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**Conference report PV in Europe - From PV
technology to energy solutions**

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Anna Helgesson



Summary

The conference "*PV in Europe, From PV technology to energy solutions*" was held in Italy, October 2002. It is an opportunity to present technical progress and to exchange experiences. The participant list included about 650 names from different countries. There were also about 100 exhibition cases at the conference, showing among other things PV-modules, inverters, and different manufacturing techniques. The conference covered a large number of topics, from research on solar cell materials, manufacturing, standardisation and system engineering, to European PV-markets and the use of PV in developing countries. Both oral and poster presentation were given. The report summarises comments from some of these.

The sun is an inexhaustible source of energy and the possibilities of PV are enormous. The PV-market has grown considerably during the last year and the market development plays an important role in the move towards a more sustainable future. In order to continue to expand, it is however important with continued research in performance, and with cost reductions. The public interest must also be increased. One of the key-barriers to an increased use of PV is *financing* problems. In order to get a successful dissemination of PV, different financing models need to be created, and a financial incentive needs to be provided. One example is in developing countries, where the people who needs the energy, often can not afford to pay for a PV-system. When comparing PV with other technologies it is important to include environmental benefits. This can be done by using an LCA-analysis. For subsidiary reasons costs should also be expressed per kWh instead of kW_p.

Not only costs, but also a lack of *quality standards* is a barrier to a larger PV-market. This matter was discussed in quite a few presentations. Standardisation is needed in order to improve quality and to decrease costs. By using quality products, the system performance will be improved, and a larger consumer confidence can be gained. An energy labelling can help the customer to identify PV-products with good quality. One interesting question for the user of a PV-system is how much energy that is produced. Measurements have shown that there is a degradation in power during the first time of exposure. This means that the actual power delivered by the system is lower than the nominal power declared by the manufacturer. A recommendation is therefore to use the "stabilised power" instead, when estimating the output of a system. The performance of a single solar cell in a module can be studied by using photocurrent mapping.

During the conference also different *manufacturing techniques* were presented, e.g. a process for buried contact multicrystalline silicon solar cells. Also the production of thin-film crystalline silicon on glass modules were described. This concept combines the advantage of crystalline silicon and thin-film technology. By using a low-weight substrate instead of glass, the weight of the solar cell can be reduced. This concept is used in the development of a flexible CdTe-solar cell. The CdTe/CdS/TCO-stack is grown on a NaCl/glass-substrate. After the cell has been processed, it is detached from the glass by dissolving the NaCl-layer.

A good PV-system not only needs an efficient PV-module. As an intermittent energy source it also requires some kind of *storage* in order to maximise the useful output. Some alternatives to conventional lead-acid batteries are NiCd and NiMeHydrid. A hybrid system with PV and fuel cells + hydrogen can be an attractive option for small loads, and can replace the use of diesel backup. Another factor that affects the system performance is *the use* of the energy. The user has to be educated in how to use and maintain the system. A load management tool gives information about system state and can help the user to adapt the consumption to the energy available. Also installers have to be trained in order to get a functioning system. Another important topic is the *design* of the system. The Solar ElectriCity Guide can here be used as a tool to provide different actors with information about PV-technology and PV implementations.

During the conference, a lot of *examples of different PV-installations* were given. Some programmes with the objective of promoting PV were also presented. Some examples were from the Italian PV programme with a goal of 23 MW being installed in 2003. Building Integrated PV (*BIPV*) was e.g. discussed in several presentations. One advantage with BIPV is that the PV-modules then act as both building envelope and energy producer. Aesthetical, electrical, and building construction issues are important. PV can be integrated in both new buildings and when retrofitting older buildings. A special kind of system is the *hybrid PV/T*, generating both electricity and heat. In this way a higher total energy efficiency can be achieved. One example presented at the conference is a facade-integrated PV/T-system using reflectors to improve the performance.

There were also a large number of presentations about the use of PV in *developing countries*. This is an area that constitutes a large potential market. Many remote areas have no access to the local power grid. Solar energy can here be used as a cost-effective and environmentally friendly energy source for e.g. lighting, vaccine refrigerators, and pumps for water supply. Examples of PV-installations were given from Nigeria, South Africa and Tanzania. A well lit healthcare centre or school can also be used as a community centre. One problem that was discussed is theft, and security measures have to be taken. One large problem with rural electrification is also the financing of the systems. Effective financing models are needed. One example of this is the HELP-package in the Himalayan. The PV-users are here offered training in how to produce handicrafts, and the income from selling the products can be used to pay off the PV-system.

Some *lessons learned* from different projects are:

- System design and project planning are important.
- Plans for maintenance needed.
- Quality control important to achieve good system performance. Standards needed.
- Education of users and installers needed.
- Monitoring important to gain experience.
- Financing question must be solved.

- Public commitment important.
- Problems with theft.
- Added values must be considered when discussing costs.

One of the most important conclusions from the conference is that we must start learning from all lessons learned and not to repeat the mistakes again. One comment about the future is that solar cells have to be made of abundant and non-toxic materials. In the future, there may also be very large scale PV-installation in e.g. desert regions.

Sammanfattning

Konferensen "PV in Europe, From PV technology to energy solutions" hölls i Italien, oktober 2002. Konferensen erbjuder en möjlighet att presentera tekniska framsteg och att utbyta erfarenheter. Deltagarlistan upptog ungefär 650 namn från olika länder. Det fanns också ungefär 100 utställningsmontrar, där bl a PV-moduler, växelriktare och olika tillverkningsstekniker visades. Konferensen täckte ett stort antal ämnesområden; från forskning på solcellsmaterial, tillverknings-, standardiserings- och systemdesign, till Europeiska PV-marknader och användning av PV i utvecklingsländer. Presentationerna gjordes i form av både muntliga presentationer och posters. Denna rapport sammanfattar kommentarer från en del av dessa presentationer.

Solen är en outtömlig energikälla och solcellstekniken har oerhörda möjligheter. Under de senaste åren har PV-marknaden vuxit avsevärt och detta spelar en viktig roll vad gäller utvecklingen mot en mer "uthållig framtid". För att marknaden skall fortsätta att öka är det emellertid viktigt med en fortsatt forskning för att uppnå bättre prestanda och kostnadsreduktioner. Även allmänhetens intresse måste öka. Ett av de största hindren mot en ökad solcellsanvändning är finansiella problem. För att få en lyckad spridning av tekniken måste olika modeller för att lösa finansieringsfrågan skapas och marknaden måste stimuleras ekonomiskt att satsa på solenergi. Detta är speciellt viktigt i utvecklingsländer, eftersom de människor som behöver energin ofta inte kan betala för ett solcellssystem. Då man jämför PV-tekniken med andra energitekniker är det också viktigt att inkludera miljömässiga fördelar. Detta kan göras genom att man gör en LCA-analys. Ur bidragssynpunkt så skall kostnaderna inte heller uttryckas per kW_p utan istället per kWh.

Inte bara kostnader utan också frånvaron av kvalitetsstandard är ett hinder för utvecklingen av en större PV-marknad. Detta diskuterades i rätt många presentationer. För att förbättra kvaliteten och åstadkomma kostnadssänkningar behövs standardisering. Genom att använda produkter med hög kvalitet kan systemprestanda öka, vilket leder till en större tilltro till tekniken hos konsumenterna. Någon form av energimärkning kan också hjälpa kunderna att välja PV-produkter med bra kvalitet.

En intressant fråga för användaren är också hur mycket energi som systemet producerar. Mätningar har visat att utbytet sjunker under den första exponeringstiden. Detta betyder att den verkligt levererade effekten är lägre än den nominella, som anges av tillverkaren. En rekommendation är därför att använda en "stabiliserad effekt" då utbytet från ett system uppskattas. Ett sätt att studera funktionen hos en enskild cell i en PV-modul är att använda "photocurrent mapping".

Under konferensen presenterades också olika tillverkningsstekniker. Bl a visades en teknik för tillverknings av "buried contact multicrystalline silicon solar cells". Också framställning av tunnfilms kristallinkiselmoduler på glass beskrevs. Detta koncept kombinerar fördelarna med både kristallint kisel och tunnfilmsteknik. Genom att använda ett substrat med låg vikt (istället för glas) kan solcellens vikt kraftigt reduceras. Detta koncept utnyttjas i utvecklingen av flexibla CdTe-celler. CdTe/CdS/TCO-cellen

tillverkas på ett NaCl/glass-substrat. Då cellen är färdig lösgörs den från glaset genom att saltbufferten löses upp.

Ett väl fungerande PV-system kräver inte bara effektiva PV-moduler. Eftersom solen utgör en intermitterent energikälla behövs också någon form av lager för att maximera det totala utbytet från systemet. Några alternativ till konventionella blysyrabatterier är NiCd- och NiMeHydridbatterier. Ett hybridssystem med både PV och bränsleceller samt vätagaslager kan utgöra ett attraktivt alternativ för små laster. En annan faktor som påverkar systemprestanda är hur energin används. Användaren måste utbildas i hur systemet skall användas och underhållas. Ett laststyrningsverktyg ger information om systemets status och kan hjälpa användaren att anpassa sin elförbrukning till den energi som finns tillgänglig. Även installatörerna måste utbildas för att effektiva system ska erhållas. Ytterligare ett viktigt område är systemdesign. Här kan "the Solar ElectricCity Guide" vara till hjälp för att förse olika aktörer med information om PV-tekniken.

Under konferensen visades ett stort antal exempel från olika PV-installationer. Även en del program med syfte att stödja PV-tekniken presenterades. Ett exempel är det italienska PV-programmet med en målsättning att 23 MW ska ha installerats vid slutet av 2003. Ett exempel på systemtyp som diskuterades i flera presentationer är byggnadsintegrerade system. (BIPV). En fördel med dessa är att PV-modulerna då utgör både byggnadsmaterial och energiproducent. Estetiska, elektriska och byggnadsmässiga aspekter är betydelsefulla för dessa system. PV-moduler kan integreras både i samband med nybyggnation eller vid renovering av äldre byggnader. Ett annat speciellt typ av system som presenterades är hybrid PV/T-system. Dessa alstrar både el och värme och på så sätt erhålls en högre total energiverkningsgrad. Ett exempel på detta som presenterades under konferensen är ett fasadintegrerat PV/T-system som använder reflektorer för att öka utbytet.

Under konferensen presenterades också många exempel på användning av PV i utvecklingsländer. Detta är ett område som utgör en potentiellt stor framtida marknad. Många avlägsna områden saknar tillgång till elnät och solenergi kan på dessa ställen vara ett kostnadseffektivt och miljövänligt alternativ för t ex belysning, vaccinkylar och vattenpumpning. Exempel gavs från installationer i Nigeria, Sydafrika och Tanzania. En positiv sidoeffekt är att en upplyst hälsocentral eller skola också kan utnyttjas som byns samlingslokal. Ett problem som togs upp är stöld. Detta kräver att speciella säkerhetsåtgärder vidtas. Ett annat stort problem med denna typ av system är hur de ska finansieras, och här krävs att fungerande lösningar utarbetas. Ett exempel på detta är det Himalayiska "HELP"-projektet. PV-användarna erbjuds här en hantverksutbildning och inkomsterna från hantverksförsäljning kan sedan användas till att betala av solcellssystemet.

Några exempel på erfarenheter som dragits från olika projekt är:

- Systemdesign och projektplanering är viktigt
- Underhållsplaner behövs.
- Kvalitetskontroll är viktigt för att erhålla en bra systemprestanda. Standarder behövs.

- Utbildning av användare och installatörer behövs.
- Mätning viktigt för att erhålla erfarenheter
- Finansiella frågor måste lösas.
- Allmänhetens engagemang är viktigt.
- Problem med stölder.
- Även ickeekonomiska fördelar måste vägas in då kostnader diskuteras.

En av de viktigaste slutsatserna från konferensen är att vi verkligen måste börja dra nytta av alla erfarenheter och att inte upprepa misstagen igen. En kommentar vad gäller framtiden är att solceller måste tillverkas av ickegiftiga material som finns i stor mängd. I framtiden kan det också eventuellt bli möjligt med mycket stora PV-installationer i t ex annars outnyttjade ökenområden.

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1 Introduction

1.1 The conference

The conference "PV in Europe, From PV technology to energy solutions" took place in Rome, Italy, October 7 - 11, 2002. The conference was held at the Palazzo dei Congressi. According to the programme, this conference is the largest event on photovoltaic science, engineering and market development in Europe during 2002. The conference offers an opportunity to researchers, technicians, manufacturers and system integrators to highlight the progress registered both in cost reduction and performance improvement of components and systems. The conference focuses on PV in Europe, in the Mediterranean area. Also PV in developing countries is covered. More information about the conference can be found on www.wip-munich.de or www.etaflorence.it.

The conference topics are divided into ten different areas:

1. Exploratory research on solar cell materials and structures
2. Progress in crystalline silicon cell development and manufacturing
3. Thin film cell research, development, and production
4. Cells and systems for concentrators
5. PV module and system engineering
6. European PV product- and system standardisation, certification, and marketing
7. European PV markets, regulations and financing
8. European PV "roof top" programmes, performances, architectural and urban planning aspects, lessons learnt, individual cases, comparison of results
9. The PV market changing scale in the Mediterranean countries and emerging economies
10. Co-operation with developing countries, village power, implementation of G8 recommendations.

The programme schedule is given in figure 1.1. The programme was organised with a number of parallel sessions with a total of approximately 200 oral presentations. In addition, there were also about 200 posters presented during the conference.

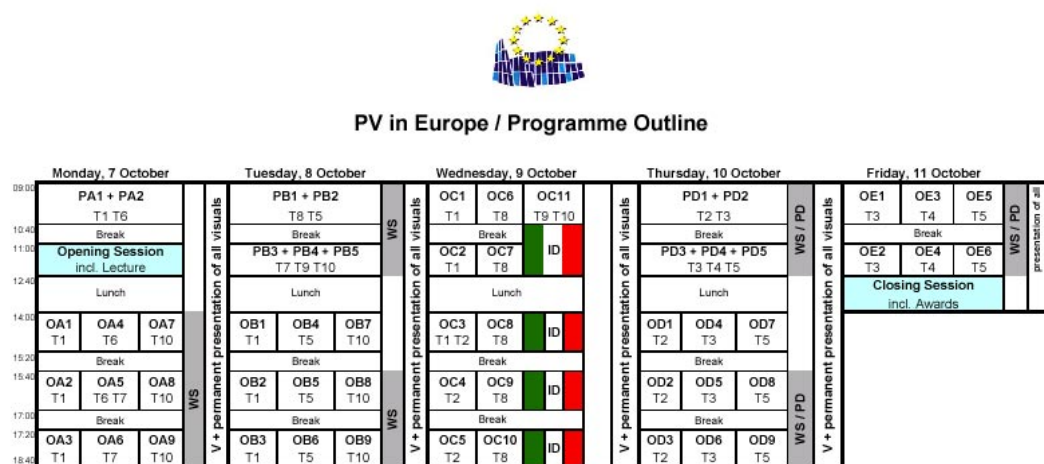


Figure 1.1: Conference programme. The T-numbers refer to the list of topics presented above the figure. P = plenary session, O = oral presentation, V = posters, WS = workshop, and ID = Italian day.

At the conference were also the following workshops held:

- Lessons learnt from on-going national PV programmes.
- Spreading PV in developing countries responding to the challenge to deliver at WSSD.
- The way forward.
- The Mediterranean initiative, a regional model for RE market acceleration: PV role.
- PV funding the best way? Feed-in tariffs vs. Green certificates.
- Towards a European PV technology platform.

The "Italian Day" was a special programme addressed to Italian authorities, organisations, industries, researchers, and PV users. The big success of the national ministerial "Roof Programme" demonstrates the new attention Italy dedicates to PV solar energy.

The list of participants included almost 650 names from 57 nations. Most participants came from Germany, the Netherlands, and Italy. Five persons came from Sweden. There were also about 100 exhibiting companies and organisations present. Some examples are ECN, Philips, Mitsubishi Electric, BP Solar, Shell Solar BV, Deutsche Solar AG, and Phaesun GmbH.

1.2 Photovoltaics, general remarks

There is an increasing awareness about atmospheric greenhouse gases and climate change, and that the world needs to reduce the use of fossil fuel and to provide access to sustainable energy resources in the long term. This can be done by using renewable energy sources such as wind or solar. The sun is an inexhaustible source of energy. *Photovoltaic* (PV) is the direct conversion of sunlight into electricity using solar cells, made of thin layers of semiconductors. The technology does not need any fuel and is free from pollution. Furthermore it is silent, modular, and requires a minimum of maintenance. Also image can be a cause to install PV. The use of solar energy shows that the owner takes environmental responsibility. A PV-module consists of a number of cells connected together. The cells can be either crystalline or made of thin-film technology. The PV-modules generate DC (direct current), which (usually) must be transformed into AC (alternating current) compatible with the building appliances and the electricity grid. This is done by using an inverter.

There are two main configurations for PV-systems: Grid-connected or Stand-alone. A *grid-connected* system is linked to the electricity network, and produced electricity not used directly can be fed into the main grid. (One issue in this context is the amount of compensation paid to the PV-owner for the produced electricity.) Most building integrated systems are grid-connected. One advantage with these systems is that no battery is needed, as in a *stand-alone* system, which is an autonomous electricity unit. Stand-alone systems are usually used in remote areas, where there is no other electricity supply. The PV-modules can be integrated into the building structure (*BIPV*) to form the outer building envelope. Here questions of architecture, aesthetics, orientation, solar

radiation, and shading are important. The electricity production can also be combined with heat production in a *hybrid PV/T*-system.

Some *applications* for PV are rural electrification, lighting, water pumping, vaccine refrigerators, desalination, telecommunication, cathodic protection, and lighting at bus-stops etc. The possibilities of PV, especially BIPV, are enormous, and the *market* development of this technology plays an important role in the move towards a more sustainable future. The PV-technology is advancing in the market and the annual world PV-module production has grown from approx. 20 MW_p/year in 1983 to about 275 MW_p/year in 2000. During the same period, the cost of small BIPV-systems has decreased from approximately 26 000 €/kW_p to approx. 7 000 €/kW_p [1]. Figure 1.2 shows the cumulative installed PV-capacity in some countries. The total installed power in Sweden during 2000 was 221 kW_p. This is roughly the same amount as installed previous years. By the end of 2000, the total cumulative installed capacity in Sweden was about 2.8 MW_p. Most of these systems are stand-alone small systems.

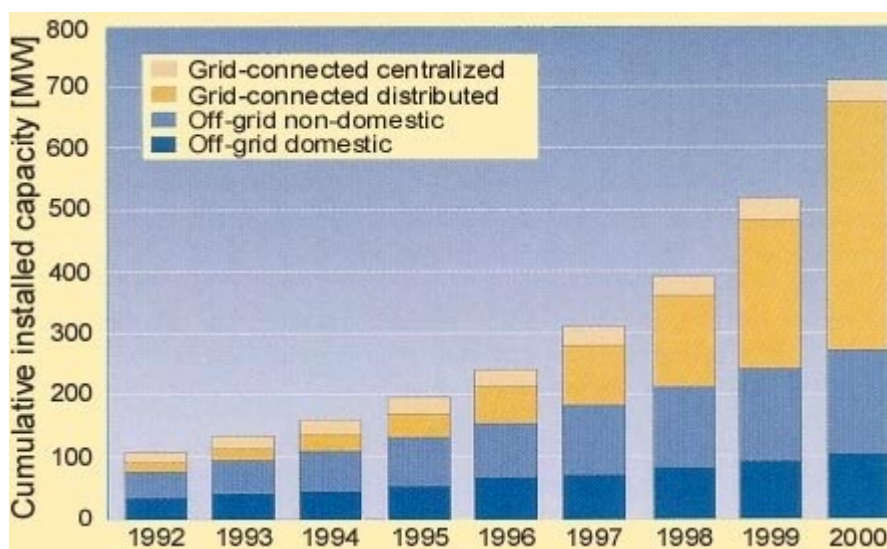


Figure 1.2: Installed PV power in IEA-PVPS-countries. [2]

The market is currently dominated by the grid-connected power generation sector. While crystalline silicon will remain the dominant technology for some time, the advent of thin-film cells open up technological opportunities. The ability of the photovoltaic technology to meet the needs of dispersed low-demand units makes it a technology worthy a development.

The following text summarises some notes from different presentations. All presented papers will be compiled in a book of conference proceedings.

2 Notes from the presentations

During the opening session, different presentations were made. R. Vigotti, the Programme chairman, started by stating that the conference is an opportunity to present technical progress and to exchange experiences. One goal is to increase the awareness of added value and market penetration.

C. Clini, Director General of the Ministry for the Environment and territory in Italy, pointed out that cost, insufficient human and institutional infrastructure, and weak incentives and inconsistent policies are some strong barriers to renewables. Almost all energy technologies have got some kind of support in the starting-up-stage. Why should renewables not? Mandatory targets must be combined with renewable education. Some areas for PV-applications are: electricity for isolated rural populations, improvement of water supply (increasing farming), household and community need for lighting, refrigeration and communication.

W. Raldow presented "PV research within the 6th framework programme". This programme will take place between 2003 and 2006 and has a budget of 17 500 M€. This is a strategy for a new research policy in Europe in order to create a single market in research. There are seven different focuses, and solar energy belongs to priority 6, "sustainable development, global change and ecosystems". Some targets are to decrease investment costs and to improve reliability. The first call of proposals will be at November 30 2002. More information can be found on www.cordis.lu/fp6/eoi-analysis.htm or <http://europa.eu.int/comm/research/conferences/2002>.

H. Schaer started by saying that PV is a coming prima donna of renewables. Two advantages are that PV can be used anywhere in the world and that no grid is needed. Many aspects must however be taken into account (economic, technological, and political). Financial and human capacity barriers have to be overcome, and both decision-makers and the public have to be engaged in solar energy.

J. Mogford from BP Solar talked about a growing market for cleaner energy. BP Solar is one of the market leaders in the areas of manufacturing, marketing and installation of PV-systems (www.bpsolar.com). In order to get closer to the customer, consideration has to be taken to the fact that people want a product underpinned by a brand. Some opportunities and challenges are:

- societal change
- increased government interest
- climate change is becoming a factor
- solar is very small in the energy market
- customers find it difficult to buy solar energy.

W. Palz talked about the PV-market and that PV is needed in the "third world". In 1997, the EU White paper stated the target of 3 GW PV produced in the EU by 2010. Both the Rio conference (1992) and the recent Johannesburg Summit affect the work with PV. The PV-industry and Greenpeace have also conducted a joint study in the field.

J.L. Bal, the Conference President, summarised the opening session and said that PV is economic already today, if only the environmental costs are taken into account.

2.1 Exploratory research on solar cell materials and structures

B. Sorensen talked about *Understanding Photoelectrochemical solar cells* and described the advantages with this technology, and some of the research being made. With certain conditions an efficiency of 10 % can be reached with this technology.

M.A. Green presented *Efficiency limits for Photovoltaic solar energy conversion*. He started to talk about material costs of silicon wafer and thin film solar cells, and concluded that the third generation of PV has to use abundant (and non toxic) materials. Green also presented different methods for calculating efficiency, using different ways to look at the matter. Some of the calculations of efficiency limits are given in table 2.1. A tracking device (using only direct radiation) can have a higher efficiency than a stationary PV-module, using both direct+diffuse radiation (omnidirectional).

Table 2.1: Efficiency limits (in %) calculated by different methods.

Method	Direct	Omni	Comment
Carnot	95.0		
Landesberg	93.3	73.7	circulator/antenna
Multicolour	86.8	68.2	tandem cells (for λ -separation)
Black body	85.4	53.6	thermo PV
Single junction	31.0		
Best laboratory	34.0	30.0	2 cell stack

B. Ghosh presented *A possible contacting technology for thermophotovoltaics cells*. TPV-cells transform thermal radiation into electricity through PV conversions. In the presentation, the use of Ni₂P was described. Two different methods (electroplating solution and electroless solution) can be used to produce the Ni₂P-layer. These two methods use different chemicals and result in somewhat different properties of the cells. Also the annealing temperature affects the properties of the sheet and the atomic percentage of phosphor varies with the plating current.

2.2 Progress in crystalline silicon cell development and manufacturing

N.B. Mason (from BP Solar) presented *Laser grooved buried grid silicon solar cells - from pilot line to 50 MW_p manufacture in ten years*. The process started in 1985, with a development phase 1986 - 89, followed by a demonstration phase in 1990 - 91 and pilot production in 1992 - 93. After that, there has been a continuous expansion and the output in 2001 was 12 MW_p. The production takes place at Tres Cantos, a large production plant. New automated processes have been introduced instead of old manual ones. Examples of areas that have been modernised are the aluminum deposition, the wafer drying, and the laser micromachining. Also the handling process have been optimised. An efficiency of 17 % has been demonstrated for thin wafers.

W. Jooss presented *Processing and characterisation of large area buried contact solar cells on multicrystalline silicon with a record efficiency of 17.5 %*. The use of multicrystalline silicon is one way to reduce the cost of the PV-module. A processing sequence for BCSC on mc-si has been developed. A very high efficiency on large cells has been recorded (17.5 % for Polix). Improved bulk passivation can further increase the efficiency to 18.3 %.

Another presentation was *Photovoltaic facade and roof elements with added value by the use of back contacted solar cells* (by E. Kerschaver et al.). Back contact solar cells can decrease the area, and integrated module production affects the system cost. An inquiry amongst architects identified following areas of interest:

- visually uniform
- colours
- transparency of modules
- product cost.

One question is how to describe the costs for BIPV. BI-costs are usually expressed in "cost/m²", whereas PV-costs are expressed in "cost/W_p".

P.A. Basore presented *Pilot production of thin-film crystalline silicon on glass modules*. The idea is to combine the advantages of crystalline silicon and thin-film technology (figure 2.1). PV-modules using CSG-technology have been produced on a research pilot line at Pacific Solar. In 2002, the best of these small modules has an efficiency of 8.2 %. Outdoor exposure and accelerated testing show a stable performance. The modules have also demonstrated high yield and durability, properties that are essential for low-cost manufacturing and market acceptance. A process sequence for modules, having an average efficiency of 7.3 %, could produce large-area modules in a 20 MW/yr factory for a cost of 1,25 €/m², corresponding to 1,80 €/W (table 2.2).

<i>Crystalline silicon</i>	<i>Thin-film technology</i>
– Proven product durability	– Low materials consumption
– Abundant non-toxic materials	– Low manufacturing cost

Figure 2.1: Advantages of different technologies.

Table 2.2: Manufacturing costs (current process).

"Component"	Cost [€/m ²]
Glass preparation	~ 32
Silicon	45
Device fabrication	29
Module assembly	13
Total	1,25 E/m² = 1.80 E/W

2.3 Thin-film cell research, development, and production

J. Klaer talked about *Mini-modules from a CuInS₂ thin-film technology*. The process of production of CuInS₂-cells was described. Mini-modules with an aperture area of about 19 cm² have been prepared on soda lime floatglass substrates. Each module has 5 - 9 series connected cells. The majority of these mini-modules have efficiencies of 8 - 9 % with 9.7 % for the best one. Parameters important for the performance are single cell-efficiency and quality of the different layers. A high FF needs a thick ZnO-layer, whereas a high efficiency needs a thin ZnO-layer. The cell has proven to be stable for 2 000 hours at 85°C.

Flexible and lightweight solar cells are interesting for a variety of terrestrial and space applications that require a high specific power (i.e. electrical output/PV-module weight). Light modules are also advantageous in terms of transport and mounting. More than 90 % of the weight is due to the glass substrate. If this is exchanged to a low weight flexible substrate (polyimide), the weight can be reduced considerably. Improvements of a novel processing method are described in *Development of high efficiency flexible CdTe solar cells* (by N. Romeo et al.). The improvements have increased the solar cell efficiency to 11 %. The CdTe-cell is fabricated in a superstrate configuration, where the light passes through the polyimide substrate. The transmission depends strongly on the polyimide thickness. Two problems are that the substrate must be flexible and that it must manage the process temperature. Absorption of incident light and possible degradation of polyimide under UV and particle irradiation are the major limitations of the configuration. To overcome these limitations, a new approach has been introduced. The CdTe/CdS/TCO-stack is here grown on a NaCl/glass substrate. After the solar cell has been processed, a polymer layer is spin coated on top and the flexible cell is detached from the glass by dissolving the NaCl-buffer layer. Solar cells of 7.3 % efficiency have been obtained.

In order to produce cells with high efficiency, high quality material is needed. In order to produce cheap solar electricity, the amount of used material must be reduced. This matter was discussed by C.S. Solanki, presenting the paper *Free standing thin-film monocrystalline silicon solar cells*. These cells are based on thin crystalline silicon films (on a low-cost substrate) using high temperature deposition. IMEC developed the so-called "lift-off" technique, which enables the lift off of thin mono-crystalline silicon films from a silicon substrate and the transfer of them onto an Al₂O₃ substrate. Different PSLT-techniques were compared. A cell efficiency of 10.6 % can be achieved with a simple process. More information is available on www.imec.be.

2.4 Cells and systems for concentrators

Equipping PV-modules with concentrators can help to bring the costs down. In 1977 was the Sandia array installed. This was the beginning of the PV concentrating area. The first USA program included among other things mirror/lenses, tracking (direct sensors), and cooling. Some examples of different early systems were given by G. Sala, presenting the paper *PV concentrator alternatives towards low energy costs*. One example of a large demo-plant is the 350 kW Solaeras plant in Saudi Arabia. Another

example is a Tenerife plant from 1989. Many concentrator technologies are candidates to reduce the PV energy cost to less than 0.09 €/kWh.

V.D. Romyantsev talked about *Experimental installations with high-concentration PV modules using III-V solar cells*. Dual junction solar cells and fresnel lenses are used. An efficiency of 21.3 % has been measured outdoors for 48 serial connected cells. Examples of different tracking structures were shown. Simple electronic circuits are used to ensure automatic searching and tracking to the sun with a high accuracy. The power consumption is as low as 0.3 % of the generated output power.

2.5 PV module and system engineering

2.5.1 Cells and modules

One problem with using glass in a PV-module is that the module then will be heavy. S. Degiampetro presented *Highly transparent components for glassless PV-modules*. By changing one of the glass layers to a transparent film material, a lower weight can be achieved. In the presentation was a SiO_x-layer presented. This is an excellent water vapour barrier with high transparency performance. Other criteria that must be considered when choosing encapsulation material is UV stability, adhesion, and mechanical stability.

H.A. Zondag presented *Design of a dual flow photovoltaic/thermal combi panel*. A PV/T-system combines power and heat production with the aim to get a higher output/m² and lower installation costs. A prototype of a dual flow PV/T combi panel has been designed and a numerical model of this prototype has been developed. Measurements on the thermal performance indicate a zero loss efficiency (η_0) of 0.70 and a heat loss factor (U_L) of 5.1 W/m²,K. The influence of the glass and water layers on the electrical efficiency of the prototype has also been measured. It was concluded that it, from an optical point of view, is no need not to have water in the gap. The dual flow PV/T combi panel was found to perform well. The concept is however heavy and fragile, and is therefore not feasible for large-scale applications.

In large systems, there are a lot of inter-module connections. A silicon solar cell can have a life of 25 years, a solar module 20 years, and the cabling may last for 30 years. How long will the DC connectors last? Two commercial PV-connectors were described in the presentation *Alternative approaches to achieving PV connector reliability: A compared study of accelerated lifetime testing* (by A.S. Bahaj et al.). The main cases of connector failure are bad fabrication and assembly. The higher the force in the connection, the more conducting pathways are established. One problem that arises due to daily temperature changes, causing lateral movements, is thermal fretting. Different connectors were studied in a special test rig. One of the tested connectors showed an increased connector resistance from about 6 000 fretting cycles, and open circuit conditions occurred at about 12 000 cycles. If current is applied during the cycling, the connector life can be prolonged.

2.5.2 Quality

H.A. Zondag talked about *Stagnation temperature in PVT collectors*. A PVT collector produces both heat and electricity. One problem is that high PV-temperatures can arise during stagnation, which occurs when heat is not withdrawn from the collector (e.g. due to pump failure or full storage). High temperatures affect the lifetime of the PV-system. There is e.g. a risk of EVA delamination for temperatures over 135°C, and yellowing is promoted by a combination of UV and high temperatures. In the project has a numerical model for calculating stagnation temperatures been validated, and stagnation temperatures for different locations in Europe have been estimated using the model. Some results from the calculations are that:

- temperatures over 135°C are very unlikely in the North of Europe
- the stagnation temperature increases if collector performance increases
- the stagnation temperature of PVT should be a point of attention.

A. Paretta presented *Analysis of optical degradation of photovoltaic modules*. Visible ageing effects are due to dust, colour-change, and EVA degradation. A "browning" of the central region of a cell is common. Optical characterisation has been made with reflectance measurements. The results show an increased reflectance with ageing. The non-destructive method presented is proposed for evaluation of module optical losses under outdoor conditions.

The performance of PV-modules is limited by the quality of individual cells. This is the subject of the paper *Large area photocurrent maps for routine PV module inspection* presented by H. Müllejans. The aim with this work is to develop a tool that can detect defective solar cells in strings and PV modules during or after the production. Photocurrent mapping of PV modules with a Large Area Light Beam Induced Current tool has been demonstrated previously. That system has now been upgraded so that large PV-modules can be scanned, maintaining the focus of the laserbeam over a scan area of 1.5x1.5 m², and with a resolution better than 0.2 mm everywhere. In order to demonstrate the possibilities of the system, presentations were made of maps obtained from two PV-modules. The total time for scanning a PV-module is about 1 hour. It is suggested that this method should be routine tool in PV module inspection (in the product line). One advantage with this method is that it detects electrically active defects even if they are not apparent to eye or in IV-curves.

2.5.3 Storage

Intermittent renewable energy sources require short-, mid- or long-term storage capacity in order to provide a permanent power supply (for stand-alone systems) and to maximise the use of the renewables (for grid-connected systems). This matter was discussed by P. Malbransch, presenting *Investigation on storage technologies for intermittent renewable energies: Evaluation and recommended R&D strategy - Investire network*. The Investire is a thematic network, with 35 partners, where different storage technologies for renewables are studied. The project is funded under the EC's 5th Framework programme and facilitates exchange of information. Some main concerns regarding the storage of renewable energy are:

- cost
- lifetime (with difficult cycling conditions)
- overall efficiency
- self discharge
- specific power (W/l or W/kg) and specific energy (Wh/l or Wh/kg)
- technology and management aspects.

One question is what future alternatives there are to conventional lead-acid batteries, and how to select storage type. Some examples of storage technologies are Ni-Zn, Ni-Cd, NiMeHydride, Fuel cells+electrolyser+hydrogen storage, compressed air, super capacitors, and flywheels. More information can be found on www.investire-network.com.

One important factor for the performance of a PV-system is the degradation of lead-acid batteries. For example has rapid degradation of starter batteries been observed. Degradation of batteries was discussed in the paper *Lifetime testing of solar home systems* (by Wiggelinkhuizen and Vervaart). It is very important to follow the whole chain from design and production to installation. Some important factors concerning battery lifetime are:

- sulphation of the plates at low state of charge
- corrosion of the positive grid
- loss of active material.

P. Passiniemi (NAPS) talked about *Seasonal back-up unit for solar electric systems in high latitudes*. When using PV at high latitudes, seasonal storage of the electricity is an interesting question. A hybrid system with solar cells and fuel cells can be a technically attractive option for small loads and can replace the use of diesel back up. The size of fuel cells has decreased during the last then years, and fuel cells have proven its reliability in field tests. Some key factors affecting the sizing of the system are the load size, the location (radiation, temperature, freezing), and the accessibility (gas delivery). Two barriers to seasonal energy storage based on hydrogen are that the gas storage is too big, and that maintenance is needed. Examples were given from Kevo field test site. Also a Dark&Cold Seasonal Back-up Unit with a design load of 5 - 50 W was described.

A stand-alone system is also described in *Stand alone power system coupling a PV field and a fuel cell - First experimental results* (by S. Busquet et al.). The described system consists of PV, electrolyser, and a fuel cell. Two advantages of the system are the clean and rational use of solar energy, and the autonomous operation of the system. Some disadvantages are the high investment and O&M-costs, and the complexity of the system. The aim of the PV-FC system European project is to develop and study two plants. Estimated future (2010) prices of different system components are given in table 2.3.

Table 2.3: Estimates of future (2010) component costs.

PV	2 500 €/kW
Electrolyser	3 000 €/kW
Fuel cell	100 €/kW
Battery	65 – 100 €/kWh
Gas storage	50 €/Nm ³
Converters	30 €/kW

2.5.4 Energy production

D. Chianese presented the paper *Power and energy production of PV modules (cycle 8)*. Some questions that concern a PV user are "Power - Energy - Reliability". How much energy is the module supposed to produce (kWh/yr)? How much power has really been acquired? How long will the PV-plant last? In the presented project were a number of different test systems studied. Standard test procedures were used and the power was measured each third month. The results show that there is a degradation in the power during the first time of exposure. This means that the actual power delivered by the system is lower than the nominal power (P_{nom}). This is important to have in mind when discussing the performance of a system.

R. Kröini presented *Energy rating of solar modules - a comparison of different methods*. The way to choose between different solar modules is often not better than to play on roulette. There are e.g. differences between different modules, and the output depends on actual irradiation and temperature. Also orientation and shading influence the output. This makes the prediction of the performance of a PV-system very unsecure. A market depends on good information, and energy rating could help to increase the use of PV. The difference in energy production from different PV-modules at given meteorological data should be easy to find.

Energy rating was also discussed in the paper *Matrix method for energy rating calculations of PV modules* (by G. Friesen et al.). The power output from a PV module depends on incident irradiance (G) and ambient temperature (T). In this work Meteo climatic data has been used. This data can be simulated from monthly data of G and T. The energy rating (ER) of a module has been achieved by multiplying a matrix describing the PV module with a Meteo data matrix. The accuracy was stated to be $\pm 5\%$ for the standard c-Si power matrix. A recommendation was given not to use the manufacturer's data of P_{nom} but to use the stabilised properties of the cell instead.

J. Merten presented *Integrated approach for load management of PV-hybrid systems*. The main actor for load management is the user. Load management requires information on system state (e.g. battery SOC, energy generation, and energy consumption). An energy management system tool, providing this information, can hale the user to adapt his/hers use of energy (e.g. to use the washing machine only when there is enough energy available). A modular power-conditioning unit including inverter control, inverter power modules, PV-charger modules, and energy management system was presented. With a remote visualisation panel showing information of the system state

(battery charge, energy flow), the use of energy can be controlled. Switching off appliances can also be automatised by using a remote control relay (e.g. should outdoor lamps only be lit during the night). When more users share a single generator, there must be a system to avoid empty batteries and conflicts. This system should stimulate the user to use energy only when it is needed. One example (from Spain) was given where 40 families share 10 kW power.

2.5.5 Costs and Pay-back times

P. Frankl presented *Life cycle assessment (LCA) of PV systems*. This was an interesting topic, and a lot of questions were posed by the audience. LCA is a technique for assessing environmental aspects of a product over its whole life cycle. In the 1980's PV was considered not to pay back for the energy spent for their production. Still in the 2000's some people think this statement is true. This can be a problem if these people are the decision-makers. It is therefore very important to present costs and payback times for PV-systems in the right way. One example of this is shown in figure 2.2, where the ranking of PV depends on the way the different technologies are compared. The results can differ between different LCI studies. It is therefore important to interpret literature data with care, since there often is a lack of transparency. Made assumptions strongly influence the results, and the assumptions should always be described thoroughly.

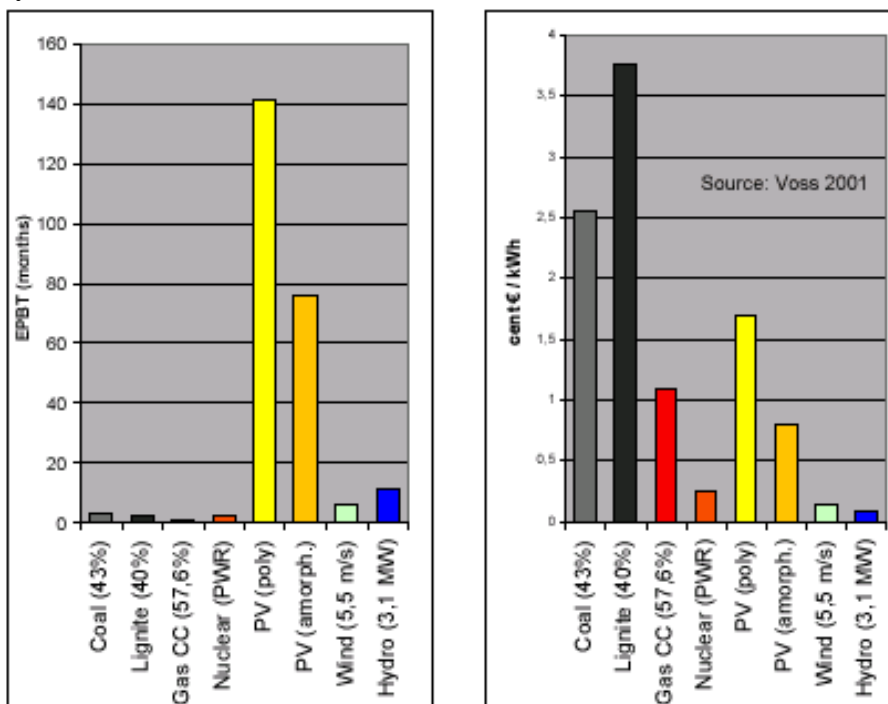


Figure 2.2: LCA of PV-systems. Results based on EsterneE - Germany [3].

Future PV-systems will have higher efficiency, lower losses, and need less feedstock material. The primary energy requirement (in 1999) for different types of solar cells is given in table 2.4. (The figures do not include BOS.) It is important to minimise the use of material and to take multi-functional use of PV into account. Other types of semi-

conductors (in particular thin films) and recycling of modules are needed. The proportional relevance of BOS will increase (dominating for future thin film technologies).

Table 2.4: Specific primary energy requirements in MJ/Wp.

sc-Si	41
mc-Si	32
a-Si	15

Some results are that LCA confirms good environmental performance of PV. The EPBT of future building integrated systems is estimated to 1 - 2 years, and future systems specific CO₂ emissions is down to 0.02 - 0.04 kg CO₂/kWh. Two new research projects dealing with LCI are ECLIPSE and SENSE.

H.A. Osenbrink presented *PV systems technology and performance in 20 years of EC R&D perspectives*. The ideal PV-performance is the delivery of electricity at lowest possible cost at any time. Factors influencing the cost (per kWh) are e.g. solar radiation, investment cost, life-cycle performance ratio, component reliability and operational cost. The installed peak power is often 5 - 15 % lower than design values. Some lessons learned from different demo-projects were presented:

- Modules (degradation).
- Components (Inverter failure - reliability improved last 10 years. Accumulators - battery charge efficiency, maintenance crucial, 10 years lifetime possible. BOS-components - mismatch, lighting systems, supervision.).
- System/building integration (sub-optimal orientation, shading losses, wiring losses, load matching, safety requirements important).

Some required future developments are:

- Thin film modules must come to the market (build-up of user confidence).
- Stand-alone monitoring and supervision through Internet.
- Standardised roof-top systems (easy to install).
- Reduction of area-related cost in building applications (replacement of existing materials).
- Modularity and standardisation. (Converters integrated in the module...)
- Accumulators with intelligent controls.
- New storage concepts (NiMH, hydrogen, water).
- Operator training needed.
- Added values (sound reduction, comfort...) need to be more assessed.

Some conclusions are that component quality has improved and that type approved PV-modules are very reliable. Many improvements have been achieved through roof-top programmes. Technology progress needs demonstration programmes and a competitive market environment.

W.C. Sinke (ECN) presented *The energy effects of the rapid growth of PV capacity and the urgent need to reduce the energy payback time*. Financing and cost-reduction are often discussed as a barrier for the implementation of PV. Instead we should start to consider PV as an investment in energy. The manufacturing of a PV-system consumes

energy. The payback time for the energy use has been reduced over the years thanks to better manufacturing technologies. The objective of the presented work is to quantify energy effects of the rapid growth in PV. The used scenario predicts a total capacity of 211 G” in 2020. Information of energy output from the worldwide PV-installations can be found from the IEA-PVPS database. According to the analysis made, the first net kWh will be produced in 2002. A sustained effort in order to reduce the energy payback time of PV-systems is needed.

2.5.6 Miscellaneous

A. Helgesson presented the paper *PV-panel with an overedge reflector for stand alone systems*. Some PV-applications need to be designed for year around performance. One problem, for e.g. PV-powering of sectionalizing switches in the electric grid, is that the energy supply can be scarce during the winter. Measurements on a system with a flat reflector mounted above a PV-panel indicate that the reflector increases the incident winter insolation and that it protects the PV-panel from snow and frost. The use of the reflector therefore reduces the need for expensive solar cell area. Due to shading during the summer, the total yearly output is reduced, but also more evenly distributed over the year. In the presented project an overedge reflector was constructed. The design should facilitate installation of the reflector. Eight reflector installations have been made at existing PV-powered sectionalizing switches. The performance of the overedge reflector will be studied by measurements on a prototype.

M.D. Basilian presented *Australia’s first combined BIPV/Thermal test facility*. One way to characterise BIPV/T-systems is by the heat-to-power-ratio. The temperature of a PV-module affects mainly the V_{OC} and cooling of the cells is an interesting factor to consider. Examples of parameters that are studied when testing a PV/T-system are U-value, reflectivity, and spectral selectivity. BIPVs were also discussed in *PV-Cool-Build (EU fifth framework project)* by M. Cross. It is estimated that an average BIPV-cell operates at a temperature of up to 50°C above ambient temperature. If this temperature could be reduced, the performance could be increased and unnecessary thermal cycling stress could be avoided. The plan is to develop a guide for PV building designers, including e.g. rules of thumb and hints.

Below is given some notes from M. Meinhardt’s presentation of *Control and communication for decentralized photovoltaic hybrid systems*:

- Grid-connected systems still need to be subsidised. A hybrid PV-system can however be an optimal solution for remote areas.
- In a PV hybrid system, AC coupling is better than DC for a number of reasons.
- The control unit of PV system often uses components from different suppliers.
- A hierarchical structure of control and communication tasks in PV hybrid systems has been proposed.
- Some examples of realised PV-systems (e.g. on Kythnos and in the Himalayan) were given.

Meinhardt also quoted an African saying worth considering: ”The one who turns towards the sun will leave the shadows behind him.”

J.-C. Marcel presented *The PV-Ingrid Association and the Energrid, dedicated datalogger and tool for Res installation in islands grid with green certificate delivery*. The PV-Ingrid project is partially funded by the European Commission and aims to analyse and promote grid connected PV-systems in insular sites. One step in the work is to set a network through the creation of a European association in order to increase the awareness of the value of PV-electricity. Another step is the establishment of an energy efficiency and rational use of energy program with RES and delivering of a Green Certificate. An Internet site is created with access at two levels:

- Free access for the public with information about principle and use of renewables, legal information, architectural acceptance, and advises for rational use of energy.
- Limited access for partners, donors, user associations, and electricity syndicates to information on meteorological data, RE production, and user consumption.

The membership is free until the end of the EC project (June 03). Also an industrial version of Energrid is available. More information can be found on www.pv-ingrid.org.

K. Kurokawa presented *PVvison - The very large scale PV system concept*. VLS-PV systems can be a way to effectively use e.g. desert regions, unsuitable for agriculture, and can give a substantial contribution to the global energy production. If only a part of all desert areas is covered with solar cells, an electricity output matching the world primary energy supply (387 EJ/yr in 1995) can be achieved. In a project are case studies for selected regions for VLS-PV (e.g. in Sahara) made. A sketch of a 100 MW plant was shown in the presentation.

P. Boulanger talked about *PV grid connected system performance statistical analysis*. A Sankey diagram from potential solar energy to energy fed into the grid was shown. The work is based on probability functions and statistical communication theory. The grid connected PV is considered as a black box. A proposal is a simplified but generalised method for PV performance evaluation.

2.6 European PV product- and system standardisation, certification and marketing

2.6.1 Quality and standards

Not only costs, but also lack of quality standard is a barrier to a larger utilisation of the PV-technology. The absence of certification, and the associated lack of confidence in the quality of PV-products, prevents the PV-market from achieving its full potential. M. Real presented the paper *Quality is the key to the photovoltaic - a global initiative on quality manufacturing harmonisation of standards and consumer protection*. The project aims at launching an initiative to enhance global confidence in PV-products by using the knowledge-base developed by the Global Approval Programme for PV (PV GAP). In this action, uniform and high quality PV-manufacturing is to be initiated worldwide. A clear quality labelling for PV-products (a Quality Mark for components and a Quality Seal for systems) is to be established. The manufacturers must fulfil certain criteria in order to get the quality mark. The products should be manufactured

according to international standard or PV GAP recommended specification, and tested in an accredited laboratory. The advantage for the manufacturers is that it assures the reciprocity of the testing results of the products (test results from one country accepted in other countries). The advantage for the customers is that the label makes it easier to identify quality PV-products. Thus, the quality label provides for greater consumer protection and confidence, and facilitates marketing. More information can be found on www.pvgap.org.

Labelling was also discussed in the paper *Dynamic performance indicator - an effective tool to promote solar electricity* (by Heidenreich and Müller). Ecolabels can be used to ensure environmental benefits and values of money. This will help the customers to do the right choice. PV needs a fair and innovative access to the liberalised market.

P. Malbranche presented *PV components and systems standardisation: State-of-the-art and R&D and marketing needs*. The work with standardisation publication is a long way of several years. Standardisation is needed in order to improve quality (safety, reliability, and performance), decrease cost, and to gain a better end-user confidence. Different areas where standardisation is needed is for components, installed systems, and services (maintenance, replacement). The manufacturers need standards for e.g. warranty issues and test procedures. The end-users need standards for component selection and quality assurance. Some kind of energy labelling of the products was suggested. Standards are not only needed for solar cells, but also for e.g. batteries. Some suggested improvements are listed below. More information about this topic can be found on www.cenelec.org, www.task3.pvps.iea.org or www.iec.ch.

- Accelerated test procedures (reduces the costs for testing and facilitates the development of new components).
- New and more useful criteria.
- Global approach of system.
- New standards should be technology independent.

J.C. Jol presented *Development of a national pre-standard for BIPV in the Netherlands*. The standard includes both thermal solar and solar electricity. One future goal is that BIPV products should be certified, showing that they comply with the standard. PV products used as building products must meet certain requirements and in 2000 a standardisation committee was established. Examples of participants are the PV-industry and installers, the roof industry, Ecofys, and ECN. The work has resulted in a green-version (2002) and comments are now considered. Only building aspects are being considered, since the electrical aspects are covered by other regulations. The pre-standard contains:

- construction
- fire-safety
- sound
- water ingress
- energy efficiency
- materials used.

Also different methods of assembly are considered. Examples of this are solar panels integrated in or placed on the building shell, solar panels positioned independently on a flat roof, and solar panels combined with flexible roofing system. Testing procedures are based on existing methods from NEN-EN standards.

Why do we need quality? This question was asked by J. Bates, presenting *Quality management of stand-alone PV systems: Recommended practices*. Quality is needed since one main cause of PV-project failure is lack of quality, and poor operation gives PV a bad reputation. Quality management is a set of rules that should help us to achieve 100 % successful projects, and is a method of documenting important project details. One way to improve quality is to use expert advice when necessary, and to use common sense. Some items are summarised below:

- *Project planning*: Ensure contracts are in place defining responsibilities for all actions. Schedule the staff required for each task. Allow time for testing. Identify organisation/persons responsible for system maintenance. Check local availability of technicians. Ensure that the company selected is stable.
- *Financing*: How will the user pay for the energy? The payment must cover both system and maintenance.
- *System design*: Include load profile. Adhere to national standards. Provide comprehensive documentation.
- *Training*: Users should be trained to get the best from the system, i.e. how to use it and what the limitations are.
- *Logistics*: Consider site access. Make sure that the components are delivered on the right time, and that there is weather protected space for storing of components until installation.
- *Quality control*: Use (inter)national standards if available. Use accredited laboratory to check components on delivery. Ensure that the components work together before they are delivered to the field.
- *Installation*: Consider contractual responsibilities. Make sure that the installers are properly trained.
- *Commissioning*: Documentation important.
- *Safety, warranties, and security measures*: Ensure safety regulations are followed. Consider necessary warranties and identify who is responsible. Measures against theft and vandalism (fasten the solar panel thoroughly and use security fencing).
- *Operation and maintenance*: Often overlooked, but very important. Regular system maintenance should be scheduled and recorded in a logbook.
- *Project evaluation and monitoring*: Learn from made experiences. Investigate financial aspects and compare with the project goals.

Standardisation is also discussed in the paper *Towards a meaningful standard for PV array installation in Australia* (by T. Spooner et al.). One important aspect when working with PV is safety, both for equipment and people. PV arrays have been installed in a wide range of applications (from small to large systems, including voltage ranging from 12 to 600 V, in either earthed or floating systems). One problem with a PV system can be arc faults causing fire. (More people die from fires caused by electricity

rather than from electrical shocks.) This means that electrical and fire protection need to be considered. Also quality and reliability must be provided. A special standard is needed for PV arrays since they differ from the usual house wiring. For example is DC wiring unfamiliar to electricians, and PV arrays can not readily be turned off. The systems are also exposed to outdoor environment. Conventional over-current protection systems do not work under all fault conditions. The systems may also include batteries or be connected to the grid. Standards have not yet addressed the very significant safety issues raised in the installation of PV systems. The paper discusses important safety issues and moves toward the formulation of a comprehensive standard for PV arrays in Australia. A draft standard ("PV Array Installation Requirements") can be downloaded from www.standards.ee.unsw.edu.au/PVarray.htm.

2.6.2 Monitoring

Since bad operation of a solar energy system affects the profit, monitoring of the system can be a way to achieve a higher profit. This was discussed in the paper *Safer'Sun - Service - Internet based visualisation, operation, billing and fault monitoring of decentralised photovoltaic power systems* (by G. Beceker). The yield can be controlled in a number of different ways: reading of a meter, comparison with neighbours, simulation based on local weather, or with permanent monitoring and active fault-detection. Safer'Sun offers a way to read the energy (using a logger) and via Internet present the status. Faults can be detected and identified and an alarm can be given. The presentation is given in a clear way, easy to understand. Safer'Sun can be used for both private and profit systems.

2.6.3 Mediterraneo

J.R. Bates (UK) presented *Mediterraneo - Urban photovoltaic awareness*. The goal is to install 862 kW_p grid connected PV in urban environments in France, Italy, Portugal, and Spain. The installed systems will be monitored so that future projects can learn from the experience gained. The large number of visible systems will raise the profile of PV in Europe. The cost of PV installations can be reduced by using bulk procurement of components and standard kits developed for roofs and facades. The standard solution should be modular and quick and easy to install. There should also be a common installation manual and standard commission procedures. The installations began in March 2002, and in August, 184 kW_p had been installed in mainly Italy and France. The system differs between the countries, and e.g. in Italy, crystalline silicon is more usual than in Spain. This affects the cost of the system in the different countries. Some factors of success noted are a streamlined commercial approach, a strong management and commitment of all partners, and a partnership of manufacturers and installers. More information about this work can be found on www.mediterraneo-pv.net.

2.7 European PV market, regulations and financing

The European PV production grew from 60.5 to 88.2 MW_p (45 %) in 2001. The extrapolation of the world wide growth rate however predicts that the share of the European PV industry will decrease in the future, from currently 22 % to approximately 10 % in 2010. Roadmaps are an important tool for the future planning of technological development. This was discussed in the paper *PVNET - R&D roadmap for European PV* (by A. Jäger-Waldau). Nine countries are taking part in the PVNET-network, developing a roadmap for PV R&D based on a broad consensus among different technologies, and industry and research institutions. Workshops and symposia are organised in order to stimulate communication and discussion within the PV community. Examples of issues are: crystalline silicon or thin-film technologies, system technology, and storing of the electricity. In order to reach an increased market, material research and quality control are needed.

Another paper presented within this area is *SolarGeneration - Solar electricity for over 1 billion people and 2 million jobs by 2020* (by M. Cameron et al.). This work is a co-operation between the PV industry association and Greenpeace. The SolarGeneration's mission is to define the role that solar electricity will play in the lives of a global population. The scenario is based on the market development up till now, and on national support programmes. Some key results indicates that PV can supply 1 % of the total electricity production in year 2020, and that the module cost is lower than 1 US\$/W_p. 160 million tonne of CO₂ will be saved, and 2.3 millions new jobs created. In order to make this happen, the following is needed:

- Extend feed-in laws throughout Europe.
- Establish export programmes to also assist with establishing production facilities in developing countries.
- Green certificates (a danger for PV?).
- More private financing must be supplied.
- Continued public commitment to investment in PV.

R. Haas presented the paper *On the success of market deployment strategies for PV systems in the built environment in Europe*. The share of small grid connected systems has increased. Different rebate programmes were discussed. When studying optimal financial incentives for BIPV, it is also important to take the willingness of the consumer to pay into account. Some key factors in order to get a successful dissemination of PV are listed below. More information can be found on www.task7.org.

- Provide a financial incentive.
- Guarantee technical performance.
- Minimise costs to the public.
- Provide targeted information.
- Improve the market and conduct marketing.

2.8 European PV “roof top” programmes, performances, architectural and urban planning aspects, lessons learnt, individual cases, comparison of result

2.8.1 Italian projects

G. Silvestrini presented *The Italian PV Programme*, with a first goal of 23 MW in 5 000 plants in 2003. At the end of September 2002, 1.3 MW had been installed. A rapid growth rate is expected, which would result in a total of 3 MW at the end of this year. This means that the next year will be busy. In the first phase more applications have been submitted than expected. Most applications are for flat roofs, and only a few of the projects are real building integrated. 63 % of the approved public installation projects are schools. Some examples of different projects were presented. The government will decide on whether to continue to spend money on this project. Silvestrini thought that it would be some kind of continuation, but he did not know to what extent.

A lot of examples of PV-installations were given in the presentation of *The Italian Roof-top program: Status and perspectives* (by M. Gamberale). A feed-in tariff for PV electricity is on discussion with the Ministry of Industry and the authority for electricity and gas.

G. Chimento presented *The Enel group for the Italian national program “Photovoltaic Roofs”*. In this presentation were a large number of different PV-systems (stand-alone-plants and BIPV) presented. Some points that were discussed are service and monitoring, training program for technicians, and PV roof design (standardised modular electrical design).

Examples of different PV installations were also given by G. Tondi presenting *The PV “roof top” programme in the province of Florence: Results and achievements with local administrations*.

2.8.2 Monitoring and information

H. Scholz presented *Results of Monitoring PV demonstration projects from the 4th and 5th EU framework programme*. The purpose of this work is to present monitoring results of European PV-demonstration sites. Collected data shall be put at the Ispra PV-Monitoring data bank to the benefit of specialists and users. Monitoring of PV-systems can be used to determine performance, reliability, and durability of the plant, and to assess the quality of the design. Monitoring also provides users with information on effective operation and gives an opportunity to exchange experiences between different installations. It can also be used for subsidiary reasons in order to study the energy yield rather than the installed capacity. Some of the main performance indices are the yield, the performance ratio, and the inverter efficiency. In order to monitor and present the result, the New Unified File Format (NUFF) can be used. This format uses six lines to present climatic and system data. Since it is a text file, it will use only little memory capacity. Some results from monitoring of 19 roof systems (à 2.04 kW_p) and 13 facade

systems (á 2.7 kW_p, tilted 38°) were presented. The weak point of the plant performance is usually the inverter.

A. Woyte presented *Two years analytical monitoring results of an experimental photovoltaic system set-up under determined shadowing conditions*. The influence of different methods of connecting on the losses was studied. Objectives of the project are:

- residential PV with partial shadowing
- different configurations (central, string or module inverters)
- shadow tolerance.

In another project was *Monitoring results of 450 domestic grid connected PV systems in Amersfoort, The Netherlands* (by A.J. Kil et al.) presented. The objective of this work is to contribute to the use of renewable energy. Data is collected by a chip card and from 469 PV systems have 355 valid data sets been gathered until 2001.

The goal with *IEA PV building integration demonstration site: DEMOSITE¹* is to promote and disseminate BIPV, to give information to architects and public, and to create collaboration between the PV and the building industry. In order to spread information, info sheets and guided visits at an exhibition site are used. Information is also available on the website www.demosite.ch.

Another way to spread knowledge about PV is to give information in schools. This is done in the German project "Sonne in der Schule" presented in the paper *Sun at school - SONNEonline results of two photovoltaic school promotions* (by G. Becker). This project has resulted in a lot of pupils (and teachers) coming in contact with the PV-technology. More information can be found on www.sev-bayern.de.

2.8.3 BIPV and examples of some installations

I. Hageman presented *Building Integrated Photovoltaic*. In this presentation it was concluded that aesthetical, electrical, and building construction issues are important. Some examples on different installations were given. One conclusion is that PV-technology is ready to be used, and that PV-system components are available. Steps needed to develop BIPV further are:

- implementation of holistic design approach
- get building professionals involved
- intensify information, education and training
- design tools.

BIPV was also discussed in the presentation of *HIP-HIP project - Fostering market penetration of PV systems integrated in buildings within Europe* (by Michel and Rambau). The objective of the project is to reduce costs for grid-connected BIPV-systems through innovative design and better system optimisation. PV is not competitive with conventional fossil energy, but it may however be used if

¹ Paper by C. Roecker et al..

environmental benefits are considered more. Two remarks were that costs should be counted per kWh instead of per kW_p, and that guarantees and quality procedures are necessary. More information can be found on www.hip-hip.net.

R. Krippner presented the paper ***Building typology and monumental protection. Projects about the integration of photovoltaic in existing buildings.*** The demand for newly constructed buildings will decrease and the challenge for architects and engineers will be the care and adaptation of the existing building fabric. A study was made of PV integration in two existing buildings. Also shading was considered. One project concerns a PV Canopy in Erfurt, which should reduce overheating in offices but also allow daylight. The construction in steel and glass is also meant to accentuate the appearance of the facade. The integration of PV-systems is a field of work including building, construction, physics, and design aspects.

P. Ruyssevelt presented the paper ***PV in the regeneration of heritage buildings.*** He talked about the work with "Titanic mills", an old six-storey textile mill that will be transformed into 125 flats and some non-residential premises. The use of PV has been accepted by the Planning authority and English Heritage. Objectives of the project are:

- To save a historic building
- Economic resurgence in the area.
- CO₂-neutral building-
- To demonstrate renewables.

The approach is a low energy design concept with an optimum mix of renewables. Important factors for the heating load are windows, surface-to-volume-ratio, air leakage, ventilation, and hot water consumption. The electricity load depends on the occupants' choice and uses. Here, low energy appliances and light can be a way to reduce the load.

T. Blewett-Silcock presented ***DTI-funded PV domestic field trial installations in Nottingham, Glasgow and Newcastle, UK.*** The objective is to use design and monitoring of domestic installations as a learning opportunity for key-players of UK PV installations. One thing that is important regarding installing is on-site-co-ordination with the normal building steps. Another important thing is to educate people about PV. Pictures from the installation work of PV in Nottingham were shown during the presentation. Also projects in Glasgow and Newcastle University of Gloucestershire were presented. More information can be found on www.esd.co.uk.

P.W.F. Deege presented ***the EarthCenter Solar Canopy. Three electrical systems on a timber frame.*** An old mining pit has been remade to a solar energy centre, visited by e.g. many schools. This is the largest solar canopy in the UK, with a peak power of 108.5 kW_p. The main features of the centre are that the canopy is seen directly at the entrance, and that the electricity is used on the site. It is designed with a timber space frame, with trapezium shaped arrays, tilted 5°. Some difficulties are a high grid voltage (253 V_{ac}) and software failure. The monthly system efficiency is about 9.6 %.

M. Snow presented *Large scale urban BIPV projects in Australia, technical and non-technical design issues and experiences from Sydney Solar Village and 16 kWp Solar Kogarah Town Square development*. In this presentation were some different examples of PV-systems integrated in roofs or facades given. One example is the Olympic village system (630 kW_p). Some Australian considerations are high ambient temperatures and high relative humidity. These items must, together with shading etc., be considered during the design phase.

Another presented paper is *Achievements of Task 7 of the IEA PV power systems programme: Final report and outlook* (by M. van Schalkwijk et al.). This program has been an international co-operation framework. Information of PV projects and a product database can be found on www.pvdatabase.com. Some interesting issues regarding BIPV technology are PV-products, non-building structure, electrical design criteria, and system reliability. Also non-technical issues (like BIPV potential and economics) and market deployment are important. The outlook is that PV can be seen as a part of a green energy portfolio or a low energy building concept and that PV should be a part of any building. More information can be found on www.iea.pvps.org or www.demosite.ch.

2.8.4 System design

Some interesting questions concerning PV-systems are the amount of incident radiation, the optimum tilt, and how much electricity that can be produced. These things were discussed in the presentation of the paper *GIS-based inventory of the potential photovoltaic output in Central and Eastern Europe* (by M. Suri et al.). The paper deals with quantification of global irradiation and estimates of electricity production from PV-systems. The maps of monthly global irradiation have been calculated from clear-sky radiation, using a radiation model and other tools integrated within a geographical information system (GIS). When estimating the output, also information on land-cover-data (residential areas) is needed. The energy yield (in kWh/yr) for different tilts and different geographic regions has been calculated. The GIS database of solar radiation can be a support tool in the phase of planning in order to identify best suitability areas (analysis of socio-economic data).

PV offers a unique opportunity to produce electricity in the urban environment. S. Nowak presented *Solar ElectriCity Guide - Implementing and experiencing photovoltaics in the urban environment*. The motivation of the project is to show that PV is an attractive energy service and that it can be used in building structures. A lot of successful PV-projects with different designs, applications, and project financing mechanisms have been made across Europe. In many of these projects has the role of municipalities been crucial. The objective of the Solar ElectriCity Guide is to provide builders and actors within local and regional authorities with the necessary information and instruments to define, evaluate, plan, and implement PV-projects in an urban area. The Guide gives access to information about PV-technology and experiences from PV-implementations, and includes the following chapters:

- Introduction
- Applications in the urban environment
- Project
- Policy
- Potential
- Urban design
- Building design
- Financing mechanisms
- Legislation
- Glossary.

2.9 The PV market changing scale in the Mediterranean countries and emerging economies

J.L. Bal presented *The world summit for sustainable development. The post Johannesburg*. The Johannesburg summit was partly a disappointment since no action plans were taken. There are however some reasons to be optimistic (article 8 & 19). The European initiative is a joint declaration, and a proposal on a renewable target of 15 % of the global total primary energy supply by 2010. (Bal presented an interesting map showing the (few) electrified areas of the world.) The objective for Energy for poverty eradication and sustainable development is to increase the access to energy services. Promotion of renewables in the Mediterranean regions in order to provide electricity for isolated rural population. Some important points are:

- The role of the state authority in energy policy has to be defined in the frame of energy sector liberalisation.
- Public/private partnership.
- Decentralised rural electrification on the maelstrom of liberal reforms, who funds?
- Payment by user and some subsidies.
- The need of economical development.

2.10 Co-operation with developing countries, village power, implementation of G8 recommendations

Many remote areas in developing countries are cut off from access to local power grid (about two billion people have no access to electricity). Solar energy can here be used as a source of electricity for e.g. lighting, vaccine refrigerators, and pumps for village water supply and irrigation. PV-systems also have a role to play in rural schools. Compared with traditional alternatives, e.g. small generators, the PV-technology is already cost-competitive. The use of PV for rural electrification in developing countries can be justified, not only from an economic point of view, and in terms of a sustainable development, but also as a contribution in the fight against poverty. The market is however advancing relatively slowly, but an impetus has now been provided by the heads of government of the G8.

A lack of energy infrastructure is a serious constraint to the development of many developing countries. L.E. Gyoh presented the paper *Affordability and successful implementation of photovoltaic projects in developing countries*. One country where the PV-market grows is Nigeria, where PV is used for medical applications (e.g. vaccine refrigerators), and water supply. In order to increase the use of PV in developing countries, financiers are needed, and spare parts must be available at reasonable cost. Examples of different financing models are consumer finance, lease financing, service contracts, and rental schemes. Some experiences from a rural electrification project in a village are that ownership and training are key factors to successful operation and maintenance.

B. Nelis presented *Progress on IFC/GEF PV Market Transformation Initiative*. The PVMTI is an initiative of the International Finance Corporation and the Global Environment Facility. It aims to promote the sustainable commercialisation and financial viability of PV-technology in the developing world. 25 million US\$ are available for concessional funding in India, Kenya, and Morocco. Some barriers to the PV promotion are lack of sustainable business models and financing. More information can be found on www.pvmti.com.

In another paper was the *Solar Development Group* presented. The SDG's goal is to accelerate off-grid electrification using renewables in developing countries. The focus is on PV-technology in areas where it is unlikely with a grid extension. The strategy is to provide financing and to adopt best principles. Solar Development Foundation provides technical and business assistance. A solution to the consumer-financing barrier is necessary. Different financing models are equity, dept, or guarantees. More information is available on www.solardevelopment.org.

M.T Eckhart talked about the *Status of worldwide financing of solar PV* and gave some examples of PV in developing countries. For small systems, PV can be a cost-effective choice. Examples of applications are lighting for night operations (shops, home based crafts), agricultural (irrigation, food processing), and powering equipment (computers, power tools). One successful example presented was a system installed for water pumping, where the increased third crop paid for the system. Also PV financing was discussed in the presentation. This is still the major constraint to market take-off. Financing is also blocked by local policies. Different areas need different methods of financing. One question is who takes the risk for rural development. Monetization of environmental benefits of PV is another question. More information about this can be found on www.solarbank.com and www.americanrenewables.org. Eckchart also presented a way to divide different energy technologies into different classes (figure 2.3).

		Spinning generator?	
		yes	no
Fuel?	yes	hydro, wind	PV
	no	nuclear, coal, gas, biomass	hydrogen, fuel cell

Figure 2.3: Classification of different energy technologies.

D.R. Younger presented the papers *Renewable energy in developing countries: Lessons with markets, financing, and policies*, and *Financing PV projects in developing countries: An expanded role for the World bank and IFC*. The Global Environmental Facility support private firms to expand and has 23 projects involving 60 000 systems. It is important to increase the awareness of PV among consumers, and it is also very important to choose a sponsor carefully. Dissatisfaction can arise if e.g. the system fails and the installer has closed down. It was also pointed out during the presentation that regulatory models should be developed and that standards are needed.

N.K. Shrestha presented *Sustainable solar village electrification program: Home Employment and Lighting Package (HELP*)*. The program is operated by the Himalayan Light Foundation, and the objective of HELP is to provide environmentally friendly electricity to rural areas by using PV-installations. "HELP" is real help for the people in Nepal. About 88 % of the people live in rural areas and only 15 % of the total population have access to electricity. This means that there is a substantial future market for renewables. One problem is the financing of the systems. The HELP program combines the dissemination and use of solar electricity with income generation activities. Villagers participating in HELP are offered a skill-training program to produce handicrafts at local level. They can then generate income through working during the extended hours provided by the solar electricity system. The incomes can be used to pay off the SHS (solar home system). The systems consist of two PV-modules, one battery, and three solar lamps. One example from a village showed how the use of PV can improve the lighting situation. Not only better light is supplied, but the risk of fire is also reduced since no open flames are used. Some points of the HELP program are listed below. More information can be found on www.hlf.org.np.

- sustainable + solar home system + income generating activities
- no asset collateral, pay with handicrafts
- local development activities and training
- selected local villagers as technicians
- participation of all category of people

C. Nyman presented *Implementation of PV in Tanzania*. Only 5 % of the population have electricity from the national grid. In the presentation were some examples of PV for healthcare centres and schools given. Healthcare programmes in Tanzania aim to improve healthcare delivery services regarding e.g. family planning, child survival, and HIV prevention. 70 % of lost life years are caused by ten major diseases (e.g. prenatal, malaria and AIDS). Actions against this include control, immunisation, and education. Vaccines are very temperature sensitive and should be stored in a refrigerator within the temperature range 0 - 8°C. PV can here be used as an alternative to kerosene or gas for the energy supply. Electricity is not used only for refrigerators. It can also be used for lighting, increasing the possibility for people to get help at the healthcare centre also during evenings. A well lit health clinic or school can also be used for evening education or serve as a community centre. Another aspect is that it might be easier to retain personnel if the staff house is provided with electricity for light. More information can be found on www.soleco.fi.

The use of PV-systems in schools was also discussed in the paper *Technical assistance for the non-grid electrification of rural schools in South Africa*. Some experiences from previous projects are poor quality systems, problems with theft and vandalism, and lack of confidence in the technology. The presented project was launched in 1998, and the installations were completed in July 2002. The installed systems consist of eight PV-modules, a battery and an inverter. The battery and the inverter are placed in boxes as a protection against theft. Some problems discovered during the technical audit were not calibrated regulators, security problems, and not optimised theft protection (used fences shaded the PV-module). The user interface could also be improved, e.g. by lamps showing the status of the system. The community interest is vital for maintenance, security and sustainability of the system. For example can schools or communities be responsible for security measures against theft. Also training of installers is important. Some quality control issues mentioned are:

- functionality testing
- commissioning
- user manual (must be made in a language that the user understand!)
- maintenance procedures.

Z. Li presented the paper *PV and Hybrid village power systems: A discussion of sustainability issues*. The un-electrified population is no less now than it was 20 years ago. Most of these people live in rural and remote areas. PV can here, in many cases, be a cost-effective option for electrification. The investment cost is however high and there is a need of promotion and financing subsidies. Some "lessons learned" were presented:

- Failed systems (not mainly due to the technology itself, but to poor system design and financial constraints) have more negative social impact than expected.
- Financial failure can arise since financial sustainability is considered less than technical sustainability. There is also a lack of continuous financial support.
- Unclear ownership and lack of a long-term strategy for operation and maintenance can affect the success of PV-installations.

In order to proceed the work with implementing PV it is important to make sure that there is a long-term commitment to performance and quality. It is also important not to choose the "lowest capital cost", a life-cycle analysis has to be made. One very important conclusion from the presentation is that **we must start learning from all "lessons learned"** from different projects, and not to repeat earlier mistakes in order to learn the lessons again.

3 Exhibition

The exhibition took part during the whole conference and was open to all visitors interested in photovoltaics. About 100 companies and organisations from Europe and overseas were present. Some examples of exhibitors are:

AstroPower, BP Solar, Deutsche Solar AG, Du Pont Ltd, ECN, ENEA, ENEL, ETA-Florence, Eurosolare, Grundfos, Helios Technology, Isofoton, Mitsubishi Electric Corporation, Oskomera Solar Power Solutions BV, Phaesun GmbH, Philips Lighting BV, PV GAP, Q-Cells AG, Santemo, Scanwafer ASA, SEMCO Engineering, Shell Solar BV, Siemens, Solar Verlag GmbH, Solaris, SUN POWER Solartechnik GmbH, Terrasolar Hungary Ltd, and UNISOLAR.

A lot of different *solar cell modules* (mostly crystalline) were displayed at the exhibition. Not only ordinary framed panels (for e.g. fixed roof or facade mounting) but also flexible cell modules, sun-tracking solar panels, and foldable panels (used e.g. as solar shields above a window or as roof hatches on boats) were presented. Also plastic solar cells (with an efficiency of 3.28 %) were shown, as were PV-modules for building integration (from e.g. UNI-SOLAR).

Other products that were presented are: solar *inverters*, *connectors*, *solar control* and communication units, PV-plant *monitoring* (Sunny boy), and PV-cell and module *testers*. Also base *materials* and special laminates were shown as were *water supply systems* and *surge protection*.

Also different *manufacturing techniques* were presented. Examples of this are automation, thin film deposition systems, coating systems, sputter sources, roll furnace for thermal diffusion, hetero wafer technology, linear edgerounding equipment, tabbing and stringing, solar cells soldering, and laminators.

4 Systems and applications

This technical coverage is supposed to discuss the topic of systems and applications. Examples of applications presented at the conference are for lighting, water pumping, cathodic protection of water supply pipelines, sound barrier along a railway, street lighting, PV shading device, powering of sectionalizing switches, and vaccine refrigerators. The systems can be either stand-alone systems or grid-connected. The PV-modules can also be integrated into the building (BIPV-system). Also hybrid PV/T-systems were discussed during the conference.

One of the applications most discussed during the conference was the use of PV for rural electrification in developing countries. One reason for the interest in this topic is that it is a large potential future market. PV can here be used, not only for lighting (of e.g. homes and schools) and powering of e.g. TV or radio, but also for water supply, and for vaccine refrigerators. One large problem with rural electrification is the financing question. Lots of people living in "unelectrified areas" are poor, and can not afford to pay for a PV-system. This means that special financing models and solutions have to be created. In order to get a good system performance it is also very important with education of both installers and users. Another problem is theft and vandalism, and it is therefore necessary to protect the installed systems in some way.

One interesting concept is also the use of Hybrid Photovoltaic/Thermal (PV/T) system. Such a system consists of PV-modules coupled to a thermal absorber, producing electricity and heat simultaneously. Some of the solar radiation absorbed by a solar cell is not converted into electricity, but increases the cell temperature instead. This results in a reduced electrical efficiency. Cooling of the solar cells contributes to improved PV performance. At the same time can useful heat be extracted, increasing the total energy efficiency of the system. This means that a hybrid PV/T-system can be an interesting alternative to conventional PV-modules. During the conference were a number of different PV/T-systems presented. One example is the developed PV/T-collectors, presented in the paper *Photovoltaic thermal panels on the brink of demonstration* (by Helden and Zondag), that will be demonstrated in an EC funded project in the UK. Due to the heat extraction device, hybrid PV/T-systems have higher cost than standard PV-modules. This matter was discussed in the paper *Economic analysis of hybrid photovoltaic/thermal solar systems and comparison with standard PV modules* (by Tselepis and Tripanagnostopoulos). A spreadsheet was developed calculating the annual energy output of different systems. The energy output and the estimated system costs are then used for calculation of the payback time for the systems.

A *Hybrid PV/T-system with improved air heat extraction modification* was presented in a paper by Y. Tripanagnostopoulos et al.. A thermally insulated air channel is mounted on the rear side of the PV-modules. Air channel depth, air-flow rate, and heat-exchanging surface area are some key factors for the system performance. In the paper a low cost improvement regarding the heat exchange surface was presented. A thin flat metallic sheet (TFMS) is placed in the middle of the air channel. The modification has been investigated both experimentally and by the use of a numerical model. The results show that the suggested modification is a low cost improvement of air heat extraction in

a PV/T-solar system. Using an inexpensive aluminum reflector is another way to improve the performance of a PV-system. M. Brogren presented a paper with the title *Design and evaluation of low-concentrating, stationary, parabolic concentrators for wall-integration of water-cooled photovoltaic-thermal hybrid modules at high latitudes*. This PV/T-system is a facade-integrated system adapted for high latitudes. The estimated annual electricity and heat production with anodised aluminum reflectors is 200 kWh and 510 kWh respectively. At a solar height of 40°, the use of aluminum reflectors approximately doubles the electric power. The electricity cost was calculated to 2 €/kWh. Different reflector materials were subjected to accelerated ageing in a climate chamber equipped with a UV-lamp. The reflectance of the samples was measured before and after ageing. Thin-film coated aluminum has a high total solar reflectance, and anodised aluminum has a high initial specular solar reflectance.

Also other examples of Building Integrated PV (BIPV) systems were discussed during the conference. Solar electricity is then incorporated either as an integral part of a new building or used when retrofitting an existing building. In this way, PV can both generate electricity and replace conventional building materials. It is however important that the orientation of the panel is considered, and that shading of the modules is avoided. Different BIPV-products, such as solar roof shingles and glass PV-facades are now available on the market. One example of BIPV-modules was found at the exhibition case of UNI-SOLAR. These modules are unbreakable, lightweight and architecturally attractive. They are also easy to install, e.g. can the PV-shingles be nailed directly on the roof decking. The UNI-SOLAR PV-products use the unique Triple Junction solar cell technology, where each cell is composed of three semiconductor junctions, stacked on top of each other.

One key issue in order to get a successful BIPV-system is the aesthetical aspects of the PV-modules. One question is how much of the maximum possible power that can be sacrificed for aesthetics sake. This matter was discussed in the paper *Aesthetical appeal of BIPV or electrical performance* (by M. Pellegrino et al.). Some PV-modules, designed to be integrated in the facade, were here tested in order to investigate their performance. The general behaviour was evaluated under both an architectural and an engineering point of view.

A lot of interest at the conference was also given to quality issues and work with different PV-standards. Quality is a very important issue for the performance of PV-systems. It is also vital for the reputation of PV. Bad quality systems, with low performance, results in a low consumer confidence in the technology. This prevents the PV-market from growing. Some kind of quality labelling or certification was suggested in some of the presentations. This marking could help the customers to choose PV-products with high quality.

In order to improve the quality, standardisation is needed, and this was discussed in a number of the presentations. Both electrical aspects (dc wiring, safety) and building integration aspects need to be considered. Preferably, PV-products should also be tested at an accredited laboratory. In addition to create opportunities for better quality, standardisation can also facilitate marketing, since a product tested and approved in one country then also can be approved in another country without a renewed testing.

Other points important to consider in order to achieve a good system performance is a proper system design, training of users and installers, and a structured maintenance plan. Also safety issues requires consideration in order to protect people and equipment from damage.

Usually, a PV-system has a fixed position. This results in energy lost in mornings and afternoons. By using a sun tracking system, it is possible to increase the output. It is however important that the energy consumption for the tracking is not too high. One example of a tracking PV-system was shown by DEGERenergie at the exhibition.

Also different methods for storing of the electricity in a stand-alone system was discussed during the conference.

5 Conclusions

The sun is an inexhaustible source of energy, and the increasing debate about climate change increases the interest in renewable energy sources, e.g. PV. Solar cells can be used to generate electricity directly from the sun, and the possibilities of PV are enormous.

A lot of different topics were covered during the conference, from research on solar cell materials, and solar cell manufacturing to system engineering, market issues and the use of PV in developing countries. Not so many presentations were directly addressing the CO₂-problem. Topics much discussed during the conference were quality, energy labelling, standards and financing. In order to achieve higher system performance and to create a larger user confidence, quality issues have to be more addressed. Energy labelling can help the customers to identify products of good quality. Developing and using standards for PV is a very important step in the quality work.

Integrating the PV-modules in the building can be a way to reduce the costs. The PV-market development plays an important role in the move towards a more sustainable future. The annual PV-installation (in MW_p/yr) has grown rapidly during the last years. An increased production and installation rate is however necessary if PV is to play a larger role of the world energy supply in the future. One important step in order to create a larger market is cost reductions. One thing that must be remembered in this context is that the way to present costs and payback times affects the comparison between different energy technologies. In order to increase the use of PV, different financing models must also be developed. This is specially important for developing countries, where people who need the energy often can't afford to pay for the PV-system.

A lot of examples of different PV-installations were presented at the conference. A special kind of system is PV/T-systems generating both electricity and heat. There were also many presentations about the use of PV in developing countries. This is an area that constitutes a large potential market. In connection with the presentation of rural applications, problems with theft were discussed. It was also concluded that it is important to train installers and users in order to get a well functioning system. Some examples of lessons learned from different projects and installations presented at the conference are summarised below.

- System design is important (modules, inverter, storage, load matching, orientation...).
- Project planning important (define responsibilities, plan the installation work...).
- Modular systems, easy to install.
- Maintenance often overlooked. Plans needed.
- Monitoring important to gain experiences.
- Bad system performance results in lack of consumer confidence. This means that quality control is important.
- Standards are needed.
- Education of users in how to use the system, and training of installers.

- Safety requirements must be considered.
- Public commitment important. Public/private partnership.
- Get building professionals involved.
- Financing, how? Financial support is needed.
- Extend feed-in laws throughout Europe.
- Commissioning.
- Use P_{stab} when estimating system performance.
- Theft and vandalism.
- Thin-film technology must advance.
- Accelerated test procedures.
- Global approach of systems.
- Start to consider environmental benefits when discussing costs.
- Added values must start being considered.

6 References

- [1] Figures read from diagram in The “Solar Electricity Guide”. (This Guide is supported by the European Commission 5th Framework Programme. Authors: M. Barker et al.. Printed in Spain 2001.)
- [2] www.iea-pvps.org.
- [3] Figure presented by P. Frankl at the conference.

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