Schweizerische Eidgenossenschaft
Confédération suisse
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Photovoltaic Programme Edition 2007

Summary Report, Project List, Annual Project Reports 2006 (Abstracts)

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Cover:

Farmhouse Elsbeth and Béat Aeberhard, Barberêche FR
110 kWp roof integration with SOLRIF® frames

(Photo: NET)

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Federal Department of the
Environment, Transport, Energy and Communications DETEC

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PHOTOVOLTAICS PROGRAMME

Summary Report on the Research Programme in 2006

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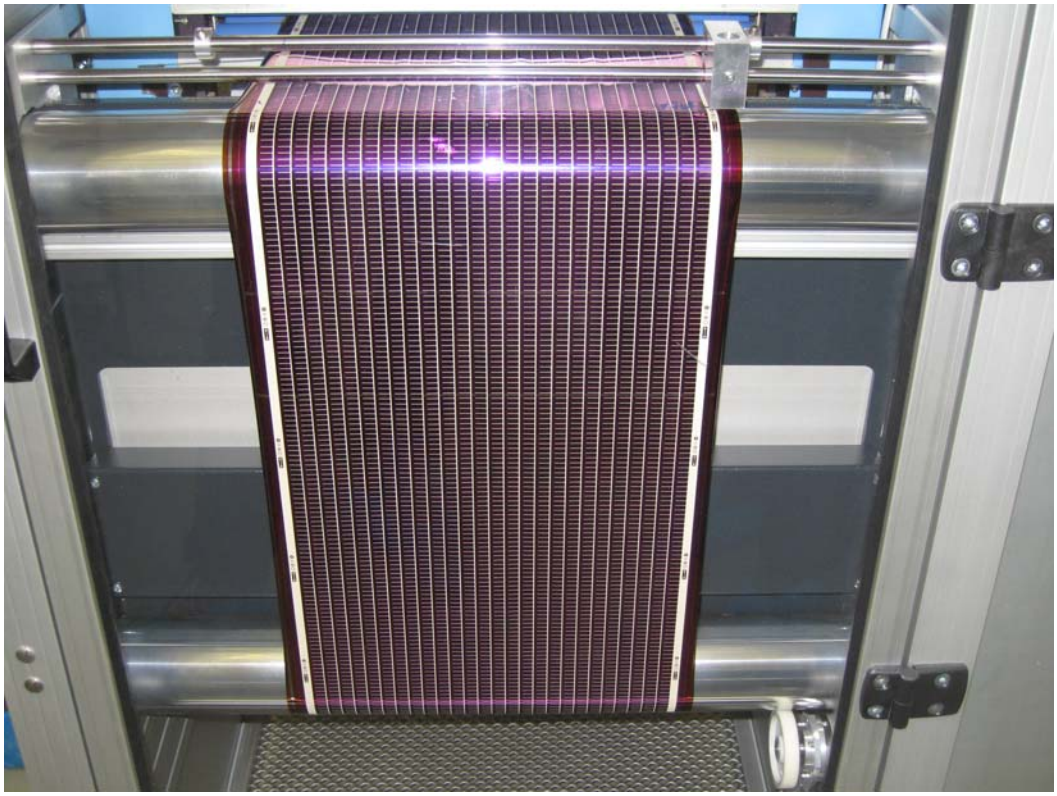

From a technology start-up to industrial investment:

VHF technologies, a start-up company founded by the IMT at the University of Neuchatel in 2000, was adopted in 2006 as a strategic investment by Q-Cells, the largest European manufacturer of solar cells. As a first step, a pilot manufacturing plant for thin and flexible solar cells with a production capacity of 2 MWp is being implemented (photo: NET).

Contents Summary Report

1. Programme priorities and targets

In 2006, the photovoltaics programme found itself in the middle of a debate concerning new and growing industrial projects and continuing low levels of research financing - in particular in the area of pilot and demonstration (P+D) projects - as well as continuing political discussion concerning energy topics in which photovoltaics continued to be at the focus of attention. As a result of extensive support for the programme in the research area, at least here levels were able to be held constant to a great extent. Continuing growth in the international photovoltaics market provides an important basis for the clear expansion of the industrial basis for photovoltaics that is still to be seen in Switzerland.

Thus, the Photovoltaics Programme has remained closely oriented towards industrial implementation and international competitiveness, both for products and for the preceding research activities. In 2006 about 50 research and development activities including remaining P+D projects were running, taking into account all known projects receiving support from the public authorities.

Based on the Energy Research Master Plan of the Federal Energy Research Commission (CORE) [56], the main objectives of the Swiss Photovoltaics Programme for the period 2004 to 2007 are [57]:

- Further cost reductions in photovoltaics energy systems (typical values for 2007: 2.5 CHF/Wp for modules; 5 CHF/Wp for complete systems) and corresponding improvements in the electrical properties of individual components (2007: thin film modules with >12 % efficiency), production costs and industrial production;
- Establishment and consolidation of the industrial basis for photovoltaic products, including solar cells and modules in selected technological areas;
- High level of integration and standardisation of products and systems for mass markets.

The Photovoltaics Programme is therefore divided into the following five sections:

Solar cells of the future

The work on **thin film solar cells** continued to focus on the principal areas: **silicon** cells (amorphous, micro-crystalline), cells based on **compound semiconductors** (CIGS); and **dye cells. New concepts** for long-term technology options (materials and processes) are gaining importance in the basic research area, and, at the same time, are moving away from pure concepts to the production of actual solar cells. The industrialisation of manufacturing processes is being pursued intensely and is, for silicon thin film solar cells, at an advanced stage, for compound semiconductors, an industry project is being set up. Solar cells on flexible substrates are becoming increasingly important.

Modules and building integration

The **integration of photovoltaics** in the built environment still continued to be the main focus of current applications. Whilst the market now offers a broad range of mounting systems, new products for building integration based on thin film cells, together with the experience gained in this area, was a theme of continued and growing importance.

Electrical systems technology

Quality assurance of photovoltaic modules, power inverters and entire systems, together with the **long-term observation** of these components, are themes of high relevance to practical application and are being worked on in appropriate competence centres at universities of applied science. Long-period measurements and the increased analysis of abnormal functioning of individual components are required to determine critical parameters and to extend service life. Based on this system-relevant work, the objective is to further increase the specific energy yield of photovoltaic installations (kWh/kWp). For **island installations,** the combination of photovoltaics with other energy technologies in hybrid installations is becoming increasingly important.

Further projects and studies

Studies in this area should provide basic information on general questions in connection with the development of the market for photovoltaics. This concerns in particular the **potential**, **environmental aspects,** and **energy planning** and practical **help** for the planning and supervision of installations. For this, the latest Internet technologies, computer models, image processing, geographical information systems and even satellite communications are being used. On the other hand, for applications in **developing countries** non-technical aspects have high priorities. This area of the programme also includes activities at the interface to other energy technologies.

International institutional co-operation

International co-operation forms an important aspect in all areas of work. Remaining abreast of international developments and an intensified exchange of information within the **EU** and **IEA** programmes were important objectives that were further pursued during the reporting period. Successful international co-operation was continued in new, large EU projects. Moreover, Swiss participation in work being done in European networks was of particular importance in the year under review (**PV-ERA-NET** and **European photovoltaics technology platform**).

2. Work completed and results achieved in 2006

CELL TECHNOLOGY

In the 2006 reporting period, a **broad spectrum of Swiss solar cell research** was successfully pursued thanks to a broad support of research. During the reporting year, new industrial projects began with the support of the CTI. Participation in EU projects was also important: in the reporting year new projects began in the area of thin-film cells. This means that Switzerland is now directly or indirectly involved in most of the current *Integrated Projects* of the European Commission in the area of photovoltaics.

Thin film silicon

The University of Neuchâtel (IMT), the EPFL (CRPP), the Haute Ecole Arc ingénierie (Le Locle), and the NTB (Buchs), together with the companies *oerlikon* (formerly *Unaxis*, Trübbach and Neuchâtel) and VHF Technologies (Yverdon), are pursuing developments in the thin film silicon field, and represent a mainstay of the Photovoltaics Programme.

During the year under review, the IMT at the University of Neuchâtel continued work on its **thin-film silicon solar cells** project [1]. The objectives of this SFOE project are to increase the efficiency of solar cells on different substrates (goal of 14 % for micromorphous solar cells) further, to continue to develop the processing and characterisation of solar cells and to ensure that the necessary infrastructure (processes, manufacture and characterisation) to support the industrial partners exists. Therefore, various deposition systems are being renewed and automated, the systems for the characterisation of solar cells are being standardised, and particular emphasis is being placed on the reproducibility of the individual production steps. Co-operation with industry is primarily with *oerlikon* and *VHF Technologies*, who are implementing the processes developed at the IMT in their products. The following results were achieved in the year under review:

On a transparent oxide coating of ZnO on glass *(Transparent Conductive Oxyde - TCO*), microcrystalline p-i-n solar cells (μc-Si:H) with an initial efficiency of 9.99% were produced. This is a record value for *LPCVD (low pressure chemical vapour deposition)*. Amorphous p-i-n solar cells achieved a good initial value of 10.2% for their part, ones made of micromorphous silicon 11.8%. As far as plastic substrates were concerned, special attention was paid to the microcrystalline cells. On PEN (Polyethylene-naphtalate) substrates, an initial efficiency of 8.3% was achieved with this material. For amorphous cells on PET (polyethylene-terephthalate), 7.8% was achieved. Concerning TCO coatings using ZnO, important basic research was done and progress was made. With respect to analysis, various methods of measurement were further developed and automated, e.g. for measurements of voltage-current characteristics, spectral sensitivity, dark current and infrared measurements. In parallel to this, laboratory infrastructure was enhanced with a new, automated double-chamber deposition system (Fig 1).

The CTI project carried out in co-operation with *oerlikon* for the **process of fast deposition of microcrystalline silicon** [2] on the basis of KAI plasma deposition plants was concluded in the year under review. This forms the basis for the industrial production of large-area (1.4m²) micromorphous solar cells. On the IMT's experimental plant, solar cells made of microcrystalline silicon with an efficiency of 8.4% were manufactured in the year under review; At Oerlikon, micromorphous mini-modules (10 x 10 cm2) were produced with an efficiency of 9.5%. With the results of this project, it was shown that the KAI deposition plant planned initially for the production of flat screens can be employed for the industrial production of thin-film solar cells.

Together with *oerlikon,* the CRPP at the EPFL has also concluded a related CTI project concerning a new, large-area **VHF reactor for the deposition of amorphous and micro-crystalline silicon solar cells** [3]. Plasma excitation frequencies of up to 100 MHz are being investigated, which permit rapid deposition (≥ 4 Å/s); assuring homogeneity of the films over an area of ≥ 1 m² is, however, a particular

challenge. The final result consists of a radio-frequency reactor in which amorphous and micro-crystalline silicon layers can be quickly manufactured with surface areas of 1m^2 and a uniformity of 5-10%.

A further CTI project between IMT and *oerlikon* concerning the **stability of the translucent oxide layers** (TCO) made of ZnO in laminated solar cells [4] was concluded in the year under review. The steam-heat test for solar modules stipulated by the IEC (IEC 61646: 1000h @ 85°C & 85% relative humidity) was passed. In this way, it was demonstrated that the LPCVD TCO layer meets demands concerning the necessary long-term reliability when appropriate encapsulated.

Together with *oerlikon*, the NTB in Buchs successfully concluded work on the CTI project for an industrial-production-oriented, spectrally resolved **photocurrent measuring instrument** (*Spectral Response Measurement System SRMS*) [5]. The project goals were reached in that full-area measurements with stable results were carried out on solar modules and the corresponding visual representations could be displayed. These various CTI projects, together with the regular work at the IMT, constitute the basis for industrial implementation with a view to production facilities for thin film silicon solar cells at *oerlikon*.

Figure 1 *Construction of the double-chamber thin-film silicon deposition system on the basis of the oerlikon KAI-M plasma box (Illustration: IMT)*

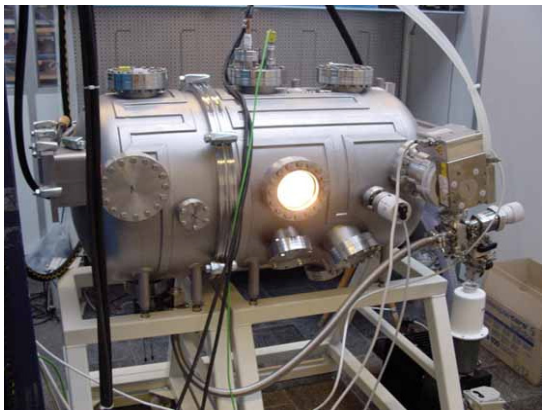

Figure 2 *Deposition system for the upscaling of CIGS thin-film solar cells (Illustration: ETHZ)*

Since autumn 2005, the IMT and *VHF-Technologies* have been working on the EU's new **FLEXCELLENCE** [6] project on the topic of flexible solar cells on plastic substrates. For the first time in the area of photovoltaics, an EU project is being co-ordinated by a Swiss partner (IMT). In the first year under review, work done by the IMT concerned the development of micro-crystalline silicon layers of high quality on 30x30 cm^2 substrates using a VHF process at high deposition rates. Deposition rates of 2nm/s with good layer characteristics were attained. On the basis of these results, comparisons are to be made with alternative production procedures. The work done by *VHF-Technologies* is concerned with the module costs to be attained using the industrial implementation on a large scale. For amorphous silicon solar cells with an efficiency of 5%, costs of less than 0.8 €/Wp at a production capacity of 50 MW should be possible to achieve.

In the year under review, the IMT started work on the EU's **ATHLET** [7] project. This *Integrated Project* - the largest research project on this subject in Europe up to now – is being co-ordinated by the HMI in Berlin and runs over a period of 4 years . It concerns two technologies in the field of the thin-film solar cells, micromorph solar cells and CIS technology (see below). The project aims to reach module costs of 0.5 €/Wp. For micromorphous tandem cells, a stable efficiency of 10% for surface areas of 1 m^2 and 10 Å/s deposition rate are being striven for. In the first year, the IMT concerned itself with work on solar cells with a small surface area as well as with scaling-up work for *oerlikon's* KAI 1200 reactor (1.4 m^2 surface area). Here, intermediate steps are being made via the KAI-S (35 x 45 cm^2) and KAI-P (45 x 55 cm^2) reactors.

Crystalline silicon

Within the framework of the new CTI **SIWIS** project [8], and in co-operation with *HCT Shaping Systems,* the EMPA in Thun, Switzerland, examined the mechanisms that can lead to surface defects when wire-sawing thin wafers with the aim of developing appropriate models. The higher aim of the project

is the production of wafers with less than 100 µm thickness for the production of crystalline silicon solar cells.

In the year under review, *HCT Shaping Systems* was able to successfully continue its participation in the EU's **BITHINK** [9] project in which highly-efficient bifacial crystalline solar cells are being developed (efficiency 16+16 %). In this case, both Czochralski material as well as multi-crystalline silicon is used. In this project, HCT concerns itself on the one hand with the topic of the production of thin wafers, whereby the number of wafers per meter of solid silicon is being considered as a target parameter. 3000 wafers per meter of silicon was achieved up to now, 3500 - 4000 wafers/m is the target. For a bifacial solar cell, this, depending on assumptions made, leads to silicon requirements of merely 4.3 - 5.9 g/Wp. On the other hand, mechanical handling and further processing of the very thin wafers thus produced is being examined.

II-VI compounds (CIGS)

The thin-film physics group at ETHZ has been working on EU projects involving solar cells based on compound semiconductors (CIGS, CdTe) for many years now. In the year under review, the first phase of the BFE's **FLEXCIM** project [10] concerning the development of flexible CIGS solar cells was concluded. These flexible 5 x 5 cm^2 CIGS solar cells were produced on polyimide and metal films. The application of sodium as developed at the ETHZ was implemented in the project, whereby efficiencies of 10-12% were regularly achieved. The earlier world record achieved on polyimide of 14.1 % for the efficiency of flexible solar cells on plastic is still the highest value achieved. In the year under review, work was done on scaling up the process to 30x30cm^2. For this purpose, a new industrially oriented deposition system is being set up (Fig. 2). As an intermediate result a mini-module of 16 cm^2 with an efficiency of 7.9% has been produced. Aluminium was examined as a further possible substrate for the flexible CIGS solar cells; this represents a new field with a large potential for use. Because of the different expansion coefficients, the deposition process has to be carried out at lower temperatures. The best solar cell on aluminium up to now achieved an efficiency of 6.6 % - still without using sodium.

The EU's **LARCIS** project [11] is concerned with large-area processes for the industrial production of CIGS solar cells. Here, the thin-film physics group at the ETHZ is concentrating on the optimisation of cell back-contacts on the basis of molybdenum as well as using alternative materials, in particular TiN. Also, work was started in the year under review on the EU's ATHLET project [12] (see above). In this *Integrated Project*, the thin-film physics group is involved in two work packages concerning CIGS solar cells. Here, supplementary development work on flexible solar cells on polyimide is in the foreground; in particular, new processes for buffer layers on the basis of In_2S_3 and the deposition of solar cells on TCO layers are being examined in depth. Further work is concerned with scaling-up onto larger surfaces and the development of tandem solar cells.

The ETHZ spin-off company *FLISOM* [58] for the transfer of flexible CIGS solar cell technology to industry was awarded prizes in the year under review, so, for example, the ZKB Technopark Zurich Pioneer Prize and the *Technology Pioneer* award of the *World Economic Forum* WEF.

Dye and organic solar cells

At the ISIC at the EPFL, the development of dye-sensitised, **nano-crystalline solar cells** [15] was pursued further. In the year under review, dye synthesis and long-term stability at higher temperatures (approx. 80°C) of the electrolytes used were foreground activities. Here, a service life of 10 to 20 years for the dye cells is being striven for. In long-term measurements on the latest cell concepts covering 1000 hours at AM1.5 radiation and 80°C, 97.7% of the original power was demonstrated. The laboratory cells themselves achieved a start efficiency of 10.1%.

Together with *Greatcell Solar*, the ISIC concluded the CTI project for the **increase of cell voltage** of dye cells [14]. The dye used was developed further as it plays an essential role here. Moreover, through *Greatcell Solar*, there is a direct link to the Australian *Dyesol* technology company [59], which announced the creation of a company for the production of dye cells in Greece in December 2005.

The EU's **MOLYCELL** project [15] was concluded in the year under review. It was concerned with flexible organic solar cells, in which both purely organic and hybrid nano-crystalline organic solar cells were developed. The EPFL was especially interested in these cells, where a solid hetero-junction is formed between nano-crystalline metal oxides and molecular or polymeric hole conductors. Prototype models using the metallic oxide-organic hybrid approach achieved an efficiency of 4.2% on glass substrates at AM1.5. On flexible metal foils, an efficiency of 3.6% was noted on a small surface (1 cm^2).

For completely organic solar cells, an efficiency of 5.5% and a certified value of 4.8% were measured. The work is being continued in the new EU project **OrgaPVNET.**

Solaronix is involved in the **FULLSPECTRUM** EU project [16], an *Integrated Project* in the area of photovoltaics, which brings together different approaches for the better utilisation of the solar radiation spectrum in ONE project (III-V multijunctions, thermophotovoltaics, intermediate band cells, molecular approaches). It is hoped that efficiencies of up to 40 % will be achieved. In this project, Solaronix is especially involved in supporting work in the module on new molecular approaches. This involves the role of solar dye cells in 2-photon processes and flat concentrators. Here, *Solaronix* is concerned with the measurements of the current-voltage characteristic and spectral sensitivity. In the year under review the functioning of a flat concentrator was demonstrated and an efficiency of 1.8% was measured. Apart from efficiency, the stability of the fluorescent dyes employed in the concentrator must also be improved.

The LTC at the EPFL together with *Konarka* finished the CTI project on **photovoltaically active textiles** on the basis of dye cells [17]. Here, active photovoltaic fibres were developed which achieved initial efficiencies of up to 5.5%. The photovoltaic characteristics of the fibres under mechanical load were determined and first prototype models of photovoltaic textiles were manufactured.

At the EMPA in Duebendorf, Switzerland, a new activity concerning **organic solar cells** [18] is being initiated in the Laboratory for Functional Polymers; these basics-oriented activities are part of the EMPA "Materials for Energy Technologies" research programme. The experimental work is concerned with use of Cyanin dyes as well as with the nano-structuring of the junction between donor and acceptor materials. Here, an inter-penetrating network for this junction is being striven for. This work is to be a part of the national CCEM **ThinPV** project [19] co-ordinated by the EMPA and starting at the beginning of 2007.

Antenna solar cells

At the University of Berne, the current stage of the **antenna solar cells** [20] project within the framework of the solar chemistry programme carried out with the support of the Swiss National Fund was concluded. Making use of dyestuff-loaded zeolite crystals, a new variant of dye-sensitised solar cell was striven for. The organisation of the crystals at the junction to a semi-conducting material was in the foreground of this basic work with respect to electronic energy transfer. In the year under review, antenna systems were built up for the first time which provided unidirectional transport of electrical excitation energy at the macroscopic level. For the dyestuff-loaded zeolite crystals, the strong diffusion of light in the visible spectrum was reduced by the installation of a polymeric matrix. This can also be employed for fluorescence concentrators. A further field of work concerns the combination of antenna system materials with organic solar cells through which better light absorption and, therefore, higher efficiency become possible.

SOLAR MODULES AND BUILDING INTEGRATION

Building-integrated installations continue to represent the most important field of application of photovoltaics in Switzerland. It is necessary, however, to specify what exactly is meant by *building integrated* plant (built-on plant or genuine integration). Whilst the least expensive flat-roof designs are often adopted by the solar stock exchanges, work on reducing the costs of systems with a stronger integration aspect is continuing. As in the meantime a series of systems have been successfully implemented for mounting on buildings (see P+D section also), such developments are increasingly being seen with respect to the solar modules themselves.

Swiss Solar system (3S) concluded the BFE project on the use of etched, **reflection-free glass** (AR) [21] to increase the performance of crystalline solar modules. The measurements on the solar modules produced using this glass demonstrated a systematic increase in performance of around 2% in both cases; the 3% expected could not be confirmed completely. Open air measurements with different angles of insolation show that the AR modules could make better use of in borderline cases with low angles of incidence, whereby this effect could not be quantified conclusively. Since the start of the project, the use of etched or coated, reflection-free glass in industry has been in increasingly successful. In the EU's **BIPV-CIS** project [22], the quality of photovoltaics building integration is to be enhanced using thin film cells. Using CIS cells as a basis, roof, overhead glass and facade elements are

to be developed. The main emphasis at 3S is on developing the roof elements. Because of the booming photovoltaics market, some of the industry partners in this project are operating at full capacity so that the project has suffered delays. New product developments do not have it easy under such circumstances.

A few new concepts and products in the photovoltaics building integration area were tried out within the framework of P+D projects (see below).

ELECTRICAL SYSTEMS TECHNOLOGY

The **main emphasis in systems technology** generally continues to lie on quality assurance aspects of components (modules, inverters), systems (design, energy yield) and installations (long-period monitoring). Particularly in the current phase of rapid market growth, the experience gained from these application-related studies is vital to ensure the safety, reliability and energy-yield of future installations as well as the standardisation of products.

The laboratory formerly known as LEEE-TISO at the SUPSI was renamed in the year under review to become the ISAAC institute (Istituto di Sostenibilità Applicata all'Ambiente Costruito). In the year under review, it continued its test measurements on solar modules in the project **Centrale LEEE-TISO 2003-2006** [23]. The laboratory, which is certified under ISO 17025 for measurements on class A solar simulators, received further official certification in June 2006. In the year under review, more than 4900 I-V characteristics (quick tests) were measured which corresponds to an increase of 88% compared to the previous year. Further, the annual comparative measurements with other certified laboratories in Europe (ESTI-JRC and ECN) took place once more. A filtered reference cell is employed for the more precise measurement of thin film modules as well as the correction for the spectral deviation introduced in the previous year. The MPPT (Maximum Power Point Tracker, Fig.3) developed in the previous year at the laboratory was tested at the University of Applied Science in Burgdorf. The static efficiency was determined to be between 99.75% and 99.99%, the dynamic efficiency was 98.4% In the year under review, 28 examples of the new MPPT were built and installed at the ISAAC, as well as a further 5 at the University of Lecce.

Figure 3 *Maximum Power Point Tracker at ISAAC (Illustration: NET)*

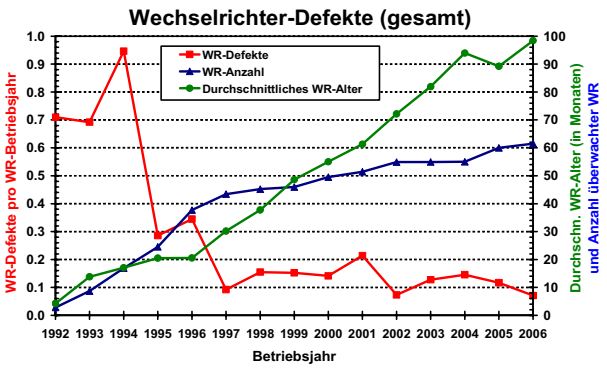

Figure 4 *Inverter defects per inverter-operating year (Illustration: FH Burgdorf)*

With respect to exterior measurements, the 10th testing series on 14 commercial modules was continued in the year under review (7 mc-Si, 3 sc-Si, 1 HIT, 2 a-Si, 1 CdTe). For the crystalline modules, a continuous improvement can be noted over the years as far as the agreement between measured and declared power is concerned. The thin-film modules are even better in this regard. The ISAAC started work in the year under review on building-integrated photovoltaics. On the one hand, a market overview was made and problem areas for architects analysed. On the other hand, measurements were made on the thermal conductivity of solar modules and the attenuation of non-ionising radiation (electro-smog) associated with this. For the latter, thin-film modules in particular exhibited favourable qualities.

The ISAAC is also participating in the EU **PV Enlargement** [24] project along with 10 European countries, (5 of which are in Eastern Europe), comprising 27 installations with a total capacity of 1.2 MWp. By the end of 2006, a total of 25 of these installations were in operation. The scientific work is almost

complete. At the ISAAC, 151 examples of 23 module types (c-Si, a-Si, CIS, CdTe) from Europe were characterised as far as their initial power was concerned, 54 of them were subjected to a further measurement after 1-2 years. In spite of better agreement with declared values, there still exists room for improvement as far as the use of and compliance to EN50380 is concerned.

In the year under review, the ISAAC started work on the new EU **PERFORMANCE** project (*A science base on PV performance for increased market transparency and customer confidence*) [25]. This 4-year *Integrated Project* co-ordinated by the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany, is concerned with all pre-normative work from solar cells through to complete systems and from short-term measurements through to long-term analyses. The ISAAC is involved in the research on the performance and energy production of photovoltaic modules as well as in modelling.

The efficiency and the annual energy production of photovoltaic modules also form part of a project at the PSI [26]. On the basis of measurements on various commercially-available modules under various operating conditions, a semi-empirical model for efficiency is being parameterised. Using this, results can be obtained for various climatic conditions.

The project on **photovoltaics systems technology PVSYSTE** [27] continued at the photovoltaics laboratory at the University of Applied Science in Burgdorf. During the year under review, the newly developed MPPT interface with integrated measurement of cell characteristics was integrated into the inverter-testing set-up. Thus, an efficient inverter test infrastructure now exists with which one can determine solar generator characteristics, DC-AC conversion efficiency, MPPT efficiency, total efficiency and current-harmonics in just one go. The test conditions for dynamic MPPT tests were loosened somewhat. The FI-check testing circuit developed in the 2005 was adjusted to meet the new DIN VDE norm 0126-1-1. As a result of the flashovers that occurred in BP-Solar solar modules last year, the photovoltaics business is once more becoming increasingly conscious of the danger of DC-side arcing. Therefore, arc detectors developed in the 1993 - 1998 within the framework of several projects (with *Alpha Real AG*) were reactivated, some new ideas were developed and a patent application was submitted. The long-term measurements at various photovoltaics locations were continued, in particular at the Wankdorf "Stade de Suisse" stadium in Bern. Also, the work on inverter statistics going on for many years now was continued (Fig. 4).

In the **SIMIBU** project, *Enecolo* is assessing the feasibility of an inverter with integrated backup on the basis of previous experience [28]. Using this approach, synergies and added-value for decentralised photovoltaic plants are to be created. At the moment, technical feasibility, market analysis, specifications and the general economical framework are the focal points.

FURTHER PROJECTS AND STUDIES

In the year under review *ESU Services* began an **update of photovoltaic Ecoinvent Data V2.0** [29]. On the basis of life-cycle inventories of current photovoltaics products, new life-cycle analyses (*Life Cycle Analysis - LCA*) were made. In this way, the aim is being pursued of publishing environmental analyses of the photovoltaics industry in the Ecoinvent database [60] that are as up-to-date as possible. In addition to the updating of monocrystalline and multicrystalline solar modules, data on the production and operation of thin-film modules (CIS and CdTe) have been included for the first time. The project is being carried out in co-operation with the European Photovoltaic Industry Association EPIA.

Enecolo is involved in the **ENVISOLAR** project run by the European Space Agency ESA [30]. The project aims to make increased use of satellite-supported solar radiation data in the solar industry. With the services developed during the project, site analyses and decisions can be simplified, and, also, automatic plant monitoring as well as forecasts concerning the energy production of solar plant is made possible. In Switzerland, a close connection exists to the online Photovoltaics Monitoring Service SPYCE [61], which is operated by *Enecolo* in co-operation with *Meteotest*.

With the support of *REPIC,* the interdepartmental platform (SECO, SDC, FOEN and SFOE) for the promotion of in international co-operation activities [62], the CUEPE at the University of Geneva has developed a module for the *PVSYST* photovoltaics software [63], which simulates **photovoltaic water pumps** [31]. The software is able to simulate many different models of pump and system configurations. The project was concluded successfully in the year under review.

The PSI is participating in international work on the topic of thermo-photovoltaics (TPV), through the **FULLSPECTRUM** [32] *EU Integrated Project*. Based on previous projects, in the thermo-photovoltaics module of this project, the PSI is developing system technology aspects in a gas-powered test system. The experimental prototype constructed includes an IR filter, emitter, connections between cells, cell

cooling and the system for recording the data obtained. Silicon solar cells are used at the PSI, whereas other institutes are continuing to develop GaSb solar cells.

In a feasibility study the LESO at the EPFL is investigating the potential of **Quantum Dot Concentrators** for photovoltaics [33]. It is being examined whether large-area concentrators (working laterally) can be made on glass using this novel method and what amount of electrical power generation is possible.

The highly symbolic **SOLARIMPULSE** project [34] of Bertrand Piccard and various partners continued during the reporting year. The aim of this project is an around-the-world flight with an aircraft powered by photovoltaics.

A further project of the visionary kind is the **PlanetSolar** project [35], which is being developed by a group in western Switzerland led by its initiator Raphaël Domjan. PlanetSolar will be a solar-powered boat, which is to round the world on water. The concept study (Fig. 5) foresees a trimaran of 30m length and 16m width, drive is to be provided by a 180 m^2 photovoltaic system with a power of approximately 30 kWp. The boat should achieve an average speed of 10 knots. A crew of 2 persons is planned. In this project, too, large technical challenges are to be faced, in particular as far as the statics of the boat in waves is concerned.

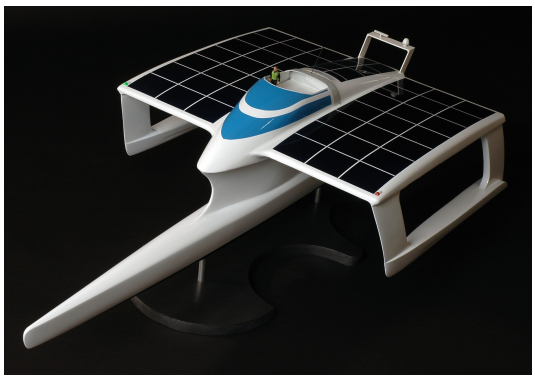

Figure 5 *Concept study for the PlanetSolar solar boat (illustration: PlanetSolar)*

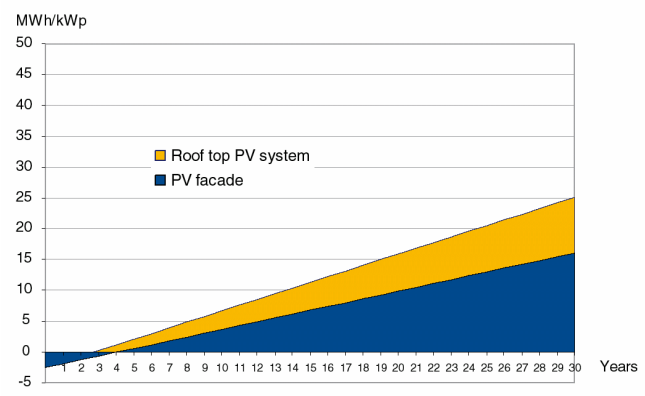

Figure 6 *Energy-payback time: Calculated cumulative energy production of a photovoltaic plant in Berne (illustration: IEA PVPS Task 10)*

INTERNATIONAL COOPERATION WITHIN IEA, IEC AND PV GAP

During the reporting period, participation in the IEA photovoltaics programme (IEA PVPS) was characterised by continuity both at the project level and in the executive committee (ExCo) [64]. Switzerland continues to chair this world-wide programme. For participation in selected projects within the framework of the IEA PVPS programme, the Swiss IEA PVPS Pool created in the previous year continued its work. This pool is at present supported by the electricity utility of the City of Zurich (ewz), the cantons Basel City and Geneva, the *Mont Soleil Society* as well as by the SWISSOLAR professional association. With this approach, a stronger participation of various target audiences in the work within the framework of IEA PVPS is guaranteed.

In IEA PVPS Task 1, which is concerned with general **information work** [36], Switzerland is represented by Nova Energie. A further national report on the photovoltaics activities in Switzerland up to 2005 [65] was prepared during the reporting period; on this basis, the 11th edition of the annual international report *("trends report")* on market trends in the photovoltaics area in IEA countries was edited [66]. Once again, this report was employed by the finance sector for its current analyses of photovoltaics [67,68]. Several Workshops were organised in the year under review: At the 21st European photovoltaics conference in Dresden a Workshop on the *Trends Report* was held in which important target audiences were informed about data procurement and interpretation. A further Workshop was intended for the finance sector [69]; it was organised by Switzerland and Japan and took place in Zurich in November 2006. The *IEA PVPS Newsletter* [70] provides information at regular intervals on the work of the IEA PVPS programme and related subjects.

TNC is responsible for the Swiss contribution to IEA PVPS Task 2 on **operating experience** [37]. The PVPS *Performance Database* was enlarged to include new data, and now covers 460 photovoltaic installations in 22 countries, with a total of around 1600 operating years and 13.4 MWp of installed power. The database is also available online [71]. 66 installations in Switzerland with a total power of 2.95 MWp are contained in the database. In the sub-project *Photovoltaic System Cost over Time*, a broadly-supported information and data base was created on developments in PV system prices and maintenance costs. For this, all available project and operating data were raised for a *Global Survey.* This data acquisition was completed in November 2006; it contains data from 680 installations in 19 countries.

Within the framework of the interdepartemental platform (SECO, SDC, FOEN, SFOE) for the promotion of renewable forms of energy in international co-operation *REPIC* [62], entec is responsible for the Swiss contribution to IEA PVPS Task 9 on **photovoltaic services for developing countries** [38]. Switzerland is responsible for co-ordination of work with bilateral and multilateral organisations. In the year under review, meetings in Canada and Japan were held. Observations show that the massive promotion of renewable energy world-wide did not especially benefit the photovoltaics option in rural electrification, as realising economic earnings and profits remains difficult. The project is, therefore, particularly concerned with this marginalisation of photovoltaics.

Planair is the new Swiss representative in IEA PVPS Task 10 concerning **Photovoltaics in the Urban Environment** [39]. From the Swiss point of view, urbanistic questions and those concerning the electricity grid are important. Through the involvement of the City of Neuchatel in the Swiss contribution, those questions pending can be dealt with concretely from this perspective. Furthermore, Task 10 published in the year under review an information pamphlet on important environmental parameters of photovoltaics [72]; the environmental parameters energy payback time and CO_2 reductions made possible were calculated for individual cities in OECD countries (Fig. 6).

Meteotest [40] and the CUEPE at the University of Geneva [41] together produce the Swiss contribution to Task 36 **Solar Resource Knowledge Management** of the IEA SHC programme. The purpose of this project is to rework the different methods and basic data on solar irradiation as a whole and to make them readily available. Task 36 is part of the IEA SHC programme, but its contents are relevant for all solar technologies; therefore, there is co-operation with the other IEA programmes on solar energy (IEA PVPS and IEA PACES). In this project, the quality of different radiation models and products derived from them are compared and optimised.

Alpha Real represents Switzerland on behalf of the professional association SWISSOLAR in the IEC's TC 82 and leads a working group which prepares and passes **propositions for international standards** [42] for photovoltaic systems. In the year under review, work was concerned in particular with new documents concerning the terminology employed, the minimum requirements placed on system documentation, safety regulations for installations on buildings as well as the definition of plant performance. Furthermore, safety regulations for inverters are an important topic; here, Swiss manufacturer were also involved in the work. Electrical contacts in photovoltaic systems (e.g. soldered joints or plugs and sockets), were highly topical in the year under review as a result of the problems encountered by BP-Solar with junction boxes. In addition*, Alpha Real* was also involved in *PVGAP* (PV Global Approval Program), a world-wide programme on quality assurance and certification of photovoltaic systems. The transfer of PVGAP to the IECEE [73] is taking place.

Participation in the EU's **PV-ERA-NET** project [43], which brings together the programme co-ordination offices and the ministries of 13 countries responsible under the ERA-NET scheme [74], was ensured by the photovoltaics programme management (SFOE, *NET Nowak Energie & Technologie*). In this project, Switzerland manages the main part of the work concerning the exchange of information on European photovoltaic programmes. Together with the continuous exchange of information, tangible research topics and models for co-operation between the various national programmes were worked on during the year under review. Another important topic was the *Strategic Research Agenda* (SRA) [75] elaborated by the European Photovoltaics Technology Platform that is considered to be an important European reference document. On the one hand, this document is of importance on account of its comprehensive description of short-term, mid-term and long-term research topics in the photovoltaics area, development time-scales for technology and economic efficiency as well as with respect to the relationships between private and public (national and EU) research.

3. National co-operation

At the national level, the diversity of co-operative effort within the various projects was kept up over the reporting period. Involved in this were the Federal Institutes of Technology, cantonal universities, the Universities of Applied Science, research institutes and private industry. Co-operation with private companies was especially intensified, showing that interest in photovoltaics has remained unbroken despite stagnation in the Swiss PV market.

At programme level, co-operation was maintained with numerous federal agencies, cantons and the electricity industry. In this connection, the constant exchange of ideas with SER, CTI, FOEN, SDC and SECO as well as with the electricity sector, the Swiss Electricity Supply Association SESA, *swisselectric* and the *Mont Soleil Association*, is worthy of special mention. The large number of contacts made in this way helped to provide a broader base for the programme's activities.

4. International co-operation

International co-operation continued over the reporting period in its many traditional ways. The institutional co-operation taking place within IEA, IEC, PV GAP and the European network projects has already been mentioned. At the project level, co-operation within the EU on new and existing projects continued. There were 10 projects in the 5th and 6th Framework Research Programmes of the EU, of which 3 are *Integrated Projects* (FULLSPECTRUM, PV-ATHLET, PERFORMANCE). A further project was carried out together with the ESA. Regular contacts occurs with those responsible for programmes in EU countries, as also with those departments responsible in the European Commission.

Switzerland is represented in European Photovoltaics Technology Platform [75] both in the steering committee as well as in individual teams. Technology platforms are a new instrument, and are to allow wider sponsoring for selected technologies and a common strategy for those involved. Typically, researchers, industry, the financial sector and government offices are brought together in a platform supported by all of them and work on the R&D efforts necessary as well as on implementation measures in a co-ordinated manner. Here, the integration of industry, which has an important role to play within the framework of the technology platforms, is of particular importance. In the year under review the *Strategic Research Agenda* (SRA) was completed to a great extent.

Further contacts were maintained with the international organisations concerned with development co-operation (World Bank, GEF, IFC, UNDP, GTZ, KfW, REEEP, etc.). Thanks to these numerous interactions, Swiss photovoltaics has remained very prominent on the international scene.

5. Pilot and demonstration projects (P+D)

For the first time since 2003, two new P+D Projects were begun in the year under review. One of them is concerned with the topic of optimal integration of photovoltaic installations in the energy concept of a zero-energy school building in Kreuzlingen, Switzerland, the other with the integration of thin-film photovoltaic elements into the roof of a gymnasium. In spite of these two new projects, the P+D programme has, meanwhile, shrunk to just a few projects which are almost all in the closing phase. This development is to be regretted very much, as here an essential link in the transfer of research and development findings to industrial products and methods - and, therefore, to the market - is weakened to a great degree. Thus, the effect of this part of the programme remains limited and, in combination with the stagnating local market being noted for some years now, means that Swiss companies have increasing difficulty bringing new and innovative products in the photovoltaics field of application onto the market. International conferences show clearly that Swiss companies can hold their ground in the field of production equipment and, partly, in the field of inverters and are able to report increasing sales figures. In the fields of product innovation and installation implementation, however, the innovations mostly come from Germany, Japan or the USA. Nevertheless, some successful Swiss projects have still had an effect in the German market over the last few years.

The world-wide market for photovoltaics is booming, with an annual rate of growth of around 35 %, as a result of large-scale promotion programmes and feed-in tariffs in many countries. World-wide module production reached around 2300 MWp in 2006. This means that, fundamentally, good export chances still exist for innovative products, and that these chances are successfully being used by some Swiss companies.

The photovoltaics P+D projects still running mainly still handle the subject of the **Inegration of Photovoltaics in Buildings**.

NEW P+D PROJECTS

- Roof installation on the roof of the gymnasium in Wiesendangen, Switzerland, with amorphous thin-film modules (using BIOSOL XXL roof elements made of UNI-Solar thin-film modules combined with Solrif frames); Management: *Enecolo*) [44]
- Photovoltaics installation on the Ekkharthof zero-energy school building in Kreuzlingen, Switzerland (integration of a PV installation in the energy concept of a zero-energy school building; Management: *Boehni Energy and Environment*) [45]

CURRENT P+D PROJECTS

Current projects include the 'PV facade system for modules with thin-film cells' project which is proving the optical qualities this facade model. The surface appears optically as being uniform, as one is used to for dark glass facades [46]. (Fig. 7)

Current projects comprise (in chronological order):

Component development

- New PV facade system for modules with thin film cells (development of a universal facade system with or without thermal insulation for thin film cell modules. Management: Zagsolar / Wyss Aluhit) [46] (Fig. 7)

Installations

- 17.6 kWp flat-roof installation with thin-film modules at the ETH Zurich (optically unobtrusive flat roof integration with amorphous cells. Management: BE Netz) [47] (Fig. 8)
- Small, stand-alone photovoltaic and fuel cell power supply system (small PV island systems with fuel cells for backup electricity supply for remote stand-alone measurement systems in pilot operation. Management: Muntwyler Energietechnik) [48]
- 12 kWp Solight pilot plant (pilot application of two different Solight variants, Management: Energiebüro) [49]

Measurement campaigns

- Wittigkofen measurement campaign (detailed measurements and evaluation with data visualisation on the 80 kWp facade installation in Wittigkofen. Management: Ingenieurbüro Hostettler) [50]

Studies - tools - various projects

- Swiss Photovoltaic Statistics 2005 (Management: Ingenieurbüro Hostettler) [51]

Figure 7 *Facade integration with thin film modules (Illustration: Zagsolar)*

Figure 8 *Part the ETHZ flat-roof plant (Illustration: Energiebüro)*

P+D PROJECTS COMPLETED IN 2006

In 2006, the following P+D projects were concluded (in chronological order):

Installations

- 15.4 kWp flat-roof integration CPT Solar (pilot installation featuring the use of a newly-developed combination of amorphous thin-film modules and a watertight plastic foil; Management: *ISAAC*) [52]
- 25 kWp Solgreen green-roof integration, Kraftwerk 1, Zurich (pilot application of a newly developed module mounting system for use on green roofs; Management: *Enecolo*) [53]
- Autonomous 5.7 kWp photovoltaic plant in combination with a CHP unit (full-year autonomous energy supply of 2 chalets by means of photovoltaics, CHP, solar-thermal collectors and wood; Management: *A. Reinhard*) [54]

Studies - tools - various projects

- Solar *Electri* City Guide - solar power guide for Swiss municipalities (management: *NET*) [55]

The publication **Solar Power in Municipalities**, which was developed from the former PV City Guide EU project, comprises a comprehensive pamphlet rich in illustrations and a further seven (electronically available) documents that handle topical focal points in depth [76]. In this way, this publication provides a new, overall look at photovoltaics at the municipal level that has not been available up to now in Switzerland and also offers numerous examples for action that can be taken.

6. Assessment of 2006 work and prospects for 2007

Globally, 2006 was an extremely successful year for photovoltaics. The photovoltaics industry continued to expand in a high-growth market. However, this rapid growth further intensified the bottleneck in availability of raw silicon. Investments in new production capacities for solar silicon are being made world-wide, which should ease the tight situation as of 2008 onwards. Already at the end of 2006, a reverse trend towards lower system prices could be noted. On account of this tense situation, there exists an interesting parallel "window of opportunity" for thin-film solar cells - in other words a chance for these technologies. As a concrete example of these recent developments, *oerlikon* received large orders for deposition plants for thin-film, amorphous silicon solar cells in the year under review.

As a result of the political discussions that occurred in 2006 in the Swiss parliament around the Power Supply Law and the promotion of renewable forms of energy planned in it, photovoltaics also received a large amount of attention in Switzerland. With the decisions passed in the meantime, a chance for improvements in the photovoltaics market now exists after many years; cost-covering remuneration is planned for the year 2008 and onwards. Although very limited on a quantitative scale, this ought to activate the Swiss photovoltaics market and, therefore, also stimulate technological developments.

The situation of Swiss photovoltaics has to be assessed against this background: research and technology have, so far, been considered to be at a high level even from an international point of view, based on broad support. The numerous CTI and EU projects indicate that industrial implementation and international orientation is working. However, there are marked disadvantages for implementation in Switzerland as a result of the lack of funding for P+D projects and a market that is stagnant up to now. Despite these difficult conditions, industrial photovoltaic activities are also growing in Switzerland. Based on surveys, exports of Swiss photovoltaics for 2006 were estimated to be at least 350 million CHF. Together with the domestic market, the total turnover for Swiss photovoltaics was estimated to be at least 400 million CHF.

The transfer of the fruits of Swiss photovoltaics research into industrial products is, in recent years, above all a success story in the area of the thin-film solar cells - which is in good agreement with the long-term aims of the programme. The situation with respect to building-integrated photovoltaics presents itself as also being promising but somewhat more difficult, since this market is not yet so

strongly pronounced, both nationally and internationally. This could change on account of new political general conditions in Switzerland and in certain other countries, e.g. France, in the next few years.

The previous efforts in Swiss photovoltaics programme define the scientific and technical starting position from which Swiss innovations and products can be present in the rapidly growing international photovoltaics market. The long practical experience with the construction and operation of numerous photovoltaic installations has resulted in important findings that have led to reliable installations and high specific energy production. In this way, the technological prerequisites exist that help Swiss photovoltaics with its scientific and technical know-how and its products be competitive and successful against international competition too.

Further, the photovoltaics programme will have to endeavour to preserve its critical size through a broad base in order to achieve a meaningful effect on the market. For this purpose, use should be made of all possible supporting mechanisms and, at the same time, use these in an optimally coordinated and targeted manner. The new CORE energy research master plan for 2008 - 2011 will, in 2007, form the basis for the development of a corresponding photovoltaics research master plan. The most recent national and international developments will be considered in order to define the priorities for the next few years. An intense exchange of ideas with those involved in research and industry should accompany this process.

The national exchange of information and experience still remains an important issue in Switzerland. In November 2007, the 7th national photovoltaics meeting will be held in Lucerne. In particular, It will be dedicated to the new Swiss regulatory framework for photovoltaics. The photovoltaics website http://www.photovoltaic.ch contains all essential information and reports and so serves as an important information instrument that is continually updated. With its contributions, the Swiss photovoltaic scene was well represented at the 21st European Photovoltaics Conference held in September in Dresden [77].

7. List of R+D Projects

(AR) Annual Report 2006 available
(FR) Final Report available

Individual annual and final reports can be downloaded from www.photovoltaic.ch
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8. List of P+D Projects

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(FR) Final Report available

Individual annual and final reports can be downloaded from www.photovoltaic.ch
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10. Further Information

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11. Abbreviations (incl. Internet Links)

General

ETH	Swiss Federal Institute of Technology	

National Institutions

CORE	Swiss Federal Energy Research Commission	http://www.bfe.admin.ch
CRPP	The Plasma Physics Research Centre of Switzerland EPFL	http://crppwww.epfl.ch
CTI	The Innovation Promotion Agency	http://www.kti-cti.ch
CUEPE	Le Centre universitaire d'étude des problèmes de l'énergie	http://www.unige.ch/cuepe
DACD SUPSI	Architecture Construction and Design Departement	http://www.dacd.supsi.ch
EMPA	Swiss Federal Laboratories for Materials Testing and Research	http://www.empa.ch
EPFL	Swiss Federal Institute of Technology Lausanne	http://www.epfl.ch
ETHZ	Swiss Federal Institute of Technology Zurich	http://www.ethz.ch
FOEN	Federal Office for the Environment	http://www.bafu.admin.ch
FH Burgdorf	Berne University of Applied Sciences / School of Engineering and Information Technology	http://www.hti.bfh.ch
IEC	International Electrotechnical Commission	http://www.iec.ch/
IMT	Institute of microtechnology University Neuchâtel	http://www-imt.unine.ch
ISIC	Institute of Chemical Sciences and Engineering EPFL	http://isic.epfl.ch
ISAAC	Institute for applied sustainability to the built environment SUPSI	http://www.isaac.supsi.ch
LEEE - TISO	Laboratory of Energy, Ecology and Economy – Ticino new ISAAC	http://www.isaac.supsi.ch
LESO	Solar Energy and Building Physics Laboratory EPFL	http://leso.epfl.ch
LTC	Laboratory of Polymer and Composite Technology EPFL	http://ltc.epfl.ch/
NTB	Interstate University of Applied Sciences of Technology Buchs	http://www.ntb.ch
PSI	Paul Scherer Institute	http://www.psi.ch
SDC	Swiss Agency for Development and Cooperation	http://www.sdc.admin.ch/
SER	State Secretariat for Education and Research	http://www.sbf.admin.ch
SESA	Swiss Electricity Supply Association	http://www.strom.ch
SECO	State Secretariat for Economic Affairs	http://www.seco-admin.ch
SFOE	Swiss Federal Office of Energy	http://www.sfoe.admin.ch
SUPSI	The University of Applied Sciences of Southern Switzerland	http://www.supsi.ch

International Organisations

EU (RTD)	European Union (RTD-Programme) Community Research & Development Information Service of the European Communities	http://www.cordis.lu
ECN	Energy research Centre of the Netherlands	http://www.ecn.nl
ESA	European Space Agency	http://www.esa.int
ESTI	European Solar Test Installation	http://ies.jrc.cec.eu.int/reu.html
GEF	Global Environmental Facility	http://www.gefweb.org
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit	http://www.gtz.de
HMI	Hahn-Meitner Institute	http://www.hmi.de
IEA	International Energy Agency	http://www.iea.org
IEA SHC	IEA Solar Heating and Cooling Programme	http://www.iea-shc.org/
IEA PACES	IEA Solar Power and Chemical Energy Systems Programme	http://www.solarpaces.org/
IEA PVPS	IEA Photovoltaic Power Systems Programme	http://www.iea-pvps.org
IEC	International Electrotechnical Commission	http://www.iec.ch
IFC	International Finance Corporation	http://www.ifc.org
KfW	Kreditanstalt für Wiederaufbau	http://www.kfw.de
PV GAP	PV Global Approval Programme	http://www.pvgap.org
REEEP	Renewable energy & energy efficiency partnership	http://www.reeep.org

UNDP	United Nations Development Programme	http://www.undp.org
UNEP	United Nations Environment Programme	http://www.unep.org

Private Institutions and Companies

	oerlikon	http://www.oerlikon.com

12. Further Internet Links

	Swiss Photovoltaic Website	http://www.photovoltaic.ch
	Programme SwissEnergy	http://www.energie-schweiz.ch
	Swiss Energy Research	http://www.energy-research.ch
SNF	Swiss National Science Foundation	http://www.snf.ch
ETH- Board	Board of the Swiss Federal Institutes of Technology	http://www.ethrat.ch
SFSO	Swiss Federal Statistical Office	http://www.bfs.admin.ch
IGE	Swiss Federal Institute of Intellectual Property	http://www.ige.ch
METAS	Swiss Federal Office of Metrology	http://www.metas.ch/
SWITCH	Swiss Education and Research Network	http://www.switch.ch
Swissolar	Swiss Professionals Association for Solar Energy	http://www.swissolar.ch
SSES	Swiss Solar Energy Society	http://www.sses.ch
	US Department of Energy, Photovoltaic Program	http://www.eere.energy.gov/solar/
ISES	International Solar Energy Society	http://www.ises.org
ESRA	European Solar Radiation Atlas	http://www.helioclim.net/esra/

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Bundesamt für Energie BFE

THIN FILM SILICON SOLAR CELLS: ADVANCED PROCESSING AND CHARACTERIZATION

Annual Report 2006

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Project- / Contract Number	101191 / 151399
Duration of the Project (from – to)	01.01.2005 – 31.12.2007
Date	December 2006

ABSTRACT

This project aims at:

- Demonstrating the preparation of ultra-high efficiency thin-film silicon based devices
- Fabricating new high-efficiency devices on flexible substrates using low-cost processes
- Exploring new routes for improved processing and characterization
- Providing the best infrastructure (technological know-how, fabrication and characterization systems) to support industrial partners in the frame of projects funded by other sources

To reach these objectives a significant effort has been made to:

- Renew, upgrade and automate several systems for the fabrication of thin film solar cells
- Install and characterize new advanced characterization systems
- Work on process reproducibility by revisiting several fabrication steps, from solar cells patterning and individual layer optimization to the full system optimization on optimized TCO

In 2006, a record efficiency of 9.9% was reached for single junction microcrystalline (µc-Si:H) silicon solar cells on an optimized ZnO front electrode on glass. The transfer of the process of the record amorphous (a-Si:H) solar cell to a newer double chamber deposition system, in which the µc-Si:H solar cells are fabricated, was carried out in order to improve the reproducibility. This transfer, resulting in a-Si:H cells with initial efficiencies higher than 10%, will allow the fabrication of micromorph tandem solar cells within a much shorter time than before as both amorphous and microcrystalline solar cells can now be made in the same deposition system.
On low-cost PEN plastic substrates, continuous progresses have been made using periodic structures: Microcrystalline silicon solar cells were produced with a record-efficiency of 8.3%; amorphous silicon solar cells with efficiencies of 7.8% were also obtained on flexible substrates.
The laboratory infrastructure was further upgraded. In particular, a new, fully automated, large area, double chamber deposition system was completely designed and is now under final assembly in the IMT's clean room. This flexible system, fully equipped with advanced characterization tools, will allow in the mid-term the development and study of innovative processes for the fabrication of the next generation thin film silicon solar cells and modules.

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HIGH RATE DEPOSITION OF µC-SI:H SILICON THIN-FILM SOLAR CELL DEVICES IN INDUSTRIAL KAI PE-CVD REACTOR

Annual Report 2006

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Project- / Contract Number	CTI 6928
Duration of the Project (from – to)	1. March 2004 – 28. February 2006
Date	December 2006

ABSTRACT

The scope of this CTI project was twofold: the first task was to upscale the fabrication process for hydrogenated microcrystalline silicon (µc-Si:H) solar cells from laboratory small area deposition (100 cm^2) up to a surface of 14000 cm^2: the latter corresponds to the size of industrial deposition equipment sold by Oerlikon. The second task of the present project was to increase the deposition rate for the fabrication of solar-grade µc-Si:H absorber layers and devices. High-rate deposition is necessary to achieve short fabrication times for the relatively thick µc-Si:H absorber layer in a micromorph tandem solar cell: for comparison, in such a tandem structure the amorphous top cell is thinner than 0.3 µm, contrary to the microcrystalline bottom cell which is typically 1 to 2 µm thick. To be fully "industry compatible" the processing for all doped and intrinsic microcrystalline silicon layers prepared at high deposition rates has to be executed within a single-chamber PE-CVD reactor.

As was already shown in a preceding CTI project, Oerlikon KAI PECVD reactors developed for active-matrix LCD technology possess a high potential for cost-effective manufacturing of thin-film silicon solar cells based on amorphous silicon. The investigation of microcrystalline silicon solar cells on the same industrial reactor was the aim of this present project. Thereby, specific issues relating to the preparation of microcrystalline devices had to be addressed, using both the small KAI-S reactor at IMT Neuchâtel, and the larger area KAI reactors at Oerlikon.

The work executed in the second half of this project focused entirely on device optimisation: the parameter space for deposition conditions could be successfully scanned and both doped and intrinsic layers could be satisfactorily fabricated. The best devices had a conversion efficiency of 8.4%, with an absorber thickness of 1.4 µm and a deposition rate of 0.7 nm/sec. The devices were fabricated in the KAI-S reactor at IMT using thereby a single-chamber process (i.e. the sample remained in the chamber during the whole processing cycle).

The know-how transfer from IMT to the industrial partner was also started: the high-rate solar-grade microcrystalline silicon absorber layer (deposition rate: 0.7 nm/sec) could be successfully incorporated into micromorph tandem solar cells. Oerlikon could prepare first micromorph modules of 10x10 cm^2 area with an initial conversion efficiency of 9.5%, and several microcrystalline layers on the full panel area (1.4 m^2).

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A NEW LARGE AREA VHF REACTOR FOR HIGH RATE DEPOSITION OF MICRO-CRYSTALLINE SILICON FOR SOLAR CELLS

Annual Report 2006

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Project- / Contract Number	KTI 6947.1
Duration of the Project (from – to)	01.05.2004 - 30.04.2006
Date	05.12.2006

ABSTRACT

A novel very high frequency (VHF) plasma source was applied for large area (1m^2) deposition of amorphous and microcrystalline silicon for thin film solar cell production. The use of plasma excitation frequencies (up to 100 MHz) higher than the standard 13.56 MHz excitation frequency allows to substantially increase the plasma density and gas dissociation rates without the drawback of high ion energy bombardment of the substrate and consequent damaging. Therefore higher deposition rates at good device quality can be attained. The crucial problem in very high frequency (VHF) plasma reactors, the non-uniform voltage on the RF electrode, was solved by using adequately shaped electrodes. The proof of principle of this new reactor had previously only been made in non-reactive plasmas. In the present project, the novel RF reactor design was used for the first time in applications, in particular for solar cell production. The achieved aim was to have at the end of the project a high density RF reactor operating at elevated excitation frequencies allowing industrial high rate deposition of amorphous and microcyrstalline (micromorph) silicon with a uniformity of 5-10% on large area substrates relevant for solar cells (typically 1x1 m^2).

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STABILITY OF ADVANCED LP-CVD ZnO WITHIN ENCAPSULATED THIN FILM SILICON SOLAR CELLS

Annual Report 2006

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Project- / Contract Number	KTI 7253.2
Duration of the Project (from – to)	01.11.2004 – 31.10.2006
Date	December 2006

ABSTRACT

The goal of this project, which is now ended, was to study and improve the overall stability of LP-CVD ZnO layers, as incorporated within encapsulated thin-films silicon solar cells. This work was done in order to validate a complete commercial concept of photovoltaic (PV) thin-film silicon solar modules.

During the year 2006, efforts have been concentrated on the understanding of the variations of opto-electronic properties that occur in LP-CVD ZnO films exposed to humid environment. Furthermore, treatments for reducing the LP-CVD ZnO degradation have been further investigated and some of them have shown significant improvement of the ZnO stability against damp-heat exposure.

In parallel, Oerlikon has continued the work on optimizing the encapsulation process for PV modules, reporting regularly PV modules containing layers of LP-CVD ZnO. Several of these 1.4m^2 modules passed successfully the damp-heat test performed by the TÜV Rheinland.

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Bundesamt für Energie BFE

SPECTRAL PHOTOCURRENT MEASUREMENT SYSTEM OF THIN FILM SILICON SOLAR CELLS AND MODULES

Annual Report 2006

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Project- / Contract Number	KTI 7112.2 EPRP-IW
Duration of the Project (from – to)	September 2004 - December 2006
Date	February 2007

ABSTRACT

In the last months the industrial project partner OC Oerlikon Solar received overall orders to deliver equipment to build up production lines of thin film silicon solar cells with a yearly production volume above 100 MW. Thereby, up scaling of an optimized laboratory thin film solar cell technology involves always losses in the efficiency of large-area modules due to losses by laser-scribing, by in homogeneities of deposited films, by low control of mass production, etc. Within this optimization process for mass fabrication the analyses of cells and modules by the spectral response measurement is one of the most powerful characterization tool. Today, there are no commercial Spectral Response Measurement System (SRMS) for thin film cells and large scale modules available.

The goal of the present project is to develop an accurate, reliable and fast scan SRMS to analyze a-Si:H single and tandem cells and modules. An SR apparatus on module scale will allow obtaining the photocurrent spectra at different positions on the module. The development process will be performed in close collaboration with the industrial partner to fit the needs of an analytical tool used in an industrial R&D laboratory.

Two SR apparatus on cell level are in operation at the laboratories of the industrial partner. A third SR apparatus measuring the spectral photocurrent on the module level was developed and setup at NTB.

For the first time mapping results of the spectral photocurrent on a 1.4m^2 a-Si:H Oerlikon module was performed. It was found that the method is sensitive to two types of inhomogeneous photocurrent mapping areas. A strong decrease of the spectral response values was localized at a small area of several millimeters, due to pinholes, which were also detected by IR thermo-analyses at the same coordinates. Large scale inhomogeneous photocurrent areas coming along with relatively small changes in photocurrent in the % range are due to changes of layer thickness across the module area.

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FLEXCELLENCE: ROLL-TO-ROLL TECHNOLOGY FOR THE PRODUCTION OF HIGH EFFICIENCY LOW COST THIN FILM SILICON PHOTOVOLTAIC MODULES

Annual Report 2006

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Project- / Contract Number	SES-CT-019948
Duration of the Project (from – to)	01 10 2005 – 30 09 2008
Date	December 2006

ABSTRACT

FLEXCELLENCE (www.unine.ch/flex) is a European project (STREP) financed by the 6th framework program. It started on October 1st 2005 and is set to last 3 years. FLEXCELLENCE aims at developing the equipment and the processes for cost-effective roll-to-roll production of high-efficiency thin-film modules, involving amorphous (a-Si:H) and microcrystalline silicon (µc-Si:H). Eight partners, with extended experience in the complementary fields of cells and processing, modules and interconnections, production and machinery and reliability are involved; IMT is coordinator of this project.

Within the first year, IMT was mainly involved in the development of high-quality and high-throughput µc-Si:H layers on 30*30cm^2 area, in the investigation of new textured plastic substrates and in the optimisation of single a-Si:H and µc-Si:H cells as well as tandem micromorph cells.

The deposition on large area and at high rate resulted in device grade quality µc-Si:H layers grown at a rate of 2nm/s on rigid glass substrates. The results will now be transferred to flexible plastic substrates. In tests on different textured PEN substrates initial efficiencies of 7.8% for a-Si:H cells and 8.3% for the µc-Si:H cells have been achieved. The combination into micromorph tandem cells yielded an initial efficiency of 9.6%. Degradation under 1000 hours of continuous illumination resulted in stabilized efficiency of 8.5% which corresponds to a degradation of only 11%. The substrate preparation and the back reflector deposition for these cells was carried out by industrially compatible by roll-to-roll processes.

In the framework of this project and in collaboration with the centre for plasma research at the EPFL, VHF-Technologies has designed and installed a new wider VHF-PECVD electrode, which is now being tested. The first deposition of amorphous layers showed good homogeneity over the web width of 50cm. In parallel to the up scaling towards higher production capacity, VHF is carrying out a wide range of module stability and reliability tests.

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Bundesamt für Energie BFE

ATHLET: ADVANCED THIN FILM TECHNOLOGIES FOR COST EFFECTIVE PHOTOVOLTAICS

Annual Report 2006

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Project- / Contract Number	IP 019670
Duration of the Project (from – to)	01.01.2006 – 31.12.2009
Date	December 2006

ABSTRACT

ATHLET (Advanced Thin Film Technologies for Cost Effective Photovoltaics) is a European integrated project (IP) financed by the 6th framework program. The consortium of 23 partners (and 5 associated partners) from 11 EU countries is led by HMI Berlin. The consortium comprises also 3 Swiss partners: IMT, Oerlikon and the ETH Zurich. ATHLET's main goal is to provide scientific and technological basis for an industrial mass production of cost effective and highly efficient, environmentally sound, large-area thin film solar cells and modules. It focused thus in the development of thin-film silicon solar cells and modules, as well as chalcopyrites cells and modules with Cd-free buffer. The project aims at providing production and module concept for a price/efficiency ratio of 0.5 €/W_p or lower.

Regarding thin-film silicon, the project target is to developed micromorph tandem > 1 m^2 modules with a stable efficiency of 10% fabricated at a deposition rate of at least 10 Å/s. In parallel, small area cells will be further developed (next generation of cells) in order to reach a stable efficiency of 14%.

Within the first year, IMT work within ATHLET was split on one hand in the further development of small area component (with a focus on the reproducibility of the deposition process) and on the other hand on the development of μc-Si:H cell in an industrial KAI-S reactor (with a focus on medium to high deposition rates). Design and assembly of a new double chamber KAI-M reactor has also been supported by the project. Finally, an upgrade of our lockin thermography system has been carried out in order to offer an important support for the analysis of defects in solar cells and modules, as well as to help optimizing laser scribing steps for the monolithic interconnection.

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SIWIS: ULTRA THIN SILICON WAFER CUTTING BY MULTI-WIRE SAWING

Annual Report 2006

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Project- / Contract Number	CTI Nº 7730.2 NMPP-NM
Duration of the Project (from – to)	01.12.05 – 30.11.07
Date	January 2007

ABSTRACT

The industrial partner, HCT Shaping Systems SA (HCT) has a specific machine concept, mutli-wire slurry saw for semiconductor and solar industry. The objectives of the SIWIS project are to understand and control the surface defect generation mechanisms governing the yield in multi-wire sawing of silicon wafers. The development activities of the project focus on analysing and characterising surfaces of sawn wafers and to develop models of free wire sawing. The main motivation of behind this project is to to develop a multi-wire-sawing process technology that allows mass production of thin crystalline silicon wafer (<100μm) suitable for solar cell production.

As of today, the following specific points were achieved:

- Measurement of roughness of sawn wafer to determine the influences of sawing parameters.
- Measurement of sub-surface defects of sawn wafer to determine the effects of sawing parameters.
- Scratching and indentation of silicon by normal nanoindentation machine as well as *in-situ* scanning electron microscope. This study allows a fundamental understanding of the deformation process in silicon.
- Compression tests of micro-pillars under Raman spectroscopy. This investigation let the phase transformation and fracture mechanisms under uniaxial condition to be explored.
- Development of a bench test for wafer strength measurements
- Development of a scale-up wire sawing bench test

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BIFACIAL THIN INDUSTRIAL MULTI-CRYSTALLINE SILICON SOLAR CELLS BITHINK

Annual Report 2006

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Project- / Contract Number	503105 / BBW 03.0086
Duration of the Project (from – to)	09.2004 – 09.2007
Date	13.12.2006

ABSTRACT

The main BiThink's objective is to reduce significantly the cost of industrial PV silicon solar cells and modules by developing new technologies based in bifacial cells and albedo modules.

The technology developed in BiTink project is yielding impressive numbers in low consumption of silicon: 3000 wafers can be get from a meter of silicon ingot and using a conservative 80% of final yield (yield after cleaning and handling) that means 1.06 m^2 of silicon wafers from a kilogram of silicon. Using the current BSF bifacial technology, with efficiency of 15%, 60% of bifaciality and using the lower albedo factor of 30% that gives to a consumption of 4.3 grams / Wp without taking account of the yield. Using the 80% of yield for the slicing process and 90% for the solar cell production this number is 5.9 g/Wp. Now, BiThink is running to 3.5 g/Wp.

Another technology has been developed in BiTink project, which opens the door to thin wafer handling. This has to be considered as a breakthrough in PV industrial processes, because the main challenge faced by industrial when going to thinner wafer is the concomitant increase in breakage rate due to handling.

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FLEXIBLE CIGS SOLAR CELLS AND MINI-MODULES - FLEXCIM

Annual Report 2006

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Project- / Contract Number	100964 /151131
Duration of the Project (from – to)	01.03.2004 – 30.08.2005 (Extended: 30.04.2006)
Date	January 2007

ABSTRACT

Thin film Cu(In,Ga)Se_2 compound solar cells (also called CIGS) are well known for high efficiency, long term stability and the high potential for low cost solar electricity generation. While generally deposited on glass substrates, CIGS solar cells on metal and polymer foils offer obvious advantages: They are flexible, lightweight and can be manufactured with roll-to-roll deposition equipment. Roll-to-roll processes offer low cost production, while lightweight and flexible solar modules are attractive for a large variety of terrestrial and space applications. High efficiency solar cells on polymer and metal foils such as steel, Mo, Ti have been already developed by several groups.

Our group has been developing flexible solar cells on polymer and steel foils of 5 x 5 cm^2 size by using vacuum evaporated CIGS layers and applying a patented process, developed by ETHZ. Within this project we could report the development of 14.1% flexible solar cells on polyimide foil. This efficiency measured under AM1.5 illumination at ISE-FhG, Freiburg, Germany is a record for any kind of solar cell grown on polymer foil. Quantum efficiency and reflection measurements suggest that efficiencies exceeding 15% can be achieved by applying antireflection coating to reduce the reflection losses.

Aluminum is an interesting substrate material because of low cost and light weight, and it is used in several applications, especially in buildings. Development of CIGS cells on Al has remained a big challenge because of mismatch in thermo-physical properties. However, we have now developed for the first time CIGS solar cells on Al-foil. The photovoltaic properties of small area solar cells were characterized with I-V and quantum efficiency measurements. An efficiency of 6.6% was achieved with Na free CIGS absorber layers.

New cell concepts for semi-transparent solar cells and tandem solar cells require transparent back contact layers with good adhesion and suitable electronic properties for high efficiency CIGS solar cells. Indium tin oxide back contacts covered with a thin buffer layer of $MoSe_2$ yielded cells with efficiencies up to 11.8%.

We have started scaling up of deposition process to grow layers on 30 x 30 cm^2 size substrates by in-house assembly of a CIGS deposition system Development of large area flexible solar cells and mini-modules has started, and as a proof of concept flexible mini-modules to run small ventilator-fans have been developed. A mini-module with a 16cm^2 total area efficiency of 7.9% has been developed. During this preliminary development the factors for further efficiency improvements were identified although this result is already among the most efficient solar modules produced on polymer foil.

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LARGE-AREA CIS BASED THIN-FILM SOLAR MODULES FOR HIGHLY PRODUCTIVE MANUFACTURING (LARCIS)

Annual Report 2006

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Project- / Contract Number	SES66-CT-2005-019757 / FP6-019757
Duration of the Project (from – to)	01.11.2005 – 31.10.2009
Date	February 2007

ABSTRACT

This European collaborative project within the FP-6 EU program involves 6 universities and 4 industries working together towards the development of large area $Cu(In,Ga)Se_2$ (CIGS) based thin film solar modules for highly productive manufacturing. The project will improve the device performance and manufacturing technologies for low-cost, more stable, more efficient solar modules. In this project vacuum evaporation and electrodeposition approaches are used for absorber deposition and other components of the solar cells are improved. Two important objectives of the overall project are:

(1) Very high-quality modules manufactured by co-evaporation of CIGS and applying cost-effective methods with target efficiency > 13.5 % on 0.7 m^2.

(2) Development of alternative buffer layers for large are CIGS modules of up to 0.7 m^2 with efficiency > 12 %.

To meet the above mentioned objectives, research and development (R&D) work of the ETH group is directed on the improvement of Mo and development of alternative back contacts for improvement of efficiency, stability and to explore the possibility of reducing the CIGS absorber layer thickness. Another R&D activity of the ETH group is to transfer the so-called “3-stage” CIGS growth process from “static-mode” to an “in-line” moving substrates, and modify the CIS absorber in such a way that a separate deposition of the buffer layer could be avoided.

In order to develop alternative (to Mo) electrical back contacts providing multi-functionality, we have investigated TiN as a possible candidate because of its physical and chemical properties. A thin layer of $MoSe_2$, which is known to facilitate ohmic transport of carriers between CIGS and back contact, was applied prior to the CIGS deposition. Growth kinetics and properties of the $MoSe_2$ layers were investigated. We have successfully developed cells of 10-12% on TiN coated glass substrates and observed that the post-deposition Na incorporation in CIGS method developed at ETH is effective to significantly increase the cell efficiency to 13.8%. This efficiency is comparable to the achieved efficiency with conventional 1 micron thick Mo layer, however, higher efficiencies should be achievable with further optimization of the processes.

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ADVANCED THIN-FILM TECHNOLOGIES FOR COST EFFECTIVE PHOTOVOLTAICS (ATHLET)

Annual Report 2006

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Project- / Contract Number	FP6-2204-Energy-3
Duration of the Project (from – to)	01.01.2006 – 31.12.2009
Date	February 2007

ABSTRACT

The ATHLET project is an integrated project of the European Union involving 24 partners consisting of universities, research institutions and industries working on the topic of $Cu(In,Ga)Se_2$ (called CIGS) and Si based thin film solar cells. The project is divided in several work packages covering diverse topics of solar cells and modules. The Thin Film Physics Group (TFP) of ETH Zurich is participating in two work packages within the integrated EU project:

- Development of high efficiency lightweight and flexible CIGS solar cells on polymer foils and improvement in processes for highest record efficiencies.
- Buffer layer deposition by spray technique for CIGS solar cells.

R&D work of flexible CIGS solar cells has been carried out to understand the influence of deposition conditions and processes on the properties of layers and solar cells. The ETH group still holds the highest (14.1%) efficiency record of flexible solar cells on polymer foil. In order to develop flexible solar cells with evaporated buffer layers we have started installation of the deposition system for In_xS_y buffer layers by vacuum evaporation method. Another vacuum deposition system for the growth of CIGS layers on in-line moving substrates is currently under development stage. CIGS solar cells on ITO transparent conducting oxide (TCO) coated glass substrates were developed for their future application in tandem solar cells. We have developed 8% to 12% efficiency CIGS solar cells where both the front and back contacts are TCOs.

A new spray technology incorporating ultrasonic fine and condensed mist forming method has been developed for the growth of buffer layers on CIGS solar cells. Initial testing of different wide band gap buffer materials was started and later on the focus was placed on In_xS_y layers. An ultrasonic spray equipment for $5x5cm^2$ substrates was established; growth and properties of ultrasonic sprayed In_xS_y layers were investigated and 9.5% efficiency cells were developed.

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DYE-SENSITISED NANOCRYSTALLINE SOLAR CELLS

Annual Report 2006

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Project- / Contract Number	Project EPFL
Duration of the Project (from – to)	January – December 2006
Date	January 2007

ABSTRACT

Sensitised photoelectrochemical devices are a significant technical and commercial alternative to the conventional solid-state junction photovoltaic devices for solar energy applications. The standard photovoltaic devices developed and now widely applied are solid state devices, with semiconductor layers absorbing light and thereby producing electron-hole pairs, which are subsequently separated to provide a photovoltage by junctions, either with other semiconductors or Schottky contacts with metals. In the photoelectrochemical system the contacting phase is an electrolyte. However standard semiconductors with absorption properties compatible with visible light are in general unstable in contact with electrolytes. Widebandgap semiconductors are suitable, if sensitised to the visible spectrum by electroactive dyes. In the dye-sensitised system the recombination loss mechanism is minimised since the processes of optical absorption and charge separation take place on distinct phases within these photovoltaic cells. In consequence oppositely charged species are restricted to separate phases. Therefore device photoconversion efficiency is maintained even at low light levels. Recent results on enhanced device stability are particularly significant for future commercial applications.

A hybrid variant is also under investigation, the dye-sensitised solid state heterojunction, where the electrolyte phase is replaced by an organic charge transport medium. A further implementation of the dye-sensitised cell is as a component in optical-series tandem cells for photoelectrolysis.

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VOLTAGE ENHANCEMENT OF DYE SOLAR CELLS AT ELEVATED OPERATING TEMPERATURES

Annual Report 2006

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Project- / Contract Number	7019.1
Duration of the Project (from – to)	01.01.2004 – 01.01.2006
Date	January 2006

ABSTRACT

The recently concluded action with the industrial partner, Greatcell Solar SA (GSA) followed on a previous cooperation, also supported by KTI/CTI (project nos. 5815.1 & 5480.3), "Highly Efficient Nanocrystalline Solar Cells for Indoor Applications". The GSA product concept is a dye-sensitised electrochemical photovoltaic cell also adapted for indoor use. As a result the environmental restrictions are less severe, but the requirement for sensitivity to low light levels is an imperative. The reported project action at increased stability, particularly at elevated operating temperatures, with enhanced efficiency, in dye-sensitised PV cells fabricated in accordance with the Greatcell Solar SA product concept. It has been recognised that recombination losses are inhibited by the specific characteristics of this type of solar cell, rendering it more suitable for operation over a wider range of incident light intensities, indoor and outdoor. Cell fabrication requires the preparation of nanoparticulate semiconductor powders, and methods of preparing mesoporous layers from these materials on transparent conducting oxide coated substrates. The layers are then sensitized to visible light by chemisorbed electroactive dyes. This photoanode is associated with a redox electrolyte and cathode to form an electrochemical photovoltaic cell. During 2006 attention was given to formulation of improved electrolytes, molecular engineering of suitable dyes which by their physicochemical effects enhance stability at a higher output voltage, and the interface engineering particularly of the photoanode semiconductor material. This project is a key contribution to the development of the company Greatcell Solar, providing relevant information and technology for its intended product.

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MOLYCELL - MOLECULAR ORIENTATION, LOW BANDGAP AND NEW HYBRID DEVICE CONCEPTS FOR THE IMPROVEMENT OF FLEXIBLE ORGANIC SOLAR CELLS

Annual Report 2006

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Project- / Contract Number	SES6-CT-2003-502783
Duration of the Project (from – to)	01.01.2004 – 30.06.2006
Date	January 2007

ABSTRACT

Organic solar cells promise a strong reduction of photovoltaics (PV) costs if rapid improvements of the solar conversion efficiency and the lifetime can be achieved. There are still some crucial obstacles to overcome before a large-scale production of polymer- and organic-based solar cells can be considered. The latter is the clear aim of all industrial partners here involved. The feasibility of this approach will be proven with a new generation of organic PV having better efficiency ($\geq$ 5% on 1cm^2 glass substrates and $\geq$ 4% on 1cm^2 flexible substrates), longer lifetime and a production cost far below those of competing technologies based on silicon.

The programme is a multinational specific targeted research/innovation project (STREP) within the 6th. Framework Programme of the European Union.

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FULLSPECTRUM

A NEW PV WAVE MAKING MORE EFFICIENT USE OF THE SOLAR SPECTRUM

Annual Report 2006

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Project- / Contract Number	SES6-CT-2003-502620 / SER N° 03.0111-2
Duration of the Project (from – to)	1.11.03 – 31.10.08
Date	01.03.2007

ABSTRACT

FULLSPECTRUM is an EU integrated project whose primary objective is to make use of the FULL solar SPECTRUM to produce electricity. The necessity for this research is easily understood, for example, from the fact that present commercial solar cells used for terrestrial applications are based on single gap semiconductor solar cells. These cells can by no means make use of the energy of below bandgap energy photons since these simply cannot be absorbed by the material. The achievement of this general objective is pursued through five strategies: a) the development of high efficiency multi-junction solar cells based on III-V compounds, b) the development of thermophotovoltaic converters, c) the research on intermediate band solar cells, d) the search of molecules and dyes capable of undergoing two photon processes and e) the development of manufacturing techniques suitable to industrialize the most promising concepts.

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PHOTOVOLTAIC TEXTILE

PHOTOVOLTAIC FIBERS AND TEXTILES BASED ON NANOTECHNOLOGY

Annual Report 2006

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Project- / Contract Number	CTI 7228.1 NMPP-NM
Duration of the Project (from – to)	01.11.2004 – 31.03.2006
Date	January 2007

ABSTRACT

The goal of this project is to develop a woven, flexible photovoltaic (PV) device. Photoactive wires were produced by depositing layers of photoactive material onto a conductive filament. The PV cell was then assembled from two wire electrodes, the photoactive wire and a titanium-coated platinum wire. The PV efficiency of a lab-scale fiber is averaging 5.5%. The mechanical integrity of the functional coatings on working electrodes, and their PV behavior under mechanical stress was investigated, from which critical tensile load and radius of curvature for loss of PV efficiency were determined. Two different textile prototypes, namely encapsulated non-woven with reflective backside, and satin, were produced.

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ORGANIC PHOTOVOLTAIC DEVICES

Annual Report 2006

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Project- / Contract Number	Empa project
Duration of the Project (from – to)	January - December 2006
Date	22.3.2007

ABSTRACT

Organic solar cells offer the advantage of low-cost production and mechanical flexibility. Quite recently the 5% power efficiency benchmark has been achieved in the laboratory and photon-to-current efficiency at a given wavelength of up to 85% was obtained. New impetus for improved efficiencies requires a) novel low-band gap materials chemically tuned to the maximum of the solar photon flux, and b) a better understanding and control of the nanoscale arrangement of the electron acceptor and donor materials.

Little synthetic work has been done to replace the most popular materials, such as buckminsterfullerene, polythiophene, poly(p-phenylene vinylene) or poly(fluorene) derivatives, which absorb primarily in the visible and near ultraviolet region. Much more effort has been devoted to the nanoscale arrangement of the electron donor and acceptor material. The present research effort contributes to both, synthesizing new photovoltaic materials and developing new approaches to nanostructured biphasic films.

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PHOTOELEKTROCHEMISCHE UND PHOTOVOLTAISCHE UMWANDLUNG UND SPEICHERUNG VON SONNENENERGIE

Jahresbericht 2006

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Project- / Contract Number	76645 / 36846
Duration of the Project (from – to)	Januar 2003 – Dezember 2006
Date	24. Januar 2007

ABSTRACT

Three important problems could be solved:

The first antenna system which manages the unidirectional electronic excitation energy transport on macroscopical level could be built (via near field interaction, not optical).

In order to absorb the strong dispersion in the visible part of the spectrum a dye-loaded zeolite L nano crystal could be successfully inserted in a polymer matrix. It has also been shown that fluorescent solar concentrators could be built with those materials, and that previous problems related to the appropriate absorption and stability have been largely eliminated.

Organic Zn-Phthalocyanin solar cells are very attractive, but they do not absorb enough light in the 400 nm - 500 nm range of the spectrum, this is the reason for the low efficiency of this kind of solar cell. It has been demonstrated that this problem could be solved with the help of the antenna materials.

Two US patent have been granted in 2006.

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PV-MODULES WITH ANTIREFLEX GLASS

Annual Report 2006

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Project- / Contract Number	100297 / 150369
Duration of the Project (from – to)	01.08.2003 – 15.12.2006
Date	12. Januar 2007

ABSTRACT

This project intends to quantify the increase in power-output of photovoltaic-elements thanks to the use of antireflective etched solar glass. It comprises production and performance testing of modules with and without treatment. Performance measurements are made indoor with a flasher and also outdoor. Outdoor measurements comprise power analysis subject to the angle of the irradiation, as well as measurements of yield.

The increase in power output of 3% or more, which the supplier states in his marketing documents, cannot be confirmed. However, a significant increase in power has been measured. A difference of at least 2% can be measured in comparison with modules without antireflective treatment. An improvement in the behaviour at low angles of irradiation in outdoor tests could be observed. It was however not possible with this tests and the limited number of samples to reliably quantify this effect.

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BIPV-CIS- IMPROVED INTEGRATION OF PV INTO EXISTING BUILDINGS BY USING THIN FIRM MODULES FOR RETROFIT

Annual Report 2006

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Project- / Contract Number	503777 / BBW 03.0046
Duration of the Project (from – to)	1.1.2004 – 31.12.2007
Date	January 2007

ABSTRACT

The results of the project will improve and widen the potential for the integration of solar (PV) energy systems into existing buildings. Special attention will be paid to architectural and aesthetic questions. Building integration of PV systems in most cases leads to a “high tech” and “modern” appearance of the building. This is caused by the typical window-like surface of most conventional PV modules. Regarding however that 90% of the building stock consists of longer existing, that means “old fashioned” buildings, it is evident that an aesthetically satisfying building integration of PV needs a lot of good will and creativity from planners and architects. In many existing building integrated PV systems the modules contrast with the building and its surroundings.

A European survey on the potential and needs for building integrated PV components and systems will identify the basis for the development of modules away from the glass /window-like appearance.In the project PV roof tiles, overhead glazing and façade elements based on CIS thin film technology will be developed and investigated which have a modified optical appearance for better adaptation to the building skin. One of the ideas is optical decoupling of substrate and cover glass.

A complete roof tile system with thin film cells adapted to the visual appearance of conventional roof tiles and innovative connection and mounting will be developed. The work includes prototype fabrication and tests according to relevant standards and subsequent performance tests.

Novel overhead glazing includes semitransparent thin film modules optimised for daylight transmission. The back side appearance will be modified in order to represent the visible inner part of the building skin. For overhead and insolating glazing an invisible interconnection and for PV roof tiles a low cost connector will be developed. Project result will be PV modules and generators for improved building integration ready for industrial manufacturing.

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CENTRALE LEEE-TISO

PERIODO VII: 2003-2006

Annual Report 2006

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Project- / Contract Number	36508 / 151135
Duration of the Project (from – to)	October 2003 - December 2006
Date	December 2006

ABSTRACT

The sixth quality audit, for the ISO17025 accreditation maintenance of the I-V measurements at STC, supervised by the Swiss Accreditation Service, was successfully passed. Moreover, a new test was verified and accredited ISO17025: the determination of the temperature coefficients of PV modules.

During 2006 more than 4900 flashes were performed with the ISAAC-TISO sun simulator, in particular for research programmes.

The new electronic device MPPT was successfully installed outdoor and the MPPT was also tested in static and dynamic condition at BFH Burgdorf.

At present, the fourteen different module types chosen for the test cycle 10 (7 mc-Si, 3 sc-Si, 1 HIT, 2 a-Si and 1 CdTe) have been exposed outdoor for 8 months.

The temperature coefficient has been determined on the 3rd sample of each type of c-Si modules.

The accuracy of power declarations of c-Si modules improved constantly. This lead to unceasingly smaller discrepancies between modules when comparing their energy output in the basis of their nominal power (differences in Wh/Wp-nominal power: ±10.9% in 2000 and ±4.9% in 2006). The divergence between commercial to technological comparison diminished to only 1.7% (±3.2% with P3 as reference and ±4.9% with Pn as reference). All thin film technologies seem to outperform the crystalline silicon technologies.

For architects and designers visual aspects of a PV integration are important. PV modules from the outdoor test cycle 10 are characterised by shape, size and color (colour palettes NCS S and 4041 Sikkens). Impact tests were carried out with PV samples of amorphous silicon module on flexible substrate according to the standard IEC 1646 and SIA V280.

PV modules can be used as shielding elements for Non Ionising Radiation (NIR). The measurement of photovoltaic NIR attenuation show that thin-film photovoltaic modules have really good NIR attenuation properties (more than 30dB) as have low-emissivity glasses (more than 20dB).

The laboratory of Energy Ecology and Economy (LEEE) has been promoted to the rank of institute with the new name: Istituto di Sostenibilità Applicata all'Ambiente Costruito - ISAAC (Institute for applied sustainability to the built environment).

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PV ENLARGEMENT

Annual Report 2006

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Project- / Contract Number	n° OFES: 03.0004, n° EU: NNE5/2001/736
Duration of the Project (from – to)	01.01.2003 - 31.12.2006
Date	Dezember 06

ABSTRACT

The consortium succeeded in implementing 93% (status 08/2006) of the planned PV capacity. Instead of 1.0 MWp (original contract) the consortium installed nearly 1.2 MWp (amendment 1) with the same EC support. From 27 PV systems to be realised within this project 25 are installed, 22 are in operation and two will soon be constructed.

On the scientific level the project is almost terminated. The power characteristics of nearly all module technologies were tested indoors (by ISAAC) and outdoors (by WIP). A total of 151 modules were characterised by our laboratory for their initial power and 54 of these have been tested again after 1-2 years of outdoor exposure to determine their degradation.

First system inter-comparisons shows that all CIS technologies outperforms the analysed crystalline silicon systems and that the CdTe module technology seems to compete very well with crystalline technologies (comparison by stabilised power determined by laboratory tests). The amorphous silicon systems has still to be evaluated. For the inverters the most important point was identified to be the ideal fit and the reliability and not the efficiency, which comes only next.

75% of the 23 different module types which were analysed demonstrated to have a stabilised power in the range of ±5% of the declared name plate value, the remaining 35% showed to be lower with some close or below the acceptable tolerance limits - according to the standard EN50380 "Datasheet and nameplate information for photovoltaic modules".

Within the second measurement campaign, a detailed analysis on all thin film modules has been done to improve the overall measurement accuracy for these technologies. A new internal test procedure for the measurement of CIGS modules, consisting in the add on of a bias light within the standard indoor test procedure, was developed by ISAAC.

Presentations on the PV system and module performance were given at several international events, such as the WCPEC-4 in Hawaii and the European PVSEC in Dresden.

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PERFORMANCE

ISAAC ACTIVITIES

Annual Report 2006

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Project- / Contract Number	n° 019718 EU: (SES6) – Integrated project
Duration of the Project (from – to)	01.01.2006 - 31.12.2009
Date	Dezember 2006

ABSTRACT

The PERFORMANCE project covers all pre-normative aspects from module to system level and from instantaneous device characterisation and system measurement to their life-time performance prediction and assessment. The limitations of current indoor and outdoor calibration measurement technology will be investigated and precision will be improved, covering current technologies as well as new and advanced cell and module concepts. Methods will be developed to connect from measurements of module power to module energy production. In a third pillar, methodologies for the assessment of the life-time performance of PV modules will be developed. Based on all these work packages, a modelling and analysis programme will provide the analytical understanding of PV performance in the broad and systematic manner mentioned above. Following this work programme, the project will produce a consistent set of measurement and modelling methodologies to create the transparency needed for the European market and industry. Next to this significant scientific effort, intense involvement of all European companies along the value chain will be organised systematically through feedback loops. Project results will be fed directly into standardisation processes on CENELEC and IEC level.

The project is divided into 8 sub-projects:

SP1 Traceable performance measurement of PV devices
SP2 Energy delivery of photovoltaic devices
SP3 PV system performance evaluation
SP4 Modelling and analysis
SP5 Service life assessment of PV modules
SP6 PV as a building product
SP7 Industry interaction and dissemination
SP8 Standardisation processes

The ISAAC institute is involved in SP1, SP2 and SP4 and is work-package leader of SP4.4 entitled "Annual Energy Rating Production and Device Comparator". The scope of this report is to present the institute activities of year 2006.

General information about the project can be found under **http://www.pv-performance.org**

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EFFICIENCY AND ANNUAL ELECTRICITY PRODUCTION OF PV-MODULES

Annual Report 2006

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Project- / Contract Number	101431 / 151715
Duration of the Project (from – to)	November 2005 – April 2007
Date	January 2007

ABSTRACT

Efficiency data of PV-modules under actual operating conditions are of vital importance for reliable prediction of their annual electricity production. For measuring these data, an outdoor test facility was erected at PSI. It consists of a sun-tracker and a PC-based measurement system. The sun-tracker is used to orient test modules continuously towards the sun. The measurement system is designed for automated acquisition of current/voltage (I/V) characteristics, from which the efficiency is determined. I/V tests performed under constant irradiation, but different module temperatures, allow the temperature coefficient of the efficiency to be determined. Measurements under varying irradiation and varying air mass allow the efficiency in these conditions to be determined. Some hundreds up to a few thousand I/V characteristics per module are required to develop semi-empirical efficiency models, which allow an accurate calculation of the efficiency under all possible operating conditions. From the efficiency models and local meteorological data, the annual electricity production of the modules at the site selected for the PV plant can be calculated. These data allow the expected cost of electricity generation for different modules to be calculated, and thus the type of modules with the highest yield-to-cost ratio for a specific installation site can be identified.

Testing and development of efficiency models were carried out for two commercial modules (SunPower SPR-90 with mono-crystalline cells, and Kyocera LA361K51S with poly-crystalline cells).

Cell efficiencies under Standard Test Conditions, STC of 19.5% and 12.7% were found for the SunPower and Kyocera modules, respectively. Efficiency maxima of 19.7% and 13.3% were observed at 519 W/m^2 and 419 W/m^2, respectively. The efficiency of both modules linearly decreases with temperature. The temperature coefficients were found to be -0.0637 and -0.0493 percentage points/°C, respectively. The SunPower module has an efficiency practically independent over the whole irradiance and air mass range. The Kyocera module also performs very well under varying irradiation, but its red light sensitivity in the late afternoon is somewhat reduced, as compared to the SunPower module. However, the Kyocera module tested is fairly old (acquired in 1994). Recent measurements on Kyocera's latest modules show a much better red sensitivity and a remarkably higher efficiency (cf. http://grid-pv.web.psi.ch).

Using measured meteorological data from a sunny site in Jordan, the electricity production for the SunPower and Kyocera modules were calculated. The yearly output of South-oriented, 30°-inclined modules was found to be 459 and 299 kWh/(m^{2}cell area). For sun-tracked modules, the annual output amounts to 636 and 405 kWh/ (m^{2}cell area). Due to the high efficiency of SunPower's SPR-90 module, the module area required for 1 kW_{STC} is only 5.9 m^2, whereas it turns out to be 9.7 m^2 for the 12.7 % efficient Kyocera module.

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PHOTOVOLTAIK SYSTEMTECHNIK 2005-2006

(PVSYSTE 05-06)

Annual Report 2006

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Project- / Contract Number	100451 / 151395
Duration of the Project (from – to)	01.01.2005 – 31.12.2006 (full project period 01.01.03 - 31.12.06)
Date	6. December 2006

ABSTRACT

Purpose and Goals of the project during 2006

- Continuation of long-term monitoring of PV plants.
- Extended semi-automated tests of grid-connected PV inverters from different manufacturers
- Realisation of a second DC power supply of 800V / 40A – 80 A
- Ongoing participation in national network of competence BRENET (building & renewable energy network).

Most important results in 2006

- Inclusion of fault-current measurement procedures for single phase inverters without transformers according to new German standard VDE126-1-1 (2.2006).
- Realisation of a new interface for MPPT measurements, allowing measurement of I-V-curve of the PV-array simulator and MPPT-behaviour of the inverter with the very same equipment.
- A new DC generator 815 V / 88 A could be purchased with enough power for a new large PV array simulator of 60 kW to be built in 2007.
- Confidential (paid) tests of different inverters for major PV trading companies.
- Confidential tests of different MPP-Trackers for project Solarimpulse.
- Extended semi-automated tests performed at new inverters with new PV array simulator. In the same measurement run, DC-AC conversion efficiency, harmonic currents, power factor, static and dynamic maximum-power-point-tracking (MPPT) efficiency and total efficiency $\eta_{tot} = \eta \bullet \eta_{MPPT}$ vs. power can be determined.
- Inspection of DC-side of several older PV plants revealed different present and possible future problems in modules and wiring which might lead to electrical arcs.
- Arcs in connection boxes of PV modules of BP Solar reported in Photon 8/2006 showed again the potential (underestimated) danger of arcs on the DC side of PV plants. The arc detector developed already in the years 1993-1998 in common projects with Alpha Real AG was reactivated and improved by some new ideas. A patent for these new ideas was filed.
- Extension of pvtest.ch with normalized monthly statistics and various on-line representations.
- Extended test reports (in German) about inverters tested now available under www.pvtest.ch.
- 2 conference contributions at the 21st EU PV conf. in Dresden, 3 conference contributions at the 21st PV symposium at Staffelstein/D and 3 publications in professional journals.

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UPDATE PHOTOVOLTAIC IN VIEW OF ECOINVENT DATA V2.0

Annual Report 2006

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Project- / Contract Number	101805
Duration of the Project (from – to)	1.11.2006 - 30.6.2007
Date	14.11.2006

ABSTRACT

Life cycle assessment (LCA) is an environmental management tool for analysing, comparing and improving products or technologies. A basic requirement for LCA are life cycle inventory (LCI) data describing the inputs and outputs of each stage of the life cycle. The ecoinvent database provides such data for currently more than 2700 unit processes. The data are used within all major LCA software products.

The last data update of mono- and polycrystalline PV plants in the Swiss ecoinvent database was made in 2003. The ecoinvent data v1.2 describe the situation of the European PV industry and the use of PV plants in Switzerland for the reference year 2000.

At the moment several projects are ongoing for the release of ecoinvent data v2.0. Existing datasets will be updated as necessary and new economic sectors such as bioenergy are additionally investigated in view of this new release.

In the past years the PV sector developed rapidly. Ongoing projects such as Crystal Clear have investigated the up-to-date life cycle inventory data of the poly- and monocrystalline technologies. However, these data are not yet implemented in the ecoinvent database and the ecoinvent data on PV does, therefore, not correctly reflect the environmental performance of the PV sector of today. An update of the existing data in the ecoinvent database has become necessary. Since there were significant improvements in performance of PV systems in recent years, it is in the interest of companies in the photovoltaics sector that these changes also appear in life cycle inventories. This project aims to update the LCI data for crystalline photovoltaics and to investigate also data for thin film technologies for the first time.

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ENVISOLAR - ENVIRONMENTAL INFORMATION SERVICES FOR SOLAR ENERGY INDUSTRIES

Annual Report 2006

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Project- / Contract Number	ESA Earth Observation Envelope Program Market Development Element, Contract number 17734/03/I-IW
Duration of the Project (from – to)	December 2004 - May 2007
Date	December 2006

ABSTRACT

The new generation of Meteorological satellites - Meteosat Second Generation (MSG) - opens a whole new era in the monitoring of irradiance from space by improving the spatial, temporal and spectral resolution of satellite data, which are thereby becoming even more accurate and synoptic than traditional ground measurements.

Integrating this information within business practices of solar energy companies is the objective of the Envisolar project (Environmental Information Services for Solar Energy Industries), funded by ESA within the framework of the Earth Observation Market Development Programme (EOMD) and managed by the German Aerospace Center (DLR).

ENVISOLAR aims at the increased use of satellite based solar radiation information in solar energy industries. The project services will help end-users in planning, construction and operation of solar energy power plants and while operating conventional power plants.

The following services providing solar radiation information will be improved through the ENVISOLAR project:

- Services for Investment Decision: Site analysis and optimisation which allows finding the best site for a planned power plant.
- Services for plant management: online monitoring service for PV system with automated failure detection (www.spyce.ch)
- Solar energy forecasting for utilities
- Time-Series Services for Science and Consulting

In Switzerland ENVISOLAR supports the development of the online PV monitoring SPYCE. SPYCE is offered as a joint venture of Enecolo AG and Meteotest. It uses irradiance data generated by the French research center Ecole des Mines de Paris with the aid of satellite data from the ESA MSG satellite. SPYCE monitors the production of solar power plants, which increases their energy yield as well as their capacity to compete with other (non renewable) energy sources.

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SCHWEIZER BEITRAG ZUM IEA PVPS PROGRAMM - TASK 1

Annual Report 2006

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Project- / Contract Number	11427 / 151 934
Duration of the Project (from – to)	01.01.2006 – 31.12. 2006
Date	15.1.2007

ABSTRACT

The Swiss contribution to the PVPS Programme included:

- **National Survey Report**, a summary of developments in the market and political areas. The report's data is integrated into the IEA's **Trends in Photovoltaic Application Report**
- Acquisition of Swiss contributions to **PV Power**, distribution of the magazine to approx. 250 addresses in Switzerland
- Targeted search for **new contacts** in the PV area
- Contributions/organizations to/of national and international **workshops**
- **PR-work** in Switzerland. Reference to the programme's international publications

The results of these activities include

- **National Survey Report** (NSR) based on the statistics provided by the Swiss Association of Solar Professionals and the Swiss Association of Utilities (grid-coupled installations)
- Distribution of the **PV Power Magazine** in May and November
- 2 **Task 1 meetings** in Vancouver and Vienna
- 2 Workshops in Dresden (September) and Zurich (November)
- Webmastering support for www.iea-pvps.org

Work still to be done:

- Organize a Workshop at the PV conference in Milano (Sept. 2007) and Fukuoka (Dez. 2007)

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Schweizer Beitrag zum IEA PVPS Programm Task 2 - 2006

Annual Report 2006

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Project- / Contract -Number	14805 / 151935
Duration of the Project (from – to)	January 2006 - December 2006
Date	12.1.2007

ABSTRACT

Switzerland takes part in the Photovoltaic Power Systems (PVPS) programme of the International Energy Agency (IEA), Task 2. The overall objectives of the Task 2 is to improve the operation, sizing, electrical and economic output of photovoltaic systems and components by collecting, analysing and disseminating information on their technical and economic performance and reliability, providing a basis for their assessment, and developing practical recommendations. The actual work of Task 2 is organised in four active Subtasks.

Activities of Phase III, 2004 - 2007

Subtask 1 : Performance Database (enrichment and dissemination of the performance database) This tool has now worldwide more than 3'000 users form 90 different countries. It is being updated at least once a year by the expert-group. The database is now available online at the public website http://www.iea-pvps-task2.org .

Subtask 5 : Technical Assessments and Technology Trends of PV Systems This Task is developing know-how and experience concerning the long-term reliability as well as the user-awareness of PV systems and ways to analyse and predict the performance of PV systems.

Subtask 6 : PV System Cost over Time (Activity leader Switzerland) The global economical survey aims at gathering information on plants, technical performance, maintenance and cost of as many PV systems as possible. With an Internet-based survey tool performance and economic data was collected over the past year.

Subtask 7 : Dissemination Acitivities, Educational Tools.

This project is supported by the Swiss Federal Office of Energy.

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SWISS INTERDEPARTMENTAL PLATFORM FOR RENEWABLE ENERGY PROMOTION IN INTERNATIONAL CO-OPERATION (REPIC)

Annual Report 2006

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Project- / Contract Number	SECO UR-00123.01.01
Duration of the Project (from – to)	March 2004 – June 2007 (Phase I)
Date	January 2007

ABSTRACT

The Swiss State Secretariat for Economic Affairs (SECO), the Swiss Agency for Development and Cooperation (SDC), the Swiss Federal Office for the Environment (FOEN) and the Swiss Federal Office of Energy (SFOE) have founded a interdepartmental platform for the promotion of renewable energy in international cooperation. The REPIC-Platform contributes to the implementation of global climate protection agreements and to a sustainable energy supply in developing and transition countries, as well as in Switzerland, and represents an important part in the implementation of the Swiss policy for sustainable development on the international level. The REPIC Platform thereby represents an important contribution to the creation of a coherent policy and strategy in Switzerland, for the promotion of renewable energy in international cooperation.

The specific goals of the REPIC platform in relationship with renewable energy in international co-operation are:

1. Information and awareness of the actors
2. Knowledge of local framework conditions and improvement of capacities
3. Project promotion and project realisation
4. Contribution to international networks
5. Co-ordination and quality control

The measures of the REPIC Platform are subsidiary to national and international promotion instruments which already exist. The measures are meant to support these instruments, especially in the area of finance (project lines of the governmental agencies involved, SOFI, mixed credits, WB, IFC, GEF, and similar) and climate policy instruments (Kyoto-mechanisms). Furthermore, the measures of the REPIC-Platform should provide for synergies between activities from the private sector and the civil society.

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IEA PVPS TASK 10 - SWISS CONTRIBUTION

Annual Report 2006

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Project- / Contract Number	101562 / 151862
Duration of the Project (from – to)	February 2006 – December 2008
Date	November 28, 2006

ABSTRACT

The challenge for Task 10 is to translate the results of the research on PV in built environment (buildings + grid) and to expand the work to a wider range of stakeholders necessary to mainstream urban-scale applications. Several stakeholder values must be combined in order for urban scale PV values to exceed the price and become a sustained market of urban energy solutions. Switzerland is active in subtask 2 (Urban Planning, Design and Development) and 3 (Technical Factors).

During this first year of the project, in-depth knowledge of the Task was acquired, international contacts were taken by the participation to two meetings (in Vancouver and in Malmö). A work plan was established for substask 2 and, on that basis, a questionnaire was developed for a standardized analysis of the present and future urban policy related to PV.

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IEA SHC TASK 36: SOLAR RESOURCE KNOWLEDGE MANAGEMENT

GLOBAL RADIATION FORECAST

Annual Report 2006

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Project- / Contract Number	101498 / 151784
Duration of the Project (from – to)	July 2005 – June 2010
Date	8.12.2006

ABSTRACT

In the framework of IEA Solar Heating and Cooling (SHC) task 36 Meteotest investigates mainly the possibilities and quality of global radiation forecast. In the first year a short validation of the global radiation forecast of Meteotest's operational MM5 model was made. The root mean squared error for a 36 hour forecast was about 30 %. This result is in the same range as the forecasts of the two other IEA team members dealing with forecast. Next year more detailed validation and the introduction of model output statistics are planned.

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NORMENARBEIT FÜR PV SYSTEME

Annual Report 2006

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Project- / Contract Number	17967 / 151661
Duration of the Project (from – to)	1.1.2005 – 31.12.2006
Date	January 2007

ABSTRACT

The worldwide use of Photovoltaic IEC standards supports international trade of uniform high-quality PV products, systems and services and assists conformity assessment such as certification and issuing quality label(s). International standards establish objective specifications that both buyer and seller can rely on. For buyers, they widen the range of choices and lower costs, primarily because they often increase the number of competitors. For sellers, global standards broaden the number of potential customers and reduce the cost of meeting their needs.

The Scope of IEC TC82 is to prepare international standards for systems of photovoltaic conversion of solar energy into electrical energy and for all the elements in the entire photovoltaic energy system. In this context, the concept "photovoltaic energy system" includes the entire field from light input to a solar cell to and including the interface with the electrical system(s) to which energy is supplied.

TC 82 has six active working groups developing standards for the photovoltaic industry. Some of the 25 current work program topics include: safety of inverters and charge controllers, islanding prevention measures for grid connected PV Systems, design qualification and type approval of solar modules, on site IV curve measurements, minimum requirements for system documentation, commissioning tests, and inspection requirements for Grid connected PV systems, requirements of PV arrays. Under the administrative lead of TC 82 is a Joint Coordination Group with TC 21, TC 88 and TC 105 which is developing a series of 10 new standards dealing with various aspects of renewable energy system integration and project management.

Switzerland, once a leading pioneer in grid connected PV systems, has in spite of shrinking federal budgets a market of about 2-3 MW/a, mainly driven by green pricing. There are several important Swiss manufacturers for plugs, grid connected and stand-alone inverters, alu-profiles to facilitate mounting of PV modules and laminates, and turn key operators as well as many consulting and engineering companies, active both in Switzerland and abroad. Next to a direct involvement in the IEC work, all relevant documents are discussed in detail in the national standard committee TK82, in order to formulate Switzerland's interest in adequate, simple and effective standards for PV. There are particular interests of the leading plug manufacturer Multicontact to elaborate more specific standards for plugs in PV array cabling. The strategic decision during last TC82 meeting on elaborating standards to avoid dangerous arcs is of interest to Prof. Heinrich Häberlin. Swissolar is evaluating to offer a workshop on standard issues, once the feed in tariffs has been adopted by the Swiss Parliament.

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PV ERA NET

NETWORKING AND INTEGRATION OF NATIONAL AND REGIONAL PROGRAMMES IN THE FIELD OF PHOTOVOLTAIC (PV) SOLAR ENERGY RESEARCH AND TECHNOLOGICAL DEVELOPMENT (RTD) IN THE EUROPEAN RESEARCH AREA (ERA)

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Project- / Contract Number	CA-011814-PV ERA NET
Duration of the Project (from – to)	1 October 2004 – 30 September 2008
Date	December 2006

ABSTRACT

PV ERA NET is a European network of programme coordinators and managers in the field of photovoltaic solar energy (PV) research and technological development (RTD). The consortium comprises major key stakeholders in the field of national and regional RTD programmes involving photovoltaics (PV). The consortium comprises 19 participants from 12 states with more than 20 national RTD programmes (or parts of programmes) and three regional RTD programmes.

The mission of PV ERA NET is to carry out activities towards networking and integration of national and regional programmes in the field of PV RTD in the European Research Area (ERA).

The overall strategic objective of PV ERA NET is to strengthen Europe's position in photovoltaic (PV) technology by improving the cooperation and coordination of PV RTD programming efforts across Europe, supporting long-term perspectives in European research policies as well as supporting related policies in order to establish a strong European Research Area and to create a durable structuring effect and impact in terms of coherence, innovation and economic growth.

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PHOTOVOLTAIC FACADE

MOUNTING SYSTEM FOR THIN-FILM-MODULES AT FACADES

Annual Report 2006

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Project- / Contract Number	100136 / 150169
Duration of the Project (from – to)	May 2003 – April 2007
Date	February 2007

ABSTRACT

Thin-film-modules are as well interesting for the application in facades. At the Technical School of Engineering and Architecture Lucerne several questions to stability by fixing standard thin-film-modules with the Aluhit-P-mounting-system were investigated and judged in view to relevant norms.

In Goldau, a 3.1kW-pilote installation at the south and east-facades of a transformer-building was realized. It demonstrates the façade-application of thin-film-modules. The data-acquisition will bring information about the energy-production and several temperatures at the facade.

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Dachintegration mit amorphen Dünnschichtzellen Turnhalle Wiesendangen

Annual Report 2006

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Project- / Contract Number	101788 / 152202
Duration of the Project (from – to)	August 2006 / December 2007
Date	December 2006

ABSTRACT

On a public sports hall in Wiesendangen, which is located east of Zurich, a new grid connected, roof integrated PV system has been installed in November 2006. New is the use of Biosol XXL roofing elements. They are made with triple junction amorphous silicon solar cells produced by Unisolar and the roof integration system SOLRIF, produced by E. Schweizer Metallbau in Hedingen. For the evaluation of the operational results, a small measurement campaign is initiated. It will basically compare the energy production with a nearby located, similar PV system based on single crystal silicon solar cells. Global solar radiation is measured in plane of the PV modules and horizontally together with two temperatures.

The production values will be displayed on www.spyce.ch .

The installation went fast and without problems.
School children helped with the installation and PV will be a future issues in the lectures for the higher level classes.
These activities were supported by the Youth Solar Project of Greenpeace.

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Nullenergieschulhaus Heilpädagogisches Zentrum Ekkharthof Kreuzlingen

Annual Report 2006

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Project- / Contract Number	101787 / 152201
Duration of the Project (from – to)	January to December 2007
Date	December 2006

ABSTRACT

The objective of the photovoltaic-plant “Nullenergieschulhaus Heilpädagogisches Zentrum Ekkharthof Kreuzlingen” was to build a photovoltaic plant (43,2 kWp) as a part of the renewable energy-concept from this zero-energy-schoolhouse. The inverter and the cells are produced by Sunways, a local company.

The building is a timber construction and highly insulated, new built 2006. The heat for heating installation and for the warm water preparation is produced with a heat pump with earth sondes. All energy for the electrical appliance is theoretically produced on the roof of the schoolhouse with the photovoltaic plant.

From January, measurements will document how far the coverage is of produced solar power and the requirement of energy for the heat pump.

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17.6 KWP INSTALLATION WITH THIN-FILM MODULES ON THE FLAT ROOF AT THE CNB BUILDING OF THE ETHZ

Annual Report 2006

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Project- / Contract Number	100176 / 150244
Duration of the Project (from – to)	June 2003 – December 2007
Date	December 2006

ABSTRACT

The CNB-building of the Swiss Federal Institute of Technology (ETH), Zurich, is located downtown. As a part of the renovation of the building, a new photovoltaic installation has been realized.

The building is subject of local historical monument preservation and protection codes. Therefore, the PV modules are of one colour and installed as symmetrical as possible.

The installation has a power of 17.6 kW peak and consists of standard thin-film-modules. A display in the new cafeteria provides information about the service of the installation.

Together with the engineering office energiebüro ag, BE Netz installed the plant in June 2006.

Foto: Ch. Meier, energiebüro ag

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FLAT ROOF INTEGRATION CPT SOLAR

Annual Report 2006

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Project- / Contract Number	100493 / 150604
Duration of the Project (from – to)	From August 2003 to December 2006
Date	11/12/2006

ABSTRACT

This project, started in August 2003, has reached its third and last year. In this period the behaviour and the energy yield of an innovative 15.36kWp PV plant was analysed. The system consists of flexible triple-junction thin-film amorphous silicon modules laminated together with a single ply roofing system based on a flexible polyolefine (FPO) membrane which acts as a waterproofing system.

Most of the results presented in this document refer to the inter-comparison between 3 strings of the CPT plant (#1, 5 and 9) and the reference modules, consisting in 3 small open-rack plants with a-Si and c-Si modules.

Thermal insulated a-Si modules reached 80°C and the mean temperature increased by up to 40-45°C above the ambient temperature. On the one hand, the high temperature of the thermally insulated modules creates higher power losses due to negative temperature coefficient, on the other hand, the higher temperature involves to better thermal annealing, reversing the main degradation mechanism.

The final energy yield of the insulated a-Si module is comparable to a 20° tilted open-rack c-Si power plant. Thus better thermal behaviour and annealing processes of a-Si compared to c-Si technologies can compensate losses due to the nearly horizontal roof integration.

Due to the low sun elevation during winter, not only the irradiation is lower but also the optical losses effects are more dominant for the nearly horizontal modules with regard to the c-Si at tilt of 20°.In order to quantify the optical losses, the reflection losses for the CPT-plant and the reference modules were simulated with PVSYST.

Compared to c-Si modules, a thermal insulated BIPV design best matches the thermal behaviour of a-Si technologies.

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SOLGREEN KRAFTWERK 1

ZÜRICH

Annual Report 2006

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Project- / Contract Number	42920 / 82869
Duration of the Project (from – to)	1st July 2001 – Summer 2007
Date	December 06

ABSTRACT

The Pilot and Demonstration plant ”Solgreen Kraftwerk 1” in Zurich, was built in June 2001 and realised the results of the Development Project `Optimierung des Systems Solgreen` in practice. The Solgreen system permits the integration of photovoltaics on green flat roofs with considerable advantages.

The project aims to investigate and demonstrate the quality and durability of the developed construction by optimized assembling and material cost at the same time. First results were made under construction and operation of the new plant in 2001. Furthermore the interacting influences of roof vegetation and photovoltaic should be examined scientifically during a long period by an external expert.

The project Solgreen is now running since 4 years. The exploration of vegetation show various results shown in the following pages. 70 different species have been detected until now. The vegetation cover reaches up to 70%. Between the 3 types of substrates there are various differences.

Parts of the construction is surrounded by soil. In order to scale the risk of metal corrosion measurements have identified pH values. In comparison with the material properties of zinc and aluminium no critical material-dependent corrosion has to be expected. As well visual inspection has shown no points at risk from corrosion.

One important goal of the Solgreen project is to inform a wide range of public about the aims und results of this project. Poster presentations at the National Photovoltaic Conference in Zurich and the 19th European Conference in Paris were great possibilities to address specialists. A newspaper article was addressed to a larger scale of population.

In 2006 the “Solgreen Kraftwerk 1” project is going to end. The final report will allow to view all the changes in vegetation. It will be shown if the developed construction is really useful for photovoltaics on green flat roofs.

Participants: Bau- und Wohngenossenschaft KraftWerk1, Enecolo AG, TISO, E. Schweizer AG, M. Maier, S. Brenneisen.

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AUTONOME STROMVERSORGUNG MIT PHOTOVOLTAIK UND BRENNSTOFFZELLEN

Annual Report 2006

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Project- / Contract Number	47994 / 99095
Duration of the Project (from – to)	15.1 .2003 - 31.12.2007
Date	

ABSTRACT

In 2006, the project ‚Autonomous Energy Supply by Photovoltaics and Fuel Cell" had the following focus

- start of the operation of the new fuel cell SFC A50 R (Nr. 4) in the laboratory of the Swiss National Hydrological Survey (SNHS) of the Federal Office of Water and Geology (FOWG) in January 2006
- field tests in three sites under different conditions
- reporting of failures and problems in the field
- discussion for a collaboration with the University of Applied Sciences of Bern in Biel for a new hydrogen FC for contin0us operations
- contacts with three users for water level measuring systems (2x) and the autonomous energy supply for telecommunication with the fuel cell SFC AS0

The main focus of the year 2006 was the field test at the Swiss National Hydrological Survey (SNHS) of the Federal Office of Water and Geology (FOWG) with the new model SFC A50 R. The fuel cell worked under different conditions as a compact monovalent autonomous power supply. The fuel cell performed better than the year before but had still some problems. Together with the producer we try to overcome them. The SNHS decided to go ahead with this kind of autonomous power supply. In parallel they try to start a project with a hydrogen fuel cell. The basic units are tested at the University of Applied Sciences of Bern in Biel. Together with the producer, the problems have been analyzed, and finally in January 2006 a new SFC S0 model has been delivered with delays. Field tests started in spring 2006.

The information activities have been lowered due to the problems with the SFC A50 R. The interest in the combination of a fuel cell with PV is still remarkable. Nevertheless, as last year, we have to report, that the state of the art of this fuel cell is not applicable for normal customers. In the meantime the three SFC models are launched for the application in remote caravan vehicles (RCV). Here the SGF are in a constantly controlled environment.

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MESSKAMPAGNE WITTIGKOFEN

Annual Report 2006

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Project- / Contract Number	100035 / 150040
Duration of the Project (from – to)	January 2003 – December 2005
Date	2. April 2007

ABSTRACT

In December 2000, a PV Façade was constructed on one of 5 high-rise apartment buildings, which are situated to the east of Bern. For a few reasons, the planned measuring system could not be completed. In collaboration with the owner of the PV installation, the Hostettler engineering company started a project in order to complete the measuring system.

The goals of this project are as follows:

- Obtain general experience on high PV Façades
- Obtain specialized experience on the influence of special measures for fire-protection
- Create a basis for the planning of high PV Façades
- Furnish information to the owner and to the public

Upon completion, the measuring system was operational at the end of April 2003. At first, data was directly obtained on site. After a modem change, a connection by phone-line was established at the end of November 2003. Also, a display for information was designed by a commercial artist and put into operation at the end of November 2003.

At the beginning of October 2004, the battery-support for the datalogger failed and had to be changed. Because of this reason, there is a little gap in the measured data.

Unexpected software problems enforced further delay of the project. The final evaluation and discussion of the gained results in the final report will be expected until summer 2007.

Information to the public with the display will be continued and works without problems.

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SWISS PHOTOVOLTAIC INTERNET PORTAL

WWW.PHOTOVOLTAIC.CH

Annual Report 2006

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Project- / Contract Number	2726 / 152593
Duration of the Project (from – to)	
Date	March 2007

ABSTRACT

The main goal of the Swiss photovoltaic website www.photovoltaic.ch is to provide comprehensive information about national and international PV activities to a target audience with specific interest in this matter.

The site delivers detailed information about photovoltaics in Switzerland from a public authority perspective, namely the Swiss photovoltaic programme (including all annual and final reports of individual projects), the IEA PVPS Programme, information concerning the market development of PV, activities of public institutions, as well as from many national and international organisations, including the corresponding links etc. The whole website is designed to be user-friendly and features pictures, graphs and diagrams, making the content easy to understand.

Since autumn 2003, the German version of the site is fully operational. The English version is now completed and operational.

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SWISS SOLAR *ELECTRI*CITY GUIDE

PUBLIKATION „SOLARSTROM IN DER GEMEINDE“

Annual Report 2006

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Project- / Contract Number	100627 / 150824
Duration of the Project (from – to)	01.07.2003 - 31.03.2006
Date	December 2006

ABSTRACT

The Swiss Solar ElectriCity Guide was a follow-up activity of the European project “PV City Guide” supported by the Swiss Federal Office for Education and Science under contract no BBW 99.0569. The European project was finalised in 2002. The country-specific Swiss editions were supported within the frame of the SwissEnergy programme.

The objective of this Solar ElectriCity Guide was to provide local and regional authorities as well as related professionals (urban designers and developers, project developers and builders) an insight into the diversity of activities in the field of photovoltaics as well as information and instruments to set up and / or optimise activities that facilitate and enable the implementation of photovoltaics on the local level.

The Solar ElectriCity Guide was designed for practical use by the target groups. The international version of the Solar ElectriCity Guide in English has been thoroughly updated, completed and adapted to the Swiss context in close relationship with experts and actors from different areas and sectors in order to consider local needs, actions and policies.

The project “PV City Guide” resulted in an international Solar ElectriCity Guide. The Swiss editions in German and French were published in spring 2006. The adaptation of the international guide led to a guide covering the wide range of activities and relevant issues in the area of implementing photovoltaics on the local level in Switzerland. The work is the most comprehensive collection of information and illustrations on the Swiss PV landscape published so far.

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PHOTOVOLTAIC ENERGY STATISTIC OF SWITZERLAND 2006

Annual Report 2006

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Project- / Contract Number	40172 / 151364
Duration of the Project (from – to)	1. March 2005 to 30. Mai 2007
Date	Mai 2007

ABSTRACT

The project reported in this paper is the follow up work to the PV Energy Statistics and Quality Assurance Project mutually funded by the Swiss Federal Office of Energy and the Swiss Electricity Producer and Distribution Union of Switzerland. This work has determined key figures for both PV performance and overall PV electric energy contribution in Switzerland.

In 2006, about 250 new PV plants were connected to the grid in Switzerland; 50 more than last year. The Swiss PV Market's installed peak power of 2.5 MWp didn't reach last year's record of 4.3 MWp. However, considering actual market conditions, it's still a remarkable result.

On account of 3.5% higher irradiation in 2006, compared to that of the last 20 years, the annual yield of all Swiss PV installations reached 845 kWh/kWp; slightly higher than the annual average of about 800 kWh/kWp. The systems overall reliability and operational availability are still considered to be very good for these kind of technical systems.