>
<th>Maximum power loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>5%</td>
</tr>
<tr>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>20%</td>
<td>25%</td>
</tr>
<tr>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>30%</td>
<td>35%</td>
</tr>
<tr>
<td>&lt;5%</td>
<td>5 - 10%</td>
</tr>
<tr>
<td>5 - 10%</td>
<td>10 - 15%</td>
</tr>
<tr>
<td>10 - 15%</td>
<td>15 - 20%</td>
</tr>
<tr>
<td>15 - 20%</td>
<td>20 - 25%</td>
</tr>
<tr>
<td>20 - 25%</td>
<td>25 - 30%</td>
</tr>
<tr>
<td>25 - 30%</td>
<td>30 - 35%</td>
</tr>
<tr>
<td>30 - 35%</td>
<td>35 - 40%</td>
</tr>
<tr>
<td>35 - 40%</td>
<td>40 - 45%</td>
</tr>
<tr>
<td>40 - 45%</td>
<td>45 - 50%</td>
</tr>
<tr>
<td>45 - 50%</td>
<td>50 - 55%</td>
</tr>
<tr>
<td>50 - 55%</td>
<td>55 - 60%</td>
</tr>
<tr>
<td>55 - 60%</td>
<td>60 - 65%</td>
</tr>
<tr>
<td>60 - 65%</td>
<td>65 - 70%</td>
</tr>
<tr>
<td>65 - 70%</td>
<td>70 - 75%</td>
</tr>
<tr>
<td>70 - 75%</td>
<td>75 - 80%</td>
</tr>
<tr>
<td>75 - 80%</td>
<td>80 - 85%</td>
</tr>
<tr>
<td>80 - 85%</td>
<td>85 - 90%</td>
</tr>
<tr>
<td>85 - 90%</td>
<td>90 - 95%</td>
</tr>
<tr>
<td>90 - 95%</td>
<td>95 - 100%</td>
</tr>
</tbody>
</table>

Dependance of P_{max} on I_{sc} and FF

- I_{sc} loss due to high delamination
- V_{oc} loss (substring loss)
- FF loss

---

227
Dependance of $P_{\text{max}}$ on $I_{\text{sc}}$ and FF

Selected modules (exhibiting maximum power loss smaller than 20%)

- $P_{\text{max}}$ losses are related to $I_{\text{sc}}$ losses.

Results from electrical performance measurements

Comparison of different type of back substrate materials and different modules conditions

The results of variance analysis (ANOVA) leads to the conclusion that:

- there is a statistically significant difference between two groups of the modules: the group connected initially to the inverter ($P_{\text{max}}$) and modules left in the open circuit ($V_{\text{oc}}$) conditions.

- there is also difference between groups of modules with the glass back sheet and polymer one.
Visual inspection results

The main type of visual defects observed on weathered modules

- encapsulant browning (cells area and/or the whole module front surface),
- delamination and bubbles formation in the encapsulant,
- back sheet polymer cracks,
- front surface soiling/frosting,
- blackening at the bottom edge of the module (ingrained dirt not possible to remove),
- junction box connections corrosion,
- busbar oxidation and discoloration,
- junction cables insulation degradation (modules without junction boxes),
- glass breakage (1 case of back sheet and 1 of the front surface)

Conclusions

- High power losses (>20%) are attributed generally to FF losses (interconnections resistance increase), while moderate modules degradation is caused by $I_{sc}$ loss due optical properties degradation and photon induced semiconductor degradation,

- There is no statistically significant difference in the performance of the modules with monocrystalline and polycrystalline cells (average degradation rate 0.7% per year),

- There is statistically significant difference between 2 groups of the modules: connected initially to the inverter (average degradation 23%) left in the open circuit conditions (average degradation 12%)
Conclusions

- There is difference between groups of modules with the glass back substrate (average 23% degradation) and polymer substrate (average 14%),

- The visual appearance of field–aged modules is often not correlated with their electrical performance and state of electrical insulation,

- Of the 204 modules studied in this work 82.4% have been verified to have the final maximum power greater than 80% of the initial power i.e. meeting the manufacturers warranty criteria,

- Furthermore two thirds of modules have the final maximum power verified to be more than 90% of the initial power value after 25 years of outdoor exposure.

Performance SP6

PV as a Building Product

Project Coordinator

Berrie van Kampen
Objectives of SP6

- Providing an overview of best practices of PV applied in buildings and of the regulations and building codes in relevant EU markets.

- Determination of test procedures that are compliant with building codes and standards in the EU.

- Identification of the elements that should be contained in a PV code to be widely acceptable.

Status SP6

Available are:
- Report on Best Practices of BIPV
- Report on present regulations and PV building codes (of Netherlands, Germany, France, Switzerland, Austria, Spain and Italy)
- Inventory of test requirements for CE-mark
Relevant PV-Building Concepts and Bottle-necks

PV on Water Tight Roof

- Constructional Integrity
- Fire Tests PV as a source of Fire
- Thermal behaviour (NOCT)

PV and Roof are to a large extent independent

---

Relevant PV-Building Concepts and Bottle-necks

Standard not-water tight Roof + PV Roof Tiles or Framed PV

- Water Tightness and Humidity
- Fire Tests PV as a source of Fire
- Constructional Integrity
- Thermal behaviour (NOCT)
Stakeholder Survey
Future standards development for the photovoltaic industry
Work Package 8

Aim of the survey

- To canvass the opinion of the photovoltaic industry on areas for future standards development.
Survey

- Designed to encourage comment
- Specific areas
- 14 questions
- 94 organisation targeted
- Telephone and e-mail

Sectors covered

<table>
<thead>
<tr>
<th>Sectors</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell manufacturers</td>
<td>31</td>
</tr>
<tr>
<td>Crystalline silicon module manufacturers</td>
<td>34</td>
</tr>
<tr>
<td>Thin film module manufacturers</td>
<td>16</td>
</tr>
<tr>
<td>Inverter manufactures</td>
<td>17</td>
</tr>
<tr>
<td>Balance of system manufacturer (cabling, switch gear, connectors)</td>
<td>11</td>
</tr>
<tr>
<td>System suppliers and installers</td>
<td>29</td>
</tr>
<tr>
<td>Developers</td>
<td>12</td>
</tr>
<tr>
<td>Research</td>
<td>16</td>
</tr>
<tr>
<td>Consultants</td>
<td>13</td>
</tr>
<tr>
<td>Investors and financing</td>
<td>3</td>
</tr>
</tbody>
</table>
Sectors which responded
10 replies

<table>
<thead>
<tr>
<th>Sectors</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell manufacturers</td>
<td>0</td>
</tr>
<tr>
<td>Crystalline silicon module manufacturers</td>
<td>3</td>
</tr>
<tr>
<td>Thin film module manufacturers</td>
<td>1</td>
</tr>
<tr>
<td>Inverter manufactures</td>
<td>0</td>
</tr>
<tr>
<td>Balance of system manufacturer (cabling, switch gear, connectors)</td>
<td>2</td>
</tr>
<tr>
<td>System suppliers and installers</td>
<td>2</td>
</tr>
<tr>
<td>Developers</td>
<td>3</td>
</tr>
<tr>
<td>Research</td>
<td>4</td>
</tr>
<tr>
<td>Consultants</td>
<td>4</td>
</tr>
<tr>
<td>Investors and financing</td>
<td>1</td>
</tr>
</tbody>
</table>

Areas examined

- Cell size
- Module size
- Module technologies
- DC connectors
- Performance standard
- Performance monitoring
- Calibration
- Wind loading
- Fire testing
Cell size

- 2 of 5 thought standard cells would not be beneficial
- If a standard cell should be developed should be done in conjunction with standard module size.
- Manufacturers of cell producing equipment should be consulted

Module Size

- Standard sizes would aid the building sector
- Obtaining agreement on a standard size difficult
- Need agreement between large manufacturers to have any credibility
- Standard module ratios
Modules technology standards

- Thin film
  - Including aSi, CIS, CIGS & CdTe
- Standards should cover
  - Efficiency and overall performance
  - Diffuse radiation
  - Fluctuating power results for thin film
  - High temperature conditions, accelerated life-time testing and life expectancy, stability under real operational conditions and endurance testing
- Concentrators
- Measurement procedures specific for modules with:
  - Heat sinks, non-flat modules, BIPV and photovoltaic thermal modules

DC Connector standard

- Conflicting opinions
  - Seen to be beneficial
  - Seen to possibly inhibit product development
- Obtaining agreement on standard design very difficult
- Potential cost reduction
- Quality standard possibly most approach
### Performance Standard

- Useful to developers and specifiers
- Must be location specific
- Development very difficult many variables
- Existing power warranties difficult to verify

### Performance monitoring standard

- General consensus was a performance monitoring standard would be beneficial
- Remote monitoring
- Life time performance monitoring
- Standard should cover
  - Monitoring equipment used
  - Sensor specifications
  - Accuracy range and stability
  - Calibration methods
  - Logging frequencies
  - Data analysis methods
Calibration and testing

- Varying opinions
  - No need for further development
  - Rather simplification
- Standards for testing solar cells and modules in the fabrication phase for classifying with respect to power output
- Specific standards for equipment e.g. flash testers and lamps and I–V curve tracing equipment

Wind loading & Fire Testing

- General consensus is a wind loading and fire testing standard would be valuable.
- There is a need to account for varying wind speeds across Europe.
- Fire testing standard in particular for building integrated systems
### Others Standards

- DC cable colour coding
  - 3 appropriate
  - 1 added cost
  - Colour blind consideration
- European wide labelling standard

### Who would be most appropriate to develop these new standards?

- IEC
- CENELEC
- Co-operation of industry
### Summary

- There is a need for future standards development
- Areas for more immediate potential development
  - Thin film technologies
  - Performance monitoring
  - Wind loading
  - Fire testing
Abstract

In the past years, the yearly world market growth rate for Photovoltaics was an average of more than 40%, which makes it one of the fastest growing industries at present. Business analysts predict the market volume to increase to € 40 billion in 2010 and expect rising profit margins and lower prices for consumers at the same time.

Today PV is still dominated by wafer based Crystalline Silicon Technology as the “working horse” in the global market, but thin films are gaining market shares. For 2007 around 12% are expected. The current silicon shortage and high demand has kept prices higher than anticipated from the learning curve experience and has widened the windows of opportunities for thin film solar modules. Current production capacity estimates for thin films vary between 3 and 6 GW in 2010, representing a 20% market share for these technologies.

Despite the higher growth rates for thin film technologies compared with the industry average, Thin Film Photovoltaic Technologies are still facing a number of challenges to maintain this growth and increase market shares.
How to obtain EU publications

Our priced publications are available from EU Bookshop (http://bookshop.europa.eu), where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents. You can obtain their contact details by sending a fax to (352) 29 29-42758.
The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.