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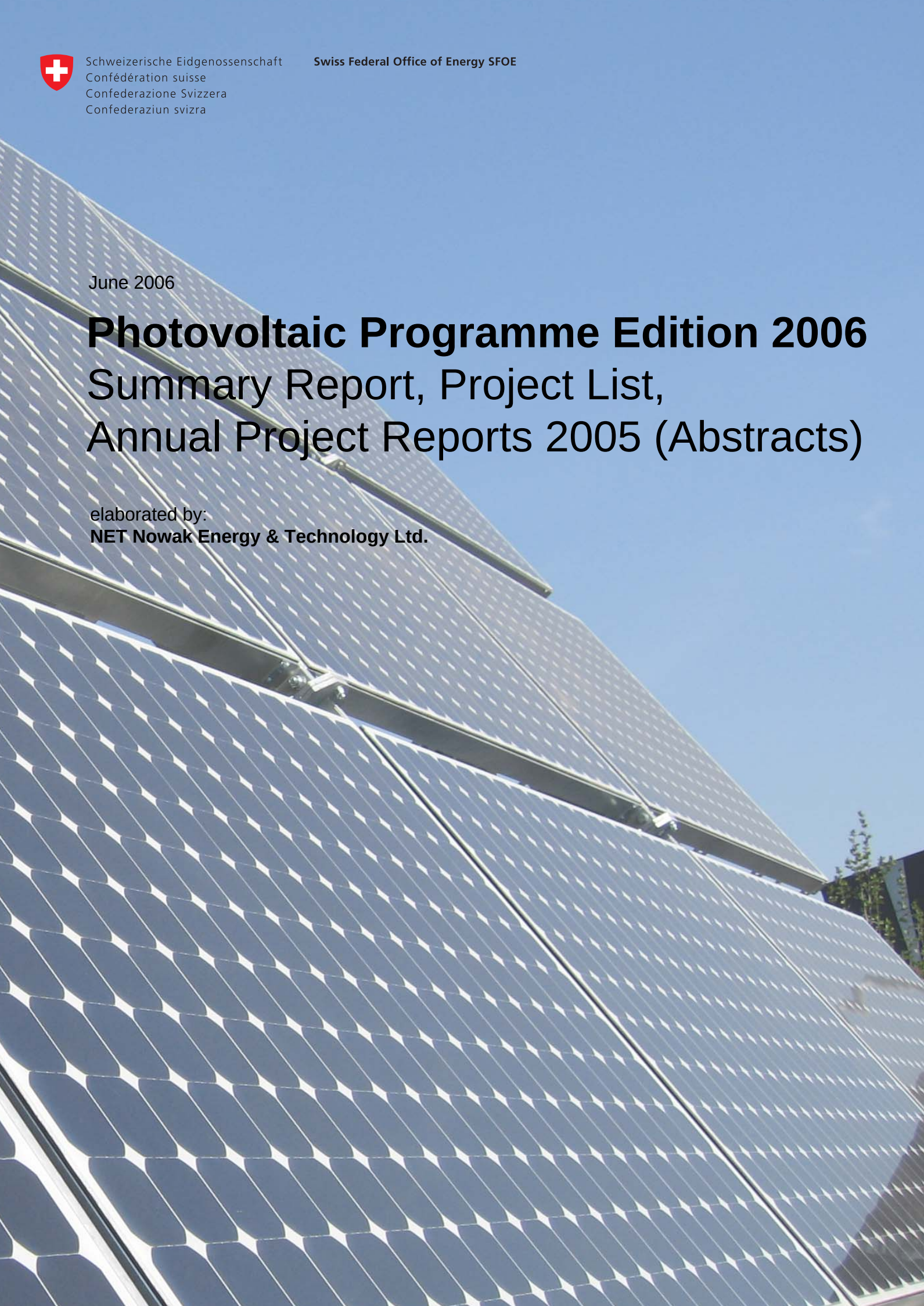

June 2006

Photovoltaic Programme Edition 2006

Summary Report, Project List, Annual Project Reports 2005 (Abstracts)

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(Photo: NET)

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

Swiss Federal Office of Energy (SFOE)
Programme manager Swiss federal photovoltaic RTD programme

PHOTOVOLTAICS

Summary Report on the Research Programme in 2005

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Photovoltaics made in Switzerland: from the laboratory to industry

The industrial implementation of thin film solar cells is making progress:

a) Laboratory deposition system at the Institut de Microtechnique, University of Neuchâtel (Photo: IMT).

b) 100 kW_p pilot production of flexible silicon solar cells on plastic at VHF Technologies (Photo: VHF Technologies)

c) Unaxis Solar KAI 1200 production installation for the mass production of thin film silicon solar modules (area 1.4 m^2, capacity of 550 modules / day) (Photo: Unaxis)

Contents Summary Report

1. Programme priorities and targets

In 2005, the Photovoltaics (PV) Programme continued to be affected by the economy measures of the 2003 Federal Relief Programme, especially in the area of pilot and demonstration (P+D) projects. In the area of research, the level was largely maintained through the programme's broad promotion base. The industrial implementation of previous research results remained a high priority. Despite the stagnant Swiss market, the continued growth in the international photovoltaics market has provided a foundation for the current significant expansion of the photovoltaics industry in Switzerland.

Thus the Photovoltaics Programme has remained closely oriented towards industrial implementation and international competitiveness, both for products and for the preceding research. In 2005 about 65 research and development activities and projects in the area of P+D installations 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) [70], the main objectives of the Swiss Photovoltaics Programme for the period 2004 to 2007 are [71]:

- A further cost reduction in photovoltaics energy systems (typical values for 2007: 2.5 CHF/Wp per module; 5 CHF/Wp per complete system) 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.

Therefore, the Photovoltaics Programme is divided into the following five sections:

Solar cells for the future

The work on **thin film solar cells** continued to focus on the principal areas: **silicon** cells (amorphous, microcrystalline), cells based on **compound semiconductors** (CIGS); and **dye cells.** The industrialisation of production processes, which has been pursued vigorously, is at an advanced stage for thin film silicon solar cells, and for composite semiconductors it is becoming a reality. Solar cells on flexible substrates are becoming increasingly important.

Modules and building integration

Furthermore, the **integration of photovoltaics** in the built environment 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 these, was a theme of continued and growing importance.

Electrical systems technology

Quality assurance of photovoltaic modules, power inverters and entire systems, together with **long-period observations** of these components, are themes of high relevance to practical application and they 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 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 are high priorities. This area of the programme also includes plans at the interface with other energy technologies.

International institutional cooperation

International cooperation forms an important aspect in all sectors. 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 report period. International cooperation continued at its customary successful level. During 2005, Swiss participation in new European networks (***PV-ERA-NET*** and the European Photovoltaics Technology Platform) was of paramount importance.

2. Work completed and results achieved in 2005

CELL TECHNOLOGY

In the report period, the **broad spectrum of Swiss solar cell research** was successfully pursued thanks to wide research promotion. 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. Thus Switzerland is now 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 Unaxis Solar (Trübbach, Neuchâtel) and VHF Technologies (Yverdon), are pursuing developments in the thin film silicon field, representing a mainstay of the Photovoltaics Programme.

During the reporting year, the IMT at the University of Neuchâtel began a new three-year phase of the project on **thin film silicon solar cells** [1]. The objectives of this SFOE project are to increase further the efficiency of solar cells on different substrates (goal of 14 % for micromorphous solar cells), to continue to develop the processing and characterization of solar cells and to ensure there is the necessary infrastructure (processes, manufacture and characterization) to support the industrial partners. Therefore, different deposition systems are being renewed and automated, the systems for the characterization of solar cells are being standardized, and particular emphasis is being put on the reproducibility of the individual production steps. Cooperation with industry is primarily with *Unaxis* and *VHF Technologies*, who are implementing the processes developed at the IMT into their products. The following results were achieved in the reporting year: on a transparent conductive oxide layer (TCO) of ZnO on glass micro-crystalline p-i-n (μc-Si:H) solar cells of 9 % efficiency and micromorphous solar cells of 11.6 % efficiency were produced. The range of important parameters (for example the fill factor FF or the open circuit voltage V_{oc}) was narrowed down. On PET films, for amorphous (a-Si:H) solar cells an efficiency of 7.3 % was achieved, for micro-crystalline solar cells 7.6 % and for micromorphous solar cells 8.3 %. Different measuring methods related to the analysis were developed and introduced as standard (VIM – variable illumination measurement, FTPS – Fourier transform photocurrent spectroscopy, IRLIT – infrared lock-in thermography).

The CTI project in cooperation with *Unaxis* for the **process of fast deposition of micro-crystalline silicon** [2] on the basis of KAI plasma deposition systems was continued in the reporting year. This work will lay the foundation for the large-area (1.4 m²) industrial production of micromorphous solar cells. At the research plant at the IMT, micro-crystalline silicon solar cells with 7.2 % efficiency were produced in 2005, and at *Unaxis* an efficiency of 9.5 % was achieved with micromorphous mini modules (10x10cm^2).

In a related CTI project, the CRPP at the EPFL and *Unaxis* have continued the development of a new, large area **VHF reactor for the deposition of amorphous and micro-crystalline silicon solar cells** [3]. Plasma excitation frequencies up to 100 MHz are being investigated. Whilst this permits rapid deposition ($\geq$ 4 Å/s), assuring homogeneity of the films over an area of $\geq$ 1 m² presents a major challenge. The formation of non-homogeneous zones in the layers was explained in the reporting year. Further work involves the process parameters, especially concerning the undesirable formation of silicon powder. This work is supplemented by a CTI project at the CRPP of the EPFL, in which a **numerical model for large area PECVD reactors** was developed [4]. This project was completed successfully in the reporting year.

Another CTI project involving a collaboration between the IMT and *Unaxis* deals with the **stability of transparent oxide layers** (TCO) of ZnO in laminated solar cells [5], especially in relation to the damp-heat test which is part of the IEC tests for solar modules (IEC 61646: 1000h at 85°C and 85 % relative humidity). It was shown that the stability required in the test is achieved.

The NTB in Buchs together with *Unaxis* successfully continued the CTI project for a spectrally resolved ***Spectral Response Measurement System*** (SRMS) geared to industrial production [6]. In 2005, two prototypes of this equipment were installed at *Unaxis* and initial experience has been very positive, especially as regards the stability of the measuring method. Therefore, full area measurements can be carried out on solar modules and images produced. These various CTI projects, together with the regular work at the IMT, constitute the basis for industrial implementation with a view to production installations for thin film silicon solar cells at *Unaxis*.

During the reporting year, the IMT together with *VHF Technologies* and other partners completed the CTI project for the use of **nanostructured optical gratings** to improve the qualities of flexible solar cells on plastic substrates [7]. The nanostructured plastic substrates (PET, PEN) were prepared by OVD Kinegram. At the IMT, amorphous solar cells with a stable efficiency of 7.3 % were produced on textured PET substrates. It was shown that the nanostructured substrates produced by OVD Kinegram are compatible with the manufacturing process of *VHF Technologies*. In the course of the project, *VHF Technologies* markedly improved its manufacturing process. Since autumn 2005, the IMT and *VHF Technologies* have continued to work on this topic in the new EU ***FLEXCELLENCE*** project [8]. It is the first time that a Swiss partner (IMT) is the project coordinator of an EU project in the area of photovoltaics.

During 2005, the IMT also took part successfully in the new EU ***ATHLET*** (*Advanced Thin Film Technologies for Cost Effective Photovoltaics*) project [9]. This Integrated Project, which is coordinated by the HMI in Berlin and is the largest research project so far on this topic in Europe, deals with two technologies in the area of thin film solar cells: micromorphous solar cells and CIS technologies (see below). Work on this began early in 2006 and will last for four years.

Crystalline silicon

HCT Shaping Systems is taking part in the EU ***BITHINK*** project [10], in which highly-efficient bifacial crystalline solar cells are being developed (efficiency 16+16 %). Czochralski-type materials and multicrystalline silicon are to be used. In the course of the project, the processes and the automated handling of solar cells less than 130 µm thick are being developed.

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 SFOE ***FLEXCIM*** [11] project, the development of flexible CIGS solar cells was further pursued in the report period. The 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 consistently achieved. The world record achieved in the previous year on polyimide for the efficiency of flexible solar cells on plastic of 14.1 % is still the highest value achieved. In the reporting year, work was done on scaling up the process to 30x30 cm^2. A new, industrially geared deposition system was made for this. Aluminium is being examined as a further substrate for flexible CIGS solar cells; this represents a new area with a great application potential. Because of the different expansion coefficients, the deposition process has to be carried out at lower temperatures. The best solar cell on aluminium achieved an efficiency of 6.6 % in the reporting year; still without using sodium.

The EU ***NEBULES*** project [12] on the topic of new buffer films for CIGS solar cells was completed in the reporting year. The ETHZ group concentrated on the structural, chemical and electronic characterization of solar cells in relation to various manufactured CdS and InS buffer films. In the reporting year, the boundary layers adjacent to the InS buffer films were analyzed in detail with regard to structure and composition. At the end of the project, there is a good overview of the different processes in these boundary layers.

The thin film physics group at the ETHZ has continued this work since autumn 2005 in the new EU project called ***LARCIS*** [13]. This involves the large area implementation of different key topics in industrial production. In the reporting year, the group also took part successfully in the new EU ***ATHLET*** project [14] *(see above)* and they will develop the part of this project for CIGS solar cells. The ETHZ spin-off business *FLISOM* was established in the reporting year, with a view to the industrial implementation of flexible CIGS solar cells.

Dye cells

At ISIC at EPFL, the development of dye-sensitized, **nanocristalline solar cells** [15] was further pursued. In the reporting year, the particle qualities of TiO_2 films were developed further. Dye synthesis and work on the electrolytes used concentrated on stability at high temperature (approximately 80°C). It is hoped to achieve a lifespan for the dye cells of 10 to 20 years.

The ISIC is working with *Greatcell Solar* on the CTI project to **increase the voltage** produced by dye cells [16]. The dye used plays an essential role here, and this was developed. Moreover, through *Greatcell Solar*, there is a direct link to the Australian technology business *Dyesol* [72], which announced in December 2005 the creation of a company for the production of dye cells in Greece.

The EU ***MOLYCELL*** [17] project is concerned with flexible organic solar cells, in which both purely organic, and hybrid nanocristalline organic, solar cells are being developed. The EPFL is especially interested in these cells, where a solid heterojunction is formed between nanocrystalline metal oxides and molecular or polymeric hole conductors. Light absorption is influenced by the molecular dye as well as the polymer. During the reporting year, the ISIC produced the first flexible dye cells on titanium films, and an efficiency of approximately 2 % has been achieved so far. Prototypes using a metal oxide-organic hybrid achieved an efficiency of about 4 %.

Solaronix is involved in the ***FULLSPECTRUM*** EU project [18], an Integrated Project in the area of photovoltaics, which brings together different approaches for better utilization of the solar radiation spectrum in a 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 in flat concentrators by means of luminescence layers.

In a CTI project, LTC at EPFL is developing **photovoltaically active textiles** [19] based on dye cells in collaboration with Konarka. It is expected that this work will lead to novel photovoltaics applications.

Antenna solar cells

Fundamental work continued at the University of Bern under the solar chemistry programme on **antenna solar cells** [20], with the financial assistance of the Swiss National Science Foundation. The objective is to develop a new type of dye-sensitized solar cell based on zeolite crystals. Fundamental work is concentrating on the question of how the arrangement of the crystals at the interface to the semiconductor material affects the electronic energy transmission. In the reporting year, four conceptual variations of thin film antenna solar cells were developed: A) sensitized solid solar cell, B) sensitized dye solar cell, C) sensitized plastic solar cell and D) thin film antenna tandem cells. For variant A the individual steps of the work were tested and submitted for patenting. It is now necessary to assemble the components to make a working solar cell.

SOLAR MODULES AND BUILDING INTEGRATION

Building integrated installations continue to represent the most important field of application of photovoltaics in Switzerland. Whilst the least expensive flat roof designs are often adopted by the solar stock exchanges, work on reducing the costs of more fully integrated systems is continuing. As, however, several successful mounting systems have now been developed (also see P+D section), the focus is increasingly shifting to the solar modules themselves.

In an SFOE project, *Swiss Solar Systems* (3S) studied the achievable increase in performance of crystalline solar modules using etched **reflection-free glass** (AR) [21]. To quantify the possible effects, etching was performed in an acid bath both before and after lamination. In both cases the measurements on solar modules produced with this glass showed a systematic increase in performance of approx. 2 %, whereas 3% was expected. Outdoor measurements at different angles of incidence show that the AR module can somewhat better exploit limiting cases with low angles of incidence. In the ***BIPV-CIS*** [22] EU-project, the objective is to enhance the quality of photovoltaics building integration 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.

Telsonic is engaged in the EU ***CONSOL*** [23] project to optimize the electrical contacting of CIGS solar cells. The technologies applied for this were: electrically conducting adhesive tapes, and ultrasound

welding. The main variables, adhesion and contact resistance, will be measured during the climatic tests, and then optimized for both technologies. The main focus at Telsonic, which is specialized in the manufacture of ultrasound welding equipment, will be to optimize this technology. The contact qualities that can be aimed for and the suitability of the procedures for different substrates were determined. The project was completed during the reporting year.

Finally, several new approaches and products for the integration of photovoltaics in buildings were tested in P+D projects (see corresponding section).

ELECTRICAL SYSTEMS TECHNOLOGY

The **main emphasis in systems technology** generally continues to lie on the quality assurance of components (modules, power 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 and the standardization of products.

In the report period, the LEEE-TISO Institute of SUPSI continued its test measurements on solar models in the **Centrale LEEE-TISO 2003-2006** [24] project. The laboratory, which is certified under ISO 17025 for measurements on class A solar simulators, was again the subject of an annual audit, which confirmed its precision level of ±1%. During the report period, over 2600 I-V characteristic curves (flash tests) were measured, of which 10% were performed for third parties. Measurements were made for comparison with those of other approved laboratories in Europe (ESTI-JRC and ECN), while the international round robin test of solar modules coordinated by NREL was continued. Laboratory measurements at the LEEE-TISO were reliable, with deviations of I_{sc}: -1.8 %, FF: 0.3 %, P_{max}: -0.6 %. For thin film modules, the laboratory now also has a procedure to take account of spectral deviation (spectral mismatch). The tenth test cycle of outdoor measurements on commercial modules began during the reporting year; 14 types of module were selected (8 mc-Si, 2 sc-Si, 1 HIT, 2 a-Si, 1 CdTe). Three instead of two modules are now being measured. The third module is measured for a short period on a Sun-Tracker, especially to determine the performance matrix $P_m(G_i,T_a)$. The recording of data and the Maximum Power Point Tracking (MPPT) have been rethought (see Fig. 1) and a spectroradiometer was reinstalled. In accordance with the strategy of the LEEE, in future the integration of photovoltaics into buildings is to be increasingly developed as a new topic.

LEEE-TISO is also participating in the EU **PV Enlargement** [25] project among 10 European countries, 5 of which are in Eastern Europe, comprising 32 installations with a total capacity of 1.15 MWp. In late 2005, a total of 20 installations representing 860 kWp were in operation. LEEE-TISO is responsible here for scientific supervision, particularly concerning calibration of the measuring systems and performance measurements on the modules. From the start of the project in January 2003, 151 out of 210 planned modules comprising various technologies (c-Si, a-Si, CIS, CdTe) and manufacturers were tested. In the first test cycle, 101 crystalline modules (17 different types) were measured and the initial degradation of the modules was quantified. Differences from the modules declared in accordance with new EU standard EN50380 were allocated to classes. So far, 50 thin film modules have been measured.

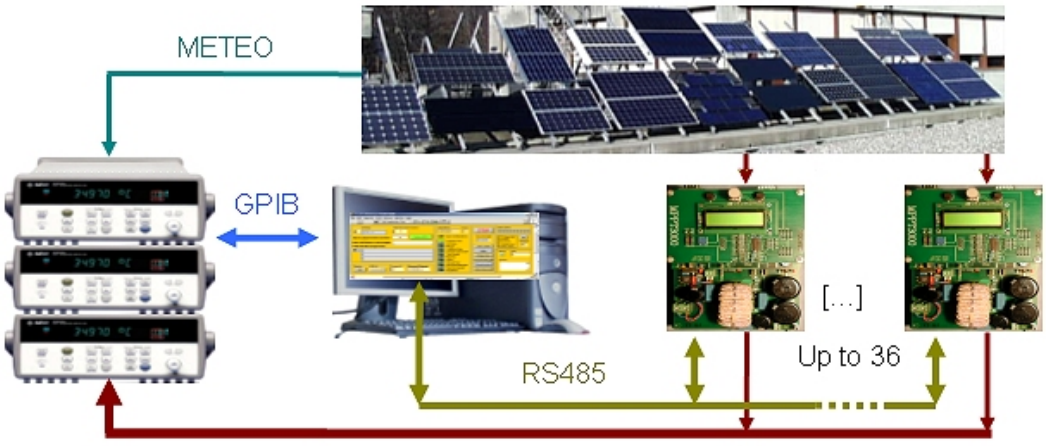

Figure 1: *Recording of data from measurements with new MPPT regulators (Photo: LEEE-TISO)*

In addition, during the reporting year the LEEE-TISO took part successfully in the new EU ***PERFORMANCE*** project (A science base on PV performance for increased market transparency and customer confidence) [26]. This Integrated Project, coordinated by the Fraunhofer Institute for Solar Energy Systems in Freiburg, is concerned with all prenormative work, from solar cells to systems and from instantaneous measurements to long-term analyses. The project is starting at the beginning of 2006 and will last for four years.

The project on ***photovoltaics systems technology PVSYTE*** [27] continued at the photovoltaics laboratory of Burgdorf Institute of Advanced Technology. A new 3·5 kW AC/DC source was integrated into the test programme for power inverters; enabling the behaviour of power inverters to be examined under unusual network conditions, (high or low voltages, strong coded control signals, low or high frequency, etc.). During the reporting year, the power inverter tests carried out so far were supplemented by measurements on the equipment currently produced by *Sputnik* and *ASP*. The individual, detailed power inverter test reports can be consulted [73]. In the sub-project concerning the long-term behaviour of PV installations, the failure statistics carried out since 1992 were continued. In the reporting year, the failure rate fell to 0.12 power inverter defect per year (see Fig. 2). The PV installation of 855 kWp at the *Stade de Suisse* in Bern was included in the measurement programme, so the programme includes a total installed capacity of 1.62 MWp (detailed measurement programme 1.52 MWp), and 62 power inverters. The results of measurements for the *Stade de Suisse* installation and other installations can be seen online [74] (see Fig. 3). Further detailed long-term measurements are taking place at the *Newtech* (thin film cells), Mont-Soleil and Jungfraujoch installations. At the Jungfraujoch installation, a new record energy yield of 1537 kWh/kWp was achieved in 2005.

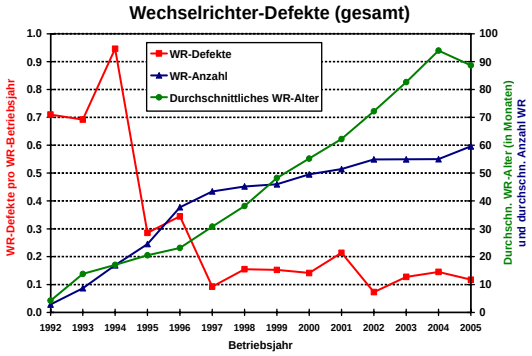

Figure 2: *Observed power inverter defects (Photo: HTI Burgdorf)*

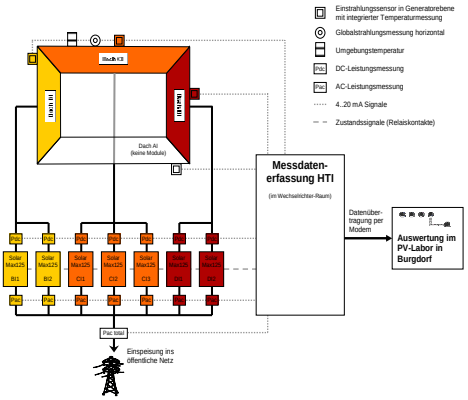

Figure 3: *Schematic diagram of Stade de Suisse (Photo: HTI Burgdorf)*

Solaronix is engaged in the EU ***EURO-PSB*** [28] project to develop a polymer solar battery. This is a small, self-charging battery for mobile applications. The principle lies in combining a novel polymer solar cell (organic solar cell) with a rechargeable lithium polymer battery. In this project, Solaronix is responsible both for the electrical circuitry between the solar cell and the battery, as well as for the entire unit. During the reporting year, functional prototypes (thermometers) were fitted with flexible solar dye cells on titanium films and with organic solar cells on glass. The project was completed during the reporting year.

FURTHER PROJECTS AND STUDIES

The LESO laboratory at EPFL is engaged in the EU **SUNtool** [29] project, embodying a universal tool for modelling sustainability in the urban environment. Typically, this can be applied to the analysis of the energy and material flows in a group of buildings or entire urban districts (< 1 km^2). The tool is based on comprehensive analytical models of the individual systems, and combines these in a single graphical user interface. For this purpose, EPFL is developing stochastic application models and has to a large extent validated them. The municipalities of Lausanne and Morges made data available for case studies. As a result of various delays the project will be completed in 2006.

Enecolo is engaged in the EU ***PVSAT2*** [30] project. In this, satellite-based performance monitoring is being further developed, firstly by the application of more precise data from satellites, and secondly by providing a central database for PV production data. Overall, the system should then provide a reliable and economic means of monitoring small-scale photovoltaic installations, for which on-site data acquisition would be too costly. During the reporting year, *Enecolo* concentrated on the fault detection routine developed in the PV-SAT procedure (faults in PV installations). The test phase showed that the PV-SAT-2 procedure is useful for long-distance monitoring of PV installations; various faults were detected (e.g. power limit resulting from low dimension power inverters, failure of power inverters, snow cover). The system can be further improved, especially with regard to data logging, the fault detection routine, the description of the equipment, the exclusion of errors that cannot be removed (for instance shade, degradation, the power inverter) and calculation of the radiation. The project was completed during the reporting year. For the commercial implementation of the results, *Enecolo* developed the new *SPYCE* [75] service together with *Meteotest*. Enecolo is also participating in the related esa **ENVISOLAR** [31] project. The task here is to process the data currently available to esa from terrestrial observations (http://www.eomd.esa.int) in a form geared to market conditions, particularly in relation to the theme of 'solar radiation for energy applications'.

The CUEPE at the University of Geneva is engaged in the EU ***Heliosat 3*** [32] project to determine the energy content of solar radiation based on Meteosat data. *Heliosat3* exploits among other sources the new Meteosat Second Generation (MSG) satellites to generate solar radiation data with higher temporal, spatial and spectral resolution. These data are required to improve the basis for decisions on investments, planning and management in the solar energy field. Suggested applications in photovoltaics are site optimization, and plant and network management (also see ENVISOLAR). During the last year of the project, particular focus was placed on the validation of the solar radiation scheme.

With the support of the interdepartmental platform (seco, SDC, SAEFL (now FOEN) and SFOE) for the promotion of renewable energies in international cooperation activities *REPIC* [76], CUEPE is developing a module for the *PVSYST* photovoltaic software [77], which simulates **photovoltaic water pumps** [33].

LEEE-TISO and Solstis are partners in the EU ***PV-Catapult*** [34] project. The objective of this interdisciplinary project is to identify and trigger market acceleration measures in a range of strategic sectors of photovoltaics, both in the fields of research, implementation and market activities. Among other things, a SWOT analysis of the situation in European photovoltaics was performed. Under the project, LEEE-TISO will deal with questions of performance measurement and prediction, while Solstis will assist in preparing a roadmap on PV-thermal hybrid collectors.

The PSI is participating in international work on the topic of thermophotovoltaics (TPV), through the ***FULLSPECTRUM*** [35] *integrated* EU project. Based on previous projects, in the thermophotovoltaics 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.

The highly symbolic ***SOLARIMPULSE*** project [36] of Bertrand Piccard and various partners continued during the reporting year. The goal of this project is to fly non-stop round the world using a photovoltaically powered aircraft. This is a major challenge from the viewpoint of materials and design, and also concerning the generation and management of energy under extreme conditions (e.g. UV radiation, humidity, temperature, frost, ageing and mechanical vibration). Alongside the extremely economical use of energy, the aircraft's photovoltaic generator will have to supply enough energy for the momentary needs of the motor, for heating and also for energy storage to cover night flying. The technical approach was developed in 2005. According to the current state of the work the aircraft will have a wingspan of 80m, a wing area of 220m^2, a weight of about 2 tonnes, 8 kg/m2 wing loading and about 40 kWp of PV capacity; the engine power should be 10 kW averaged over 24 hours. The aircraft should rise to 12,000 m by day and slowly descend at night.

INTERNATIONAL COOPERATION WITHIN IEA, IEC AND PV GAP

Over the report period, participation in the IEA (IEA PVPS) photovoltaics programme was characterized by continuity both at the project level and regarding Switzerland's membership in the executive committee (ExCo) [78]. Switzerland continues to chair this world-wide programme. During the reporting year, a common Swiss IEA PVPS pool was established to finance Swiss participation within selected projects of the IEA PVPS programme. This pool is currently supported by the electricity board of the City of Zurich (ewz), the Canton of Basel City and the *Mont Soleil* Association. Other partners are still under discussion and it is hoped to extend the number of partners. The intention of this pool is to ensure the involvement of different target groups in the work of the IEA PVPS.

In IEA PVPS Task 1, which is concerned with general ***information work*** [37], Switzerland is represented by Nova Energie. A further national report on the photovoltaics activities in Switzerland up to 2004 [79] was prepared during the report period. This formed the basis of the 10th annual international trends report on market developments in photovoltaics in IEA countries [80]. The report was used during the report period particularly for the ongoing analyses of the photovoltaics industry on the part of the financial sector [81, 82, 83]. In the reporting year, at the 20th European Photovoltaics Conference in Barcelona a workshop was organised under Swiss management on the topic of environmental aspects of photovoltaics. The PVPS programme will pursue this topic further, possibly as new task. The *IEA PVPS Newsletter* [84] provides information at regular intervals on the work of the IEA programme and associated themes.

TNC is responsible for the Swiss contribution to IEA PVPS Task 2 on ***operating experience*** [38]. The PVPS *Performance Database* (edition June 2005 [85]) was enlarged to include new data, and now covers 431 photovoltaic installations in 21 countries, involving a total of around 15 500 monthly data sets and 12.3 MWp of installed capacity. The data base contains 64 installations from Switzerland, with a total capacity of 2 MWp. In one sub-task, a broad base of information and data is being created concerning the prices and maintenance costs of PV systems. Project data and running data that are available can be input for a global economic survey [86]. The data collected in this way, from as many regions of the world as possible and from as many different time periods as possible are analyzed under Task 2 as regards changes in life cycle costs.

Under the interdepartmental REPIC platform to promote renewable energies in international cooperation [76], which comprises seco, SDC, SAEFL (new FOEN) and SFOE, entec is responsible for the Swiss contribution to IEA PVPS Task 9 on **photovoltaic services for developing countries** [39]. Switzerland is responsible for coordination with bilateral and multilateral organizations. In the reporting year, workshops were held in Vietnam, Burkina Faso and China in the framework of this project together with the usual project meetings. Task 9 was also represented at conferences in Bangkok, Washington and Barcelona.

Meteotest [40] and the CUEPE at the University of Geneva [41] together produce the Swiss contribution to the new Task 36 (S*olar Resource Knowledge Management)* of the IEA SHC programme. The purpose of this project is to rework the different methods and basic data on solar energy 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 cooperation with the other IEA programmes on solar energy (IEA PVPS and IEA PACES).

Alpha Real represents Switzerland in TC 82 of the IEC in the name of the SOLAR (now SWISSOLAR) association, and heads the working group to prepare and issue **proposals for international standards** [42] for photovoltaic systems. Alpha Real is also participating in the work of *PV-GAP* [43] (PV Global Approval Programme), a worldwide programme on quality assurance and certification of photovoltaic systems.

Swiss participation in the EU ***PV-ERA-NET*** project [44], which brings together the programme coordination offices and responsible ministries of 13 countries under the ERA-NET scheme [87], was ensured by the photovoltaic programme management (SFOE, *NET Nowak Energie & Technologie*). In this project, Switzerland leads the main piece of work for the exchange of information on European photovoltaic programmes. In the reporting year, detailed reports about the orientation and contents of these programmes were compiled and analyzed with a view to reinforcing cooperation [88].

3. National cooperation

At the national level, the diversity of cooperative effort within the various projects was upheld over the report period. Involved in this were the federal institutes of technology, cantonal universities, the universities of applied science, the research institutes and industry. Furthermore, cooperation with private companies was intensified, showing that interest in photovoltaics has remained unbroken despite stagnation in the Swiss PV market.

At programme level, cooperation was maintained with numerous federal agencies, cantons and the electricity industry. In this connection, the constant interchange with the State Secretariat for Education and Research SER, CTI, SAEFL (new FOEN), SDC and seco, and also with the electricity industry SESA, the *swisselectric* and the Mont Soleil Association, is worthy of special mention. The many contacts made in this way helped to provide a broader base for programme activities – an ever increasing important aspect. The IEA PVPS pool, which was created during the reporting year, should be mentioned as an example of this successful cooperation (see above).

4. International cooperation

International cooperation continued over the report period in its many traditional ways. The institutional cooperation taking place within IEA, IEC, PV GAP and the European network projects was mentioned. At project level, cooperation within the EU on new and existing projects continued in 2005. In 2005, there were 16 projects in the 5th and 6th Framework Research Programmes of the EU, and participation in two new integrated projects started at the beginning of 2006. Another project was carried out with the esa. Thus Swiss photovoltaics have been very successful in their involvement in the 6th Framework Research Programme of the EU. A regular interchange takes place with those responsible for PV RTD programmes in EU countries and with the teams responsible in the European Commission.

Following *A Vision for Photovoltaic Technology* [89], a report of the *Photovoltaic Technology Research Advisory Council (PV TRAC)* of the European Union, the European Photovoltaic Technology Platform [90] was established in 2005. Technology platforms are new instruments to enable certain technologies to extend their range of support and to enable those involved to have a common strategy. Typically, research circles, industry, the financial sector and state authorities join together to support a platform, and the necessary R+D efforts and implementation measures are coordinated. The involvement of industry is particularly important, and plays a fundamental role in the technology platforms. Also, a strategic research agenda is defined and implemented through the technology platform. This is especially important for photovoltaics to prepare the 7th Framework Research Programme of the EU. The creation of this Photovoltaics Technology Platform underlines the long-term strategic importance of photovoltaics. Switzerland is represented both on the steering committee and in working groups.

Further contacts were maintained with the international organizations concerned with development cooperation (World Bank, GEF, IFC, UNDP, GTZ, KfW, REEEP, etc.). Thanks to the multiplicity of these interchanges, Swiss photovoltaics has remained very prominent on the international stage.

5. Pilot and demonstration (P+D) projects

The cut-backs made in the 2003 Federal Relief Programme have had a particularly marked effect on P+D projects since 2004. This has had a drastic effect on the photovoltaics programme. In the 2005 reporting year, as in 2004 **no new P+D projects** could be supported with SFOE funding. This is highly regrettable, because it greatly weakens an essential link in the chain of implementation of research and development in industrial products and procedures, and thus to the market. This is detrimental to the photovoltaics programme at a time when implementation should be reinforced after a long preparatory period.

Indeed, the world-wide market for photovoltaics is booming, with an annual rate of growth of 35 % and more, as a result of large-scale promotion programmes and feed-in tariffs in many countries. In 2005, worldwide production of modules reached more than 1500 MWp. This currently provides a good opportunity for exports of innovative products. In contrast, the Swiss photovoltaic market has stagnated for about 10 years around 2 MWp/year. In 2005, thanks to the initiative of some innovative suppliers of electricity leading to a number of larger utility driven projects, the market volume reached more than 4 MWp.

The remaining photovoltaic P+D projects mainly continue to focus on the **integration of photovoltaics in buildings**, especially installations on flat roofs and the use of thin film modules.

OVERVIEW OF SOME P+D SUCCESSES IN RECENT YEARS

A selection is given here of **photovoltaic P+D projects** which have been successful in recent years, and which were either implemented sustainably in the market, or received awards for innovation.

The *Sarnasol* system was first tested using the 15 kWp installation in Trevano at a scale of 1:1, and consists of amorphous thin film cell modules combined with a tight flexible polymeric roofing membrane [45]. It is now marketed by Sarnafil in collaboration with *Solar Integrated*, under the name of *SmartRoof*! ®. So far, several installations have been produced successfully with this system (see Fig. 4).

After some delay, the 'Montagesystem AluTec' project [47] (concluded in 2002) and the new development of 'Montagesystem AluStand®' [48] (see Fig. 5) were implemented successfully. In 2005 profiles corresponding to a PV capacity of 10 MWp were sold, mainly in Germany. Since the introduction of this system on the market, installations with a total capacity of about 30 MWp have been installed.

Figure 4: *188 kWp "Smart Roof" in Fulda (Photo: Sarnafil)*

Figure 5: *Hünenberg 27 kWp Alustand installation (Photo: Urs Bühler Energy Systems)*

Figure 6: *Solarmax 2000 / 3000 (Photo: Sputnik Engineering)*

Figure 7: *5 MWp Sonnenfleck roof integration (**www.sonnenfleck.com**)*

Over the years, the Sputnik Engineering company showed in an exemplary way in the field of inverter technology, how the research and P+D project sequence from early development in collaboration with Biel University of Applied Science can take place. They subsequently developed prototypes and carried out intense practical testing. Today, SolarMax® appliances (see Fig. 6) are number 3 in the European inverter market. In 2005, power inverters were produced corresponding to an installed PV capacity of approximately 125 MWp. Sputnik and their suppliers currently employ about 120 people in Switzerland and other countries.

Another example from the list of successful projects is the photovoltaic P+D 'SOLRIF® roof integration frame developed in collaboration by the two companies Schweizer Metallbau and Enecolo [51] (see Fig. 7). Since its market introduction, SOLRIF® frame for roof-integrated installations with a total output of over 10 MWp have been delivered in Europe.

As shown by the examples SolarMax®, SOLRIF® and AluStand®, innovative photovoltaic research and P+D projects were repeatedly the basis for successful implementation of products in the domestic market and for export.

CURRENT P+D PROJECTS

Among the current projects, the integrated 15.4 kWp flat roof installation of CPT Solar (Centro professional Trevano) with amorphous thin film cells [45] (see Fig. 8) showed the potential of this approach. The high specific energy yield achieved so far of over 1000 kWh/kWp, (2004: 1070 kWh/kWp; 2005 1077 kWh/kWp) is based on the optimal planning and design of this installation with modules that are almost horizontal (3°).

The analyses taking place until summer 2006 on the 25 kWp 'Solgreen Kraftwerk 1' green roof installation [49] (see Fig. 9) clearly show that the combination of a green roof and photovoltaics represents a successful variation from the point of view of the generation of solar energy and that of green roofs. At approximately 1000 kWh/kWp, the annual energy yield is comparatively high. The pH observed is approximately neutral for all substrates used as soil and is not a problem for the supporting sub-structure anchored in the ground. The amount of vegetative growth that occurs depends on the substratum used. On nutrient-poor areas, no plants crossed the lower edge of the modules, whereas on test areas rich in humus, a few taller plants appeared here and there, and they were removed to prevent shading.

Figure 8: *5.4 kWp flat roof integration CPT Solar (Photo: NET)*

Figure 9: *Solgreen Kraftwerk 1 (Photo: NET)*

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) [52]

Installations

- 15.4 kWp flat roof integration CPT Solar (pilot application of a newly developed combination of amorphous thin film modules with thick plastic sheeting. Management: LEEE-TISO) [45] (see Fig. 8)
- Stand-alone 5.7 kWp photovoltaic installation in combination with a CHP (all year round stand-alone energy supply for 2 houses using photovoltaics, CHP, thermal collectors and wood. Management: A. Reinhard). [54]
- 17.6 kWp flat roof installation with thin film modules at ETH Zurich (optically unobtrusive flat roof integration with amorphous cells. Management: BE Netz) [55]
- 12 kWp Solight pilot plant (pilot application of two different Solight variants, Management: Energiebüro) [56]
- Small stand-alone photovoltaic and fuel cell power supply (small PV island systems with fuel cells for backup electricity supply to the remote stand-alone measurement systems in pilot operation. Management: Muntwyler Energietechnik) [58]
- 25 kWp Solgreen Kraftwerk 1 green roof installation, Zurich (exploratory use of a newly developed support module for green roofs. Management: Enecolo) [49] (see Fig. 9)

Measurement campaigns

- Wittigkofen measurement campaign (detailed measurements and evaluations with data visualization on the 80 kWp facade in Wittigkofen. Management: Ingenieurbüro Hostettler) [59]

Studies - tools - various projects

- Swiss photovoltaic statistics 2005 (Management: Ing. Büro Hostettler) [60]
- Solar electricity from the utilities (Management: Linder Kommunikation) [61]
- Solar *Electri* City Guide – Swiss solar electricity guide for municipalities. (Management: NET) [62]
- Solar energy potential in Geneva (study of the area potential for thermal solar installations and photovoltaic installations in buildings owned by the public authorities in the Canton of Geneva). (Management: *NET*) [63]

PROJECTS COMPLETED IN 2005

The following P+D projects were completed in 2005 (in chronological order):

Installations

- 23.5 kWp PV installation in Zollhof in Kreuzlingen (flat roof demonstration installation with demo stand and large display panel at well frequented site. Management: Böhni Energie und Umwelt) [64] (see Fig. 10)
- 62 kWp flat roof installation with PowerGuard solar roof panels (multifunctional PV flat roof installation with integrated thermal roof insulation, where the panels serve the dual function of thermal insulation and support structure for the modules. Management: Zagsolar [53] (see Fig. 11)
- Corviglia cable car photovoltaic installation and Piz Nair installation in St. Moritz (implementation of a 17.8 kWp installation along the Corviglia cable car and a 9.7 kWp facade integrated installation in the lower and 13.5 kWp installation in the summit station on Piz Nair. Management: SunTechnics Fabrisolar) [65]
- 27 kWp AluStand installation in Hünenberg (demonstration plant using the flat roof version of the AluTec module support system (AluStand). Management: Urs Bühler Energy Systems and Engineering) [48] (see Fig. 5)
- 3 kWp installation at Amburnex farm (mobile island installation with auxiliary diesel generator supplying electric power to an alp, stand-alone installation. Management: Services Industriels Lausanne) [66]
- RESURGENCE – Renewable Energy Systems for Urban Regeneration in Cities of Europe (realisation of a total of 1.3 MWp PV installations in city areas in the 5 countries of Great Britain, the Netherlands, Denmark, Germany and Switzerland, EU project. Management of the Swiss part: Enecolo) [50]

Measurement campaigns

- Migros PV ThinFilm test, Zurich (18 test installations with PV thin film modules in juxtaposition. Total capacity: 24.5 kWp. Management: Energiebüro) [57] (see Fig. 12)
- 100 kWp Monitoraggio dell'impianto AET III PV installation (detailed measurement campaign on the renovated 100 kWp PV installation along the SFR Bellinzona-Locarno railway. Management: LEEE-TISO) [46] (see Fig. 13)
- Measurement campaign on the 100 kWp installation along the A13 (Management: TNC Consulting) [67]

Studies - tools - various projects

- Integration of the new IEC photovoltaics standard 60364-7-712 in the national installation standards NIN (amendment or replacement of the older PV installation standards. Management: Electrosuisse) [68]
- GISS building integrated solar electricity systems (study on improved implementation of building integrated solar electricity systems through reduction of administrative hindrances, information bottlenecks and higher professional competency of planners, investors and promoters. Management: SZFF Schweizerische Zentralstelle für Fenster- & Fassadenbau) [69]

Figure 10: *PV installation on Kreuzlingen Zollhof (customs building) (Photo: NET)*

Figure 11: *62 kWp flat roof installation with Power Guard solar roof panels (Photo: Zagsolar)*

Figure 12: *PV ThinFilm test (Photo: NET)*

Figure 13: *Monitoring campaign at the 100 kWp AET III PV installation (Photo: TISO)*

6. Assessment of 2005 and prospects for 2006

Globally, 2005 was an extremely successful year for photovoltaics. The photovoltaics industry continued to expand in a high-growth market. The analysis of the industrial sector published by the Regional Bank of Baden-Württemberg [81] summarised this development by: "the industrial age has begun". However, the rapid growth has created a bottleneck in the availability of raw silicon. This situation has exerted enormous pressure on the industry: production capacity has not been fully utilised, it has not been possible to deliver products, and prices have risen. But silicon is not a scare commodity; it is to be found "like sand on the beach". However, as a result of the rapid growth in the photovoltaics market, there has been a shortage of raw silicon sooner than anticipated, and earlier than the new additional silicon production capacity was ready. It is generally expected that this situation will cease during 2006 and that an improvement will begin in 2007 at the earliest. On the contrary, for thin film solar cells, this tense situation creates an interesting "window of opportunity".

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 internationally, based on broad support. The numerous CTI and EU projects show industrial implementation and international orientation. However, there are marked disadvantages for implementation in Switzerland as a result of the lack of funding for P+D projects and the stagnant market. Despite these difficult conditions, industrial

photovoltaic activities are also growing in Switzerland. Based on surveys, exports of Swiss photovoltaics for 2005 were estimated to be at least 80 million CHF. Together with the domestic market, the total for Swiss photovoltaics was estimated to be at least 100 million CHF.

The efforts made so far in the Swiss Photovoltaic Programme constitute the scientific and technical starting point for innovations and products to be present in the rapidly growing photovoltaics market. Long practical experience with the construction and running of numerous photovoltaic installations produced important findings, which have resulted in the reliability of installations and high specific energy production. Thus there are the technological prerequisites for Swiss photovoltaics - with their scientific and technical know-how and their products - to be competitive and successful at the international level.

In addition to the fact that Switzerland is at a disadvantage compared with other countries regarding the basic conditions of the market, a similar trend has recently become apparent in the area of research. International surveys show that expenditure for photovoltaic research is increasing in many countries and the importance of research is generally on the rise. This is underlined by the creation of the European Photovoltaics Technology Platform. However, the situation in Switzerland is becoming more and more difficult, despite broad support for the programme. This creates further discrepancy at the international level, which does not do justice to the performance of Swiss photovoltaics, in research or in industry. Swiss photovoltaics have very good international relations at all levels, and their know-how is acknowledged world-wide, so they have the potential to play an important part in the rapidly expanding market.

The photovoltaics programme will continue to strive to preserve a critical size through broad financial support. To do this, all possible promotion mechanisms have to be exploited, and these should be optimally coordinated and well-targeted. However, this alone will not suffice to implement the potential of Swiss photovoltaics sustainably. There is a need for appropriate measures and for a reversal of the change in financing, to allow Swiss photovoltaics to keep up internationally in research. In recent years, Swiss photovoltaics have produced impressive proof that they are among the top performers, which justifies courageous steps in this direction.

In April 2005, EMPA organised a technical seminar on solar cell research [91]. Swiss photovoltaics were also well represented by contributions at the 20th European photovoltaics conference held in Barcelona in June [92]. In November 2005, the 6th National Photovoltaics Convention was held at the SIG in Geneva, and it was particularly well attended by representatives from industry [93]. The national information and experience exchange remains an important topic in Switzerland. The photovoltaics webpage http://www.photovoltaic.ch contains all relevant information and reports, serving as an important source of information, which is regularly updated.

7. List of R+D Projects

(AR) Annual Report 2005 available
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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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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.energie-schweiz.ch
CRPP	The Plasma Physics Research Centre of Switzerland EPFL	http://crppwww.epfl.ch
CTI	The Innovation Promotion Agency	http://www.bbt.admin.ch/kti/index.html?lang=en
CUEPE	Le Centre universitaire d'étude des problèmes de l'énergie	http://www.unige.ch/cuepe
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
HTI Burgdorf	Berne University of Applied Sciences / School of Engineering and Information Technology	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	http://isic.epfl.ch
LEEE - TISO	Laboratory of Energy, Ecology and Economy - Ticino	http://www.leee.supsi.ch
LESO	Solar Energy and Building Physics Laboratory EPFL	http://lesomail.epfl.ch/
LTC	Laboratory of Polymer and Composite Technology EPFL	http://dmxwww.epfl.ch/ltc/ltc_main.htm
NIN	Low Voltage Installation Standard	http://www.electrosuisse.ch/
NTB	Interstate University of Applied Sciences of Technology Buchs	http://www.ntb.ch
PSI	Paul Scherer Institute	http://www.psi.ch
SAEFL	The Swiss Agency for the Environment, Forest and Landscape - New: Federal Office for the Environment	http://www.umwelt-schweiz.ch/buwal/eng/index.html
SDC	Swiss Agency for Development and Cooperation	http://www.deza.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
SIG	Services Industriels de Genève	http://www.sig-ge.ch/
SUPSI	The University of Applied Sciences of Southern Switzerland	http://www.leee.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/Renewable_Energies.85.0.html
GEF	Global Environmental Facility	http://www.gefweb.org
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit	http://www.gtz.de
IEA	International Energy Agency	http://www.iea.org
IEA SHC	IEA Solar Heating and Cooling	http://www.iea-shc.org/
IEA PACES	SolarPACES	http://www.solarpaces.org/
IEA PVPS	Photovoltaic Power Systems Implementing Agreement (IEA)	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
NREL	National Renewable Energy Laboratory	http://www.nrel.gov/
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

	Unaxis	http://www.unaxis.ch

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
	Swiss Federal Office of Metrology metas	http://www.metas.ch/
	Swiss Education and Research Network Switch	http://www.switch.ch
Swissolar	Swiss Task Force for Solar Energy Swissolar	http://www.swissolar.ch
SOLAR	Swiss Professionals Association for Solar Energy, from 01.01.06 Swissolar	http://www.solarpro.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/

Annual Report 2005

Thin film silicon solar cells: advanced processing and characterization

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Project- / Contract Number	OFEN 101191 / 151399
Duration of the Project (from – to)	1.01.2005-31.12.2007

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 (process 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 standardize new advanced characterization systems
- Work on process reproducibility by revisiting several fabrication steps, from solar cell patterning to individual layer optimization.

In 2005, an important step was achieved by fabricating for the first time high efficiency p-i-n micro-crystalline (9%) and micromorph tandem solar cells (11.6% initial) directly on LPCVD-ZnO coated glass substrates. The ZnO layers were specially tailored to allow the fabrication of high efficiency devices.

Using “industry compatible” processes, high efficiency 7.3% amorphous single junction, and 8.3% micromorph tandem solar cells were prepared on plastic textured PET substrates, whereas microcrystalline cells with 7.6% efficiency could be prepared on flexible steel foils.

The projects with industrial partners could directly benefit from this SFOE project, using both the know-how gained in processing and the new infrastructures of the laboratory (deposition and characterisation systems).

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Annual Report 2005

High rate deposition of µc-Si:H silicon thin-film solar cell devices in industrial KAI PE-CVD reactor

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Project- / Contract Number	6928.1 IWS-IW
Duration of the Project (from – to)	1. March 2004 – 28. February 2006

ABSTRACT

The scope of this CTI project is twofold: the **first** task is 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 1400 cm^2: the latter corresponds to the size of industrial deposition equipment sold by UNAXIS AG. The **second** task of the present project is 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 should typically be 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, UNAXIS KAI PE-CVD 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 development of a fabrication process for microcrystalline silicon solar cells on the same industrial reactor is 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 Unaxis. A successful conclusion of the project will allow for cost-effective production of micromorph modules in the future.

The work executed in the second half of this project has focused entirely on device optimisation: the parameter space for deposition conditions has been successfully scanned and both doped and intrinsic layers can now be satisfactorily fabricated. Our sofar best devices have a conversion efficiency of 7.2% (in 2004, 5.5%), with an absorber thickness of 1 µm and a deposition rate of 0.7 nm/sec. The devices are fabricated in the KAI-S reactor at IMT using thereby a single-chamber process (i.e. the sample remains in the chamber during the whole processing cycle).

The know-how transfer from IMT to the industrial partner has 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. Unaxis 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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Annual Report 2005

A new large area VHF reactor for high rate deposition of micro-crystalline silicon for solar cells

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Project- / Contract Number	KTI 6947.1
Duration of the Project (from – to)	1.5.2004 - 30.04.2006

ABSTRACT

A novel very high frequency (VHF) plasma source shall be 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, is solved by using adequately shaped electrodes. The proof of principle of this new reactor has up till now only been made in non-reactive plasmas. In the present project, the novel RF reactor design shall be used for the first time in applications, in particular for solar cell production. The aim is 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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Annual Report 2005

Numerical Modelling for large area plasma enhanced chemical vapour deposition (PECVD) reactor development

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Project- / Contract Number	KTI 6236.2
Duration of the Project (from – to)	1.4.2003 - 1.04.2005

ABSTRACT

Since the substrate size used in the flat panel industry is rapidly increasing, the use of numerical simulation for the development of the PECVD reactors will help the industrial partner UNAXIS Displays to reduce their development cost and to speed-up the reactor upscaling and design, leading to earlier market penetration, higher market share and therefore the guarantee of long-time survival of the activity of UNAXIS in the AMLCD machine business.

A numerical model for Plasma Enhanced Chemical Vapour Deposition (PECVD) processes in large area rectangular reactors has been developped. This model is able to predict the uniformities of the film thickness and composition over the substrate area as a function of the process conditions and reactor geometry. The numerical results have been validated for a-SiN:H PECVD with experiments performed on the existing industrial KAI type reactors of UNAXIS Displays. This numerical model, developped by the CRPP, can now be used to improve the geometrical design and process conditions of the next larger reactor generation in order to reduce the film thickness and composition non-uniformities.

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Annual Report 2005

Stability of advanced LP-CVD ZnO within encapsulated thin film silicon solar cells

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Project- / Contract Number	KTI 7253.2
Duration of the Project (from – to)	01.11.2004 – 31.10.2006 (2 years)

ABSTRACT

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

During the year 2005, the degradation mechanisms of ZnO material have been studied in details and some means to improve the stability of ZnO have been tested. Some of these treatments have been found to improve in a significant manner this stability.

In parallel, encapsulation tests have been done, which lead to PV modules that stay stable when submitted to a humid environment. In particular amorphous Si modules with size from 10x10 cm^2 to 1.4 m^2 successfully passed the so-called damp-heat test (exposure to 85% humidity at 85°C during 1000 hours), with degradation below 1%.

The year 2006 will be dedicated to continue to improve the ZnO stability, in order to be able to simplify the encapsulation step.

Annual Report 2005

Spectral photocurrent measurement system of thin film silicon solar cells and modules

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

ABSTRACT

The goal of our industrial project partner UNAXIS SOLAR is to become the leading equipment supplier for thin film silicon solar cells. 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 tools. Today, there is no commercial Spectral Response Measurement System (SRMS) for thin film cells and modules available.

The goal of the present project is to develop an accurate, reliable and fast scan SRMS to analyse 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 with the main focus to develop a mass production line.

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. First mapping results of the spectral photocurrent on a test module were successfully demonstrated.

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Annual Report 2005

Optical nano-gratings and continuous processing for improved performance flexible solar cells

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Project- / Contract Number	CTI 7013.1
Duration of the Project (from – to)	01 01 2004 – 01 07 2005

ABSTRACT

The Swiss company VHF-Technologies S.A. is currently developing a roll-to-roll continuous production line for thin film amorphous silicon (a-Si:H) solar cells on flexible substrates. The goals of the reported project were to enhance the quality/price ratio of photovoltaic modules produced by VHF-Technologies as well as to open-up the promising market for flexible photovoltaic elements.

With the goal of enhancing the performance of the photovoltaic modules, the possibility to increase the photo-generated current by using nano-structured gratings promoting light trapping into the flexible solar cells was exploited. Simultaneously, the series connections and current collection were improved in the completed solar modules. In order to reduce the fabrication cost, more cost-effective substrates (PET or PEN instead of polyimide), faster structuring methods and better-adapted VHF electrodes were investigated.

Different nano-structured gratings, produced by OVD-Kinegram A.G. through a roll to roll process, were tested as substrate for solar cells. The most remarkable result, in term of light-trapping, is an increase of the photo-generated current density (J_{sc}) of 15%, as compared to the J_{sc} of the best cell on the reference flat substrate. At the moment, laboratory-scale a-Si:H solar cells with 7.3% stable efficiencies have been obtained at IMT on a back reflector fabricated at VHF-Technologies (Al-based reflector coated on textured PET foil). All the experiments were realized with a fabrication process compatible with the one running at VHF-Technologies S.A.

Furthermore, VHF-Technologies showed that PET and PEN substrates with gratings, as supplied by OVD-Kinegram A.G., are compatible with their fabrication process on the production line. The series resistance and the “dead surface” of the modules were reduced, a full roll-to-roll process for interconnection was implemented and a new VHF-electrode with an improved design was installed in the reactor at VHF-Technologies. In that way, higher reliability of the process, higher environmental stability, higher yield and higher efficiencies were obtained. Overall, the performance in the production of the 28cm x 60cm standard module product was increased from 5 Watt (2.9%) at the beginning of the project to 7 Watt (4.1%) at the end of the project.

Besides, a new stable and thoroughly tested code was developed at PSI in order to calculate the dimensions of the gratings for optimum light-trapping into cells (essentially arbitrary 1-dimensional grating structures).

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Annual Report 2005

Flexible CIGS solar cells and mini-modules (FLEXCIM)

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Project- / Contract Number	100964 /151131
Duration of the Project (from – to)	01.03.2004 – 30.04.2006

ABSTRACT

Thin film Cu(In,Ga)Se_2, called CIGS, solar cells are known for high efficiency, long term stable performance and potential for low cost solar electricity generation. CIGS solar cells on metal and polymer foils offer several advantages: They are flexible, lightweight and can be manufactured with roll-to-roll deposition processes. The roll-to-roll production is potentially low cost, 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 metal foils of 5 x 5 cm^2 size by using vacuum evaporated CIGS layers and applying a patented process, developed by ETHZ, for controlled and reliable incorporation of Na in CIGS. This low temperature CIGS deposition process offers several advantages for development of high efficiency solar cells on different substrates. In the report of 2004 we reported the development of 14.1% flexible solar cell on polyimide foil. This efficiency measured under AM1.5 illumination at ISE-FhG, Freiburg, Germany is a highest 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. We have grown CIGS layers at different substrate temperatures and investigated the properties of evaporated CIGS layers by different methods (SEM, SIMS, EDX). 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.

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 with self designed and constructed mechanisms for substrate heater, in-line movement of heated substrates, linear thermal evaporation sources. Testing of evaporation sources and other mechanisms has started. Development of large area flexible solar cells and mini-modules has also started, and as a proof of concept flexible mini-modules to run small ventilator-fans have been developed.

Annual Report 2005

New buffer layers for efficient chalcopyrite solar cells (NEBULES)

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Project- / Contract Number	BBW-NR. 02.0074 / EU PROJECT ENK6-CT-2002-00664
Duration of the Project (from – to)	01.12.2002 – 31.12.2005

ABSTRACT

The contribution of the ETHZ group in this collaborative project of the European Union is focussed on the structural and electronic characterisation of Cu(In,Ga)Se_2 (CIGS) solar cells developed with different types of buffer layers.

Structural, inter-diffusion and chemical analyses of interfaces between CIGS and In_xS_y buffer layers deposited by various techniques have been performed and the effects of buffer deposition method have been investigated. For the In_2S_3 buffers deposited by atomic-layer deposition (ALD) and sputtering the optimum deposition temperatures of about 210-230 °C have been found. Efficiencies of the corresponding solar cells increase with increasing temperature below and decrease with increasing temperature above this temperature range. Energy-dispersive x-ray spectrometry (EDX) suggests inter-diffusion of Cu, Ga and In across the In_xS_y/CIGS interfaces. The Cu depletion and In enrichment found on the CIGS side of these interfaces indicate the presence of an intermediate Cu-depleted Cu-(In,Ga)-Se layer between CIGS and In_xS_y. The width of this layer increases with increasing temperature, as the Cu depletion and In enrichment are more enhanced at elevated temperature. Such an intermediate, Cu-depleted Cu-(In,Ga)-Se layer may considerably improve the band alignment between CIGS and In_xS_y and thus the solar-cell performance. For substrate temperatures of about 340 °C, the deposition of In_xS_y on CIGS by sputtering has led to the formation of $CuIn_5S_8$. Its intrinsically large densities of vacancies and defects of this layer may affect recombination of the generated charges, and thus reduce considerably the efficiency of the solar cell. Since $CuIn_5S_8$ formation has been revealed for interfaces between CIGS and In_xS_y deposited by various techniques for temperatures above about 250°C, this formation may be an explanation for the deteriorated performances of the corresponding solar cells at elevated temperatures.

In addition, structural and chemical properties have been studied between CIGS and ALD-Zn(O,S) buffers deposited with varying ratios of H_2O and H_2S sequences (as O and S sources), and on different CIGS absorbers. Best solar-cell efficiencies have been obtained for Zn(O,S) layers with a H_2S/H_2O sequence ratio of 10% (“Zn(O,S)10%”). Elemental distribution profiles obtained by means of EDX exhibit a local maximum of the S signal near the Zn(O,S)/CIGS interface, whereas the O signal shows a local maximum near the Zn(O,S)/front contact interface for Zn(O,S)10% samples. For Zn(O,S)20% or Zn(O,S)5% samples, such local maxima have not been found. This may indicate a different compositional gradient and thus different band alignments to CIGS for Zn(O,S) layers with different O/S ratios.

Annual Report 2005

Dye-sensitised Nanocrystalline Solar Cells

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Project- / Contract Number	Project EPFL
Duration of the Project (from – to)	January – December 2005

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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Annual Report 2005

Voltage Enhancement of Dye Solar Cells at Elevated Operating Temperatures

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Project- / Contract Number	7019.1
Duration of the Project (from – to)	24 months: 2004 - 2006

ABSTRACT

The present action with the industrial partner, Greatcell Solar SA (GSA) follows on the 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 present action aimed during the year at increased stability, particularly at elevated operating temperatures, with enhanced efficiency. 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 2005 particular attention was given to molecular engineering of suitable dyes which by their physicochemical effects enhance stability at a higher output voltage. Attention was also given to 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.

Annual Report 2005

MOLYCELL - Molecular Orientation, Low bandgap and new hYbrid device concepts for the improvement of flexible organic solar CELLs

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

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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Annual Report 2005

Photovoltaic Textile

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Project- / Contract Number	KTI Nr. 7228.1 NMPP-NM
Duration of the Project (from – to)	01.11.2004 – 31.03.2006

ABSTRACT

The goal of this project is to produce a working prototype of a photovoltaic textile based on third generation photovoltaic technology. Konarka Technologies, Inc, the parent company of Konarka Technologies AG, demonstrated a proof of concept photovoltaic fiber device in 2002, based on dye sensitized photovotaics. This project will focus on 1) improving the photovoltaic, physical and mechanical performance of such photovoltaic fiber devices, 2) combining them in the form of a woven textile, and 3) determining methods of interconnecting the fibers to achieve a useful device. The goal at the end of the project is to produce a working prototype PV textile sample with an efficiency of greater than 4%

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Annual Report 2005

Photoelektrochemische und Photovoltaische Umwandlung und Speicherung von Sonnenenergie

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Project- / Contract Number	76645 / 36846
Duration of the Project (from – to)	January 2003 – December 2005

ABSTRACT

Thin silver chloride layers evolve oxygen under UV/Vis illumination in aqueous solution under appropriate conditions. AgCl deposited on a conducting support photocatalyzes the oxidation of water to O_2 in the presence of a small excess of silver ions in solution. The light sensitivity in the visible part of the spectrum is due to self-sensitization caused by the formation of silver species during the photoreaction. Anodic polarization reoxidizes the reduced silver species. Experiments were carried out with gold colloids sedimented on AgCl layers. We observed that small traces of Au colloids greatly influenced the photoelectrochemical activity. AgCl photoanodes as well as gold colloid modified AgCl photoanodes were combined with an amorphous silicon solar cell in a setup for photoelectrochemical water splitting. Illumination of the AgCl photoanode and the amorphous Si solar cell led to photoelectrochemical water splitting to O_2 and H_2. For AgCl photoanodes modified with gold colloids an increased photocurrent, and consequently a higher O_2 and H_2 production were observed. To increase the active surface area of the AgCl photoanode new synthesis procedures are being developed. Microporous materials as support for the AgCl layer (Zeolite A and L), as well as mesoporous materials as matrix (TiO_2 nanotubes, mesoporous WO_3, and Al_2O_3 membranes) are being used.

No experimental evidence has been published so far to prove 1-dimensional electronic excitation energy transport. One-dimensionality is sometimes understood as a transport along a line or at least along a path. Quasi 1-dimensionality in 3-dimensional space of an object with e.g. cylinder morphology means that the net transport resulting from the individual transfer steps occurs along the cylindrical axis. (1) We have found that quasi 1-dim. Förster transport occurs in dye-loaded zeolite L crystals. (2) An important step towards adding further functionality to dye-zeolite systems and to achieve a higher level of organization is the controlled assembly of zeolite crystals into oriented structures. For zeolite L this implies the alignment of the unidirectional channels over a large number of crystals. We have found a way to prepare oriented monolayers of zeolite L crystals on a substrate and have been able to modify them such that energy transfer from molecules inside the channels to a stopcock attached at the top of the crystals takes place. (3) We have found a general route for preparing fully transparent devices based on dye-loaded zeolite L materials. This is important for the preparation of highly efficient and stable solar cells and fluorescent solar concentrators. (4) A US patent we applied for in Nov. 2000 has been granted on Aug. 23, 2005.

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Annual Report 2005

Photovoltaics Modules with Antireflex Glass

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Project- / Contract Number	100297 / 150369
Duration of the Project (from – to)	1th August 2003 – 15.12.2006

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.

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 to reliably this effect.

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Annual Report 2005

BIPV-CIS - Improved integration of PV into existing buildings by using thin film modules for retrofit

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

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.

Annual Report 2005

CONSOL Connection Technologies for Thin-Film Solar Cells

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Project- / Contract Number	NNE5-2001-00556 / ENK6-CT-2002-00688
Duration of the Project (from – to)	01.01.2003 – 30.06.2005 (30 months)

ABSTRACT

CIGS solar modules consist of a stack of thin layers of metals and semiconductors deposited onto a glass substrate. They are connected to the external electrical circuit via two metallic tapes: on the Mo back contact and on the ZnAlO front contact of the stack. In this project, two connection technologies for attaching the tapes were investigated: i) using conductive adhesives and ii) ultrasonic welding. These techniques were applied and optimised for CIGS solar cells on conventional glass substrates as well as on flexible substrates (metal and polyimide substrates).

The most important technical goals concerning contact stability were to maintain a contact resistivity $\rho_c \leq 1000$ mΩcm^2 and a low power loss of $\leq 5\%$ (rel.) of the test modules even after exposure to a damp/heat environment (DH) with 85°C/85% humidity for 1000 hours and thermal cycling (TC: -40°C/+85°C) for 200 cycles. Moreover, the tape adhesion should be sufficiently high to prevent delamination.

The test structures were exposed to damp/heat (DH) and thermal cycling (TC) tests and the contact resistance, the 90° peel strength, and a minimum bending radius (using flexible substrates) were determined. Furthermore, 10x10 cm^2 test modules on glass substrates were also contacted by adhesive bonding and ultrasonic welding using the same contact configurations and tested in DH and TC tests.

The contact resistivity of Sn-plated Cu tapes bonded on Mo or ZnO/Mo with the best conductive adhesive remains on a low level. Tapes on ZnO/CIGS/Mo, however, show a significantly higher conductivity during DH.

A good and reliable bond for the ultrasonically welded contact tapes can be obtained with the contact configurations A (Mo/glass) and D (additional Al coating on the ZnO layer) using single welding points spaced 10 to 20 mm apart. Configuration A is prepared by scraping away the ZnO/CIGS layer. The welding areas must be thoroughly free of CIGS. Nevertheless, an increased fraction of glass outbreaks below the single welding points (“glass shelling”) is still a problem with configuration A. Configuration D does not show any outbreaks. The 90° peel strength of tapes welded to Mo is significantly higher than for adhered tapes. Welded connections on Mo/glass showed a significant increase of the contact resistance after DH, caused by severe corrosion of the scraped Mo layer around the welding points. For a practical application, these areas must be protected by lamination and encapsulation. The increase of the contact resistance is much smaller during the TC test.

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Annual Report 2005

Centrale LEEE-TISO Periodo VII : 2003-2006

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

ABSTRACT

During 2005, more than 2600 flashes were performed with the LEEE-TISO sun simulator for research programmes (test centre, EU projects and other projects), I-V measurements for third-parties and maintenance measurements (accreditation maintenance, initial tests with the new thermostatic chamber, multiflash measurements).

During the last audit, the measurement of the temperature coefficients of PV modules underwent expert verification and the result has been positive. The official ISO 17025 accreditation of this measurement is foreseen for the beginning of 2006.

The “International PV module measurement intercomparison” between accredited laboratories shows that our measurement for c-Si are reliable as the differences from the mean value of all laboratories are in the uncertainty limits.

The laboratory performs spectral mismatch correction to be applied to all thin-film technologies tested during the coming test cycle as well for indoor and outdoor measurement, also thanks’ to the reinstallation of the outdoor spectroradiometer.

A new outdoor test cycle (10) on the most commonly sold PV modules on the market started at LEEE with two different procedures for crystalline silicon and thin-film technologies. Fourteen different module types have been chosen: 8 mc-Si, 2 sc-Si, 1 HIT, 2 a-Si and 1 CdTe , and initial performance measurements have been executed. Initial degradation for c-Si modules range from -1.0% to -2.7%. The maximum difference between the power of c-Si modules given by the manufacturer and the measured initial one is -2.5%, but not all the modules are within the initial minimum limits.

The inter-comparison of the indoor measured IV-curve and temperature coefficients with the STC corrected outdoor IV curves and the outdoor measured coefficients proved the validity of the new measurement facility with the sun-tracker system.

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Annual Report 2005

PV Enlargement

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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

ABSTRACT

In the project coordinated by WIP, 27 PV demonstration systems with an overall generation capacity of more than 1,150 kWp will be installed in 10 different European countries. At this stage of the project, 860 kWp, corresponding to 85% of the total project capacity, are fully operational.

“PV Enlargement” is not only a demonstration project, but it comprises as well various testing activities, which have mainly the scope to allow a realistic inter-comparison of PV module and system performance. The coordinator of the project is responsible of the quality control on system level and the LEEE laboratory is instead responsible of the quality control on module level. A correlation of system and module performance measurements will be used to compare the real Watt peak weighted energy output (kWh/Wp) of all monitored installations.

The LEEE laboratory is continuously monitoring the quality of single randomly selected modules. In this year 54 new modules of 9 different PV systems have been measured under standard test conditions. In total up to now 151 modules of various technologies (mono-crystalline Si, EFG Si, poly-crystalline Si, amorphous Si, CdTe, and CIS) underwent a quality control through our laboratory. The first test phase, with the objective to verify the initial power values, is almost completed. The second test phase, which will be dedicated to the determination of possible degradations, will start in 2006.

All PV systems have been equipped with crystalline silicon irradiance sensors, supplied by T.N.Z.. For this purpose 46 sensors were first light soaked and then calibrated by the LEEE laboratory. Calibration certificates have been prepared for all sensors.

In 2005 the official web page www.pvenlargement.com was updated by WIP with details about each single installation.

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Annual Report 2005

Photovoltaik-Systemtechnik 2005-2006 (PVSYTE)

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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)

ABSTRACT

Purpose and Goals of the project during 2005

- Extended semi-automated tests of grid-connected PV inverters from different manufacturers at least for 3 different DC voltages using the PV array simulators 25 kW and 20 (instead of 7,5) kW of the PV laboratory.
- Continuation of long-term monitoring of PV plants after end of former monitoring project LZPV2.
- Ongoing participation in national network of competence BRENET (building & renewable energy network).

Most important results in 2005

- Inclusion of over- and undervoltage and over- and under- frequency tests with new programmable AC-source in the inverter test procedure in order to examine inverter behaviour under unusual line conditions.
- Development and commissioning of a test facility with a large resonant circuit (Q_L and Q_C up to 12 kVar) for single-phase islanding tests according to new draft standard IEC 62116 and DIN VDE 0126-1-1.
- Development of fault-current measurement procedures for single phase inverters without transformers according to draft German standard DIN VDE 0126-1-1.
- Extended semi-automated tests performed at several new inverters (Solarmax 2000E, 3000E, 6000E, 6000C, 25C) with the new PV array simulators on 3 different DC voltage levels. 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 $\eta_{tot} = \eta \cdot \eta_{MPPT}$ vs. power can be determined.
- Extended test reports (in German) about inverters tested now available under www.pvtest.ch > publications.
- Confidential (paid) tests of different inverters for major PV trading companies to extend project budget.
- Purchase, commissioning and inclusion in automated measurement system of a new power meter (Yokogawa WT3000) with significantly increased measurement accuracy.
- To increase measurement accuracy of MPP-tracking efficiency η_{MPPT} further, a new MPPT-interface is being developed that can measure P_{MPP} and operational MPP-tracking behaviour with the very same electronic circuit, thus reducing measurement errors due to differences in absolute accuracies of two different measuring circuits used before.
- Continuation of long-term monitoring of PV plants. Examination of plants with significant reduction of energy production. Successful inclusion of the large PV plant Wankdorf (855 kWp, on the roof of the new football stadium “Stade de Suisse” in Bern) into the monitoring program in April 2005.
- 2 conference contributions at the 20th EU PV conf. in Barcelona, 3 conference contributions at the 20th PV symposium at Staffelstein/D, 3 poster contributions at the 6th Swiss national PV conference in Geneva and 3 publications in scientific journals on different project results.

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Annual Report 2005

The European Polymer Solar Battery EURO-PSB

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Project- / Contract Number	02.0248 / ENK5-CT-2002-00687
Duration of the Project (from – to)	01.01.2003 to 31.12.2005

ABSTRACT

The aim of EURO-PSB is to develop a self-rechargeable solar battery, i.e. a « tandem module », by coupling a polymer solar cell together with a thin rechargeable lithium-polymer battery. This completely new tandem device would have performances (capacity, voltage, current output, etc) and specifications (dimensions, efficiency and lifetime) compatible with small devices mentioned below. The use of organic polymers allows the use of flexible substrates like plastic sheets. It would then reduce the size and weight of conventional solar batteries and avoid dangers related to glass substrates. Beside, organic materials to be used here are absolutely non-toxic molecules, in sharp contrast to materials used in today's batteries (lead, etc).

The self-rechargeable polymer solar battery is a new concept that would not only overcome problems but also open new markets. A battery recharging itself by just leaving it exposed to room or day light for a few hours or devices with its power supply open to illumination through a transparent window and thereby powering itself (e.g. in remote controls, electronic games, wireless headsets, wireless keyboards for computers, safety lights for bikes, electronic tags) might even one day replace most of primary and rechargeable batteries sold today.

Annual Report 2005

SUNtool - A Sustainable Urban Neighborhood Modelling Tool

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Project- / Contract Number	EU NNE5-2001-753, OFES 02.0066
Duration of the Project (from – to)	January 2003 to December 2005

ABSTRACT

The project SUNtool (Sustainable Urban Neighborhood modelling tool) aims at elaborating a design tool for the urban planners, taking into account the criteria of sustainable development, and particularly the energy and resource flows. In particular, the renewable energy sources and the energy savings are considered.

The size of projects to be handled by the future tool can be anything between a small group of buildings and a whole urban area (maximum size considered should be around one km^2). A graphical user interface will allow the planners to enter the geometric data, and a smart building properties entry system will allow sensible default values, depending on building use, location and climate, and similar data, to be automatically chosen, with the possibility given to the tool user to override them.

The project has been started on January 2003. Its planned duration is 3 years, i.e. until December 2005. The tool version delivered by the project will be a "beta" version, ready for use by practitioners but with some space left for improvements.

The preceeding reports (years 2003 and 2004) presented rather in details the goals of the project and the results of the two first years of the project. The interested reader should refer to these reports for a complete description. In the present report, essentially the results of the last year of the project, as well as the perspectives for future work, will be presented.

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Annual Report 2005

PVSAT2 - Intelligent Performance Check of PV System Operation Based on Satellite Data

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Project- / Contract Number	BBW Nr. 02.0236 , ENK5-CT-2002-00631
Duration of the Project (from – to)	November 2002 until November 2005

ABSTRACT

PVSAT-2 is part of the EU program „energy, environment and sustainable development“ and aims to reduce outage time and maintenance effort of PV systems by developing a satellite based, fully automated monitoring via internet. The procedure calculates reference values of the energy production with the help of irradiance data derived from satellite pictures. On a central server these reference values are collected and compared with the monitored energy yield of the PV systems. (Monitored energy yield is transferred to the central server with a hardware device). Monitored and measured energy yields are automatically compared and analysed on a daily basis with an automated routine. This Failure Detection Routine considers also the behaviour of the PV system in the past and not only detects but also identifies different failures. All data and results are communicated to the operator of the PV system on a password protected internet platform. In case of a malfunction there's also the possibility of alarms via email or sms.

The PVSAT-2 project ended in November 2005 after a half year field test with 100 PV systems all over Germany, the Netherlands and Switzerland. The results showed that the procedure functions well and that the Failure Detection Routine could detect several failures as e.g. defect inverter, degradation, shading and power limitation due to undersized inverter. Accuracy of the irradiance derived from satellite data is about 10% on a daily basis and 5% on a monthly basis. Main problem was the transfer of the energy yield from the PV system to the central server, as the data logger developed within the project didn't function properly.

Enecolo will set up the PVSAT-2 procedure as a commercial service together with the company Meteotest with the name SPYCE. SPYCE will be commercially available in 2006 (www.spyce.ch)
The procedure will be further developed in other projects. Especially quality of irradiance data will be improved with a better model for snow and cloud detection and with the integration of actual aerosol data. These improvements are expected within one or two years. Information about snow cover will additionally be helpful for the Failure Detection Routine. The Failure Detection Routine will be extended by adding new failures and refining the methods for analyzing the failure patterns.

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Annual Report 2005

Energy specific Solar Radiation Data from Meteosat Second Generation: The Heliosat-3 project

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Project- / Contract Number	ENK5-2000-00332 / SBF 00.0364
Duration of the Project (from – to)	2001 - 2005

ABSTRACT

Remote Sensing from satellites is a central issue in monitoring and forecasting the state of the earth's atmosphere. Geostationary satellites such as Meteosat provide cloud information in a high spatial and temporal resolution. Such satellites are therefore not only useful for weather forecasting, but also for the estimation of solar irradiance since the knowledge of the light reflected by clouds is the basis for the calculation of the transmitted light. Additionally an appropriate knowledge of atmospheric parameters involved in scattering and absorption of the sunlight is necessary for an accurate calculation of the solar irradiance.

An accurate estimation of the downward solar irradiance is not only of particular importance for the assessment of the radiative forcing of the climate system, but also absolutely necessary for an efficient planning and operation of solar energy systems. Within the EU funded HELIOSAT-3 project solar irradiance data with a high accuracy, a high spatial and temporal resolution and a large geographical coverage will be provided, using the enhanced capabilities of the new MSG satellite.

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Annual Report 2005

Optimisation Technico-économique de systèmes de pompage photovoltaïques

Outil pédagogique et de simulation dans le logiciel PVsyst

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Project- / Contract Number	2005.04
Duration of the Project	July 2005 – March 2006

ABSTRACT

The main objective of this project is the elaboration of a general procedure for the simulation of photovoltaic pumping systems, and its implementation in the PVsyst software.

This first implies establishing a general model describing the pump electrical and hydraulic behaviour, valid over any running conditions encountered within a photovoltaic system. In order to be useful in such a general software, this model should be built using data usually available in the manufacturer's data sheets. We have developed a phenomenological model, which may be completely determined from several kinds of manufacturer specifications, including simplified to very detailed running data sets. The model precision will of course be function of the completeness of the input parameters data set.

This model will then be included in a simulation process of the whole PV and pumping system (hourly-step simulation), taking the environmental conditions into account, and involving the major technologies available on the market (direct coupling, booster, DC-input or MPPT converters or inverters, buffer batteries, use of conventional AC pumps, etc). Beyond the usual environmental variables (meteo, user's needs), many other operating characteristics should also be user-defined (variable static level over the year, dynamic drawdown level in a buried well, head corrections for pressure or level in the tank, friction losses, level limits, etc).

The simulation results include a great number of significant data, and quantify the losses at every level of the system, allowing to identify the system design weaknesses. This should lead to a deep comparison between several possible technologic solutions, by comparing the available performances in realistic conditions over a whole year.

This will be completed by a "preliminary design" tool performing a quick pre-sizing of the system. The whole design procedure will be extensively explained in the "Help", making a practical and pedagogic tool for pumping systems study, even for not quite expert engineers.

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Annual Report 2005

PV Catapult - WP9

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Project- / Contract Number	n° EU: 502775 (SES6) – Coordination Action
Duration of the Project (from – to)	01.12.2003 – 31.01.2006

ABSTRACT - WP9 ENERGY PREDICTION OF PHOTOVOLTAICS

The accuracy of several modelling methodologies of the energy yield of photovoltaic devices has been investigated within this work-package of the PV-Catapult project.

The starting point was the existence of a number of different modelling approaches but a lack of knowledge of accuracy of these (most are validated for single sites only). The aim was to identify accuracy and research needs in energy production approaches.

The work have been split into four stages:

1. Review of existing energy prediction methods on the basis of a questionnaire
2. carry out ‘best-case’ round robin comparison of prediction methodologies
3. carry out ‘realistic’ round robin of prediction methodologies
4. Phrase the lessons learnt in guidelines to be used for future use

Crystalline as well as thin film modules were investigated within these round robins. The best case round robin leaded to statistical variations in the order of 2-3% deviation of the predicted energy yield with respect to the measured values. Once translations from one site to another are considered, this inaccuracy goes up to 4-6% as long as the precise efficiency of the module is known. If the modules have changed significantly or the name-plate efficiency of the module to be modelled deviates significantly from the input, errors in the 15% range were observed. Overall the rating is the single most important input into any of the models, as this has a direct influence on the accuracy of energy prediction.

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Annual Report 2005

Schweizer Beitrag zum IEA PVPS Programm Task 1

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Project- / Contract Number	11427 / 151471
Duration of the Project (from – to)	01.01.2005 – 31.12. 2005

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 to 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 June and November
- 1 **Task 1 meetings** in Lyon, France
- 2 Workshops in Barcelona (June) and Shanghai (October)

Work still to be done:

- Organize a Workshop at the PV conference in Dresden (Sept. 2006)

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Annual Report 2005

IEA PVPS Programm Task 2 Schweizer Beitrag 2005

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Project- / Contract Number	14805 / 151472
Duration of the Project (from – to)	1. January 2005 - 31. December 2005

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 acitve Subtasks.

Subtask 1 : Performance Database (enrichment and dissemination of the performance database)
This tool has now worldwide more than 2'992 users form 90 different countries. It is beeing updated at least once a year by the expert-group.

New activities: In Phase III 2004 - 2007

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 lead Switzerland)
The global economical survey aims at gathering information on plants, technical performance, maintenance and cost of as many PV systems as possible. The Internet-based survey tool became available during the Photovotaic Conference Barcelona on 08 June 2005. It can be reached at the public website http://www.iea-pvps-task2.org.

Subtask 7 : Dissemination Activities.

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Annual Report 2005

Swiss Interdepartmental Platform for Renewable Energy Promotion in International Co-operation (REPIC)

including Swiss contribution to IEA PVPS Task 9

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Project- / Contract Number	seco UR-00123.01.01
Duration of the Project (from – to)	March 2004 – February 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 new 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 foreseen 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 are expected to provide for synergies between activities from the private sector and the civil society.

Under these goals, the REPIC-Platform also provides the Swiss contribution to IEA PVPS Task 9 - *Photovoltaic Services for Developing Countries.*

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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

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), which is considered a key technology and industry. The consortium comprises 17 participants from 11 countries with more than 20 national RTD programmes (or parts of programmes) and two 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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Annual Report 2005

Photovoltaic-Facade

Mounting System for Thin Film Modules in Facades

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

ABSTRACT

Due to optical and financial issues, PV thin film modules are well suited for large area façade application. Based on the well known Aluhit mounting system, a new mounting structure has been developed within this Photovoltaic Façade project, and the façade-integration possibilities of several types of thin film standard modules have been investigated.

In 2005, the main project activity was the development of new rubber-profiles. The purpose of these new profiles is the long term fixation of frameless thin film modules in façades, eliminating horizontal movements. Mechanical stress acting on the modules is reduced to a minimum due to the specific material characteristics of the selected rubber type.

Investigations made by the Lucerne Technical School of Engineering and Architecture focused on the compliance of relevant construction norms and the mechanical stability of the system.

Based on the project results, a 3 kWp pilot installation is planned for 2006.

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Annual Report 2005

Flat roof integration CPT Solar

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

ABSTRACT

The goal of the project is to analyse the behaviour and the energy yield of a 15.36kWp PV system based on flexible triple-junction thin-film amorphous silicon modules incorporated into a flexible polyolefine (FPO) membrane which acts as a waterproofing system for a flat roof and, in particular, to verify in which order of magnitude the better thermal behaviour of a-Si technologies can compensate for losses due to the quasi-horizontal roof integration.

In the last year of operation (from 1.12.2004 to 30.11.2005) the incident energy (Ho=1329 kWh/m2) was higher than the standard 10 year meteorological data (1143 kWh/m2). In this last two winter period the amorphous silicon modules underwent a complete degradation and regeneration. The plant production was 16'550 kWh (i.e. **Yf = 1077 kWh/kWp**).

This means that the behaviours of a-Si technologies compared to c-Si modules can compensate for losses due to the quasi-horizontal roof integration. Improvement in the energy rating is attained thanks also to the lower temperature coefficient and the thermal annealing of a-Si modules.

The thermal insulation of the roof does not allow a ventilation of the modules and this leads to operating temperature of the modules reaching 80°C on hot summer days, and during more than 1000 hours of operation the module temperature is over 40°C. Thus it can reach the level where the main degradation mechanism can be reversed and thermal annealing can be observed.

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17.6 kW_p Installation with Thin-Film Modules on the Flat Roof at the CNB Building of the ETH

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

ABSTRACT

The CNB-building of the Swiss Federal Institute of Technology (ETH), Zurich, is located downtown. The building has to be renovated and as a part of the renovation a new photovoltaic installation will be realized. The building is subject of local historical monument preservation and protection codes.

Therefore, the PV modules as well the fixing construction will be of the same colour and installed as symmetrical as possible.
The installation will have a power of 17.6 kW peak and will consist of standard thin-film-modules.

A display in the new cafeteria will provide information about the service of the installation.
The realization should be executed in 2005 in winter (mounting structure, together with the roof renovation work) and autumn (rest of the plant), but because of the uncertainty of the use the whole conversion of the building is stopped.

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Annual Report 2005

Preparation and Realisation of the Test- and Pilot Installation SOLIGHT

New Light-Weight Flat Roof PV Module Mounting System

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Project- / Contract -Number	100116 / 150134
Duration of the Project (from – to)	2003 -2006

ABSTRACT

Almost all of the mounting systems for solar PV modules available on the market require additional weight to withstand heavy wind loads. As the roof of many building is not used for any other purpose, it is an ideal place to mount solar PV modules. However, many modern buildings are built to reduce material and labour to build the roof structure, therefore reducing the cost of the building. They are built to just satisfy the demands of structural engineering, but most of the times hardly allow any additional weight on them.

These roofs prohibit any placing of PV-solar modules on them. Many roofs in Switzerland, however, furbish as an uppermost surface a layer of 3 to 8 cm of loose gravel. This gravel functions as an UV-protection and wind load proofing of the watertight foil below it.

The main goal of the project is to sum up the experience of the previous project and to implement a pilot and test installation to put the findings of SOLight to the proof. In the first phase of this new project, which has been successfully completed in 2003, the design has been refined, tested and completed. As a next step, the realisation of the pilot installation is executed with SOLight structures to test the system for its usability in real outdoor condition, e.g. under special consideration of wind and snow loads. This will help to learn important lessons on the application and the usability of this new mounting approach.

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Annual Report 2005

Solgreen Kraftwerk 1 Zürich

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Project- / Contract Number	42920 / 82869
Duration of the Project (from – to)	1st July 2001 – Summer 2006

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 ist 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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Annual Report 2005

Autonome Stromversorgung mit Photovoltaik und Brennstoffzellen

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Project- / Contract Number	47994 / 88095
Duration of the Project (from – to)	15.1.2003 – 31.12.2005

ABSTRACT

In 2005, 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 in the laboratory of the Swiss National Hydrological Survey (SNHS) of the Federal Office of Water and Geology (FOWG)
- reporting of failures and problems in the laboratory to the producer
- exchange of the SFC A50 R by an improved model in January 2006
- integration of the autonomous energy supply for telecommunication with the fuel cell SFC A50
- first results of this field test

The main focus of the year 2005 was the preparation for 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. It could be proven that the fuel cell is even interesting for a compact monovalent autonomous power supply. The fuel cell performed better than the year before but was still insufficient. Together with the producer the problems has been be analyzed and a new SFC A50 model has been be delivered with delays finally in January 2006. With this new improved model we will start the field test in spring 2006, on the sites evaluated in 2003.

In the meantime an autonomous power supply with PV and the SFC A50 for a telecommunication of a fireguard has been be built by our partner Steca. Therefore we have first field results in the configuration PV and SFC. After first problems the system performs well.

The information activities have been reduced 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 reliable for normal customers. Practical experience with fuel cells in autonomous power supply installations is very helpful for consultations.

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Annual Report 2005

RESURGENCE

Renewable Energy Systems for Urban Regeneration in Cities of Europe

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Project- / Contract -Number	NNE5/00340/2001 BBW 01.0370-1/-2/-3
Duration of the Project (from – to)	Jan. 2002 – Dec. 2005

ABSTRACT

Turn PV systems to a common part of social housings – that's the goal of the EU project „Resurgence". Therefore, social housing associations, utilities and engineers from 5 european countries (GB, D, NL, CH, DK) are installing PV plants with a total power of 1.5MW. In the course of the project several options for financing, technical design and operation of the systems are investigated. Especially analysed are also the feedbacks of the tenants in the affected residential areas. Project partners of "Resurgence" in Switzerland are the general building association of Zurich (ABZ), the Edisun Power AG and the engineering office Enecolo.

In 2005, Switzerland has finished the reports about the social integration survey and the commissioning procedure. The results of the social integration survey were very encouraging as they demonstrate, that the rating of photovoltaics in the population can be improved, if a personal relation to PV power is established. Monitoring of the PV plants was continued and the results of the social integration survey were disseminated in several magazines.

On the international level, not all countries reached the project goals. In Germany there has still no PV plant been built within "Resurgence" and in Denmark the project status is unclear. In the Netherlands several PV plants have been installed in autumn 2005 and other PV plants could not be built due to a of lack of money. The financial problems were mainly caused by non professional communication between the project leader and the EC: several changes in project partners and members were not completely and in time communicated to the EC. Additionally, several reports were not delivered in time. Therefore the EC holds back the fundings for the project.

The goals for 2005 therefore have not overall been achieved. Especially in Germany the installations still are not operating. Because a monitoring period of at least one year is required, the project duration must be elongated.

In 2006 Switzerland will continue the monitoring and disseminate the results to further magazines. More information on www.resurgence.info and on www.solarstrom.ch.

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Annual Report 2005

Messkampagne Wittigkofen

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Project- / Contract Number	100035 / 150040
Duration of the Project (from – to)	January 2003 – December 2005

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 will be expected at the beginning of 2006.

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

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Annual Report 2005

Monitoraggio dell'impianto PV da 100 kWp AET III a Riazzino

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Project- / Contract Number	43907 / 83947
Duration of the Project (from – to)	From 1.1.2002 to 31.12.2004

ABSTRACT

The 100 kW AET III grid connected PV plant, located in Riazzino, was constructed in 1992 by the TNC company on behalf of the Swiss Federal Office of Energy. In 2001 the plant had to be modernised. The old 100kW converter has been substituted by three new converters, 33kW each, and part of the wiring has been redone. The renovated PV plant was put into service on November the 30th 2001. Since then the AET (Azienda Elettrica Ticinese) has acquired this PV plant which has therefore been renamed AET III (originally Mark II). This project was intended to precisely monitor for 3 years the behaviour of the plant after renovation, by continuous and annual measurements. The data acquisition system was adapted to the new configuration and it was put back into operation at the beginning of 2002.

The project finished on December 31st 2004. All the goals have been achieved. Along the year 2005 only the continuous main parameters (basic monitoring) have been collected, whereas the continuous strings and periodic annual measurements (STC measurements of reference modules, thermographic analysis and outdoor I-V measurements) have not been performed. In the future, on commission of the plant owner - Azienda Elettrica Ticinese – a basic data acquisition and a maintenance cooperation are foreseen to continue to check the good plant operation and to pursue the annual data communication to the IEA database.

The behaviour of the plant has being yet analysed for 4 years: since the renovation the plant is working properly. Its daily and hourly PR now exceeds 70% (right from 65 W/m2), and it is better with respect to the one of previous years. The plant produced respectively 95.977 MWh (2002), 115.322 MWh (2003), 108.492 MWh (2004) and 117.547 MWh (2005); this annual productions exceed, for the third consecutive year, the limit of 100 MWh/a, never reached in the 11 previous years of operation (maximal production 98.5 MWh in 1999, average 93.5 MWh). This is due to the favourable meteorological conditions, but in particular to the excellent performances of the new converters. This energy yield (Yf_{2005}= 1'124 kWh/kWp.y) clearly exceed the production estimation of 95-100 MWh. Since the PV plant was put into service in 1992, it produced 1'130.488 MWh, that corresponds to a total inverters operating time of 38'343 hours (31.12.2005).

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Annual Report 2005

100 kWp PV-Netzverbundanlage A13 Messkampagne, Periode 2005

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Project- / Contract -Number	31883 / 150161
Duration of the Project (from – to)	January 2005 - December 2005

Abstract

15 years ago this 100 kWp PV-Plant built on top an existing sound-barrier structure along the A13 motorway in the Swiss Alps went into operation. At the time this project was unique, as it was the first PV-plant along a motorway worldwide and the largest PV-plant in Switzerland.

The purpose of this project is to gain information on the long-therm behaviour of a large gridconnected PV-plant and its components under real operating conditions. The monitoring and evaluation is carried out in accordance with the EU-Guidelines for PV Monitoring.

The plant produces on average 110'000 kWh per annum at a specific annual yield of 1'030 kWh/kWp. The plant operated for the first 10 years without any mayor interruptions. In the years 2000, 2001, 2003 and 2004 it suffered some mayor interruption due to inverter failure.

In the period from June 2003 until May 2005 a total 508 Modules were stolen from the plant in five separate incidents.

In November 2004 the 15 year old 100 kW Siemens inverter was replaced with two modern Sputnik SolarMax 60 kW inverters.

Since November 2005 the plant is back in operation with all the stolen modules replaced by a newer type.

In this report the first two months (Nov. 2005 and Dec. 2005) of operational data of the renovated plant is analysed.

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

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Annual Report 2005

Solar Energy Potential in Geneva

Assessment of the Solar Energy Potential (PV and Thermal) in the Public Building Stock in the Canton of Geneva

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Project- / Contract Number	
Duration of the Project (from – to)	June 2003 – January 2005

ABSTRACT

Context:
The Canton of Geneva (Switzerland) is renowned for its energy policy promoting both renewable energy and sustainable energy supply. Besides tangible quantitative targets, the policy also aims at optimising the interfaces and interactions between the relevant stakeholders (authorities in energy issues, building / urban design and land planning, multi-utility, customers, etc.) in order to facilitate and promote solar energy.

Objectives:
The objectives of the assessment of the (thermal and photovoltaic) solar energy resources are:
i) to analyse the roofs of public buildings with respect to their suitability for solar energy use purposes
ii) to provide general information on the solar energy potential in the public building stock
iii) to build the basis for an inventory of the public buildings (also compatible with the local Geographic Information System),
iv) to strengthen strategies in order to exploit the solar energy resources and potential available.

Results:
The assessment provides i) quantitative results based on the analysis of 1637 buildings and ii) qualitative conclusions for the solar energy potential in the public building stock and ways to exploit this potential.

Conclusions: The technical report built some ground for providing information to the government in order to respond to the parliamentary initiative (motion) in the canton of Geneva.

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Annual Report 2005

Solar *Electri*City Guide - Publikation „Solarstrom in der Gemeinde“

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Project- / Contract -Number	100627 / 150824
Duration of the Project (from – to)	01.07.2003 - 30.06.2005

ABSTRACT

Introduction:
The Swiss Solar ElectriCity Guide is 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 are supported within the frame of the SwissEnergy programme.

Purpose of the work:
The objective of this Solar ElectriCity Guide is 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.

Approach:
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 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.

Results:
The project “PV City Guide” resulted in an international Solar ElectriCity Guide. The Swiss editions in German and French are being published. 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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Annual Report 2005

IEC Normenarbeit für PV Systeme

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

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 and actual work program of IEC TC 82 is given in www.iec.ch

Swiss interest and contribution: Switzerland, once a leading pioneer on grid connected PV systems, has in spite of shrinking federal budgets many leading companies in the manufacturing of machines for making Si-wafer- and for laminating PV modules, inverters, both grid connected and off-grid, plugs and special solar cables, PV array mounting systems, both for flat and tilt roofs. The political decision to move to a feed-in tariff system such as implemented with success in Germany, and now also in Spain, Portugal and other EU countries are now discussed on Swiss parliament level.

The national Standard committee for PV is organized within TK82, under the secretarial support of Electrosuisse. After years of work being performed by a rather small group of experts, industry has now joined the national committee, and the working group has grown from a few number of experts to a large and competent group, representing expertise in engineering, inverters, plugs, cables, support structures, test labs and research groups, as well as coordination links to the Swissolar, representing the association of companies involved in PV.

Most important works for the year 2005 till 2007 are standards on: Inverter safety and testing, Module safety, BOS components, charge controllers, plugs, PV grid connected harmonized commissioning procedures. Also islanding prevention, max power tracker (MPT) efficiency measurement, PV plant monitoring are on the agenda.

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Swiss Photovoltaic Internet Portal www.photovoltaic.ch

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Project- / Contract Number	39490 / 79286
Duration of the Project (from – to)	1.9.2000 – 31.3.2004

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 of 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. During 2006, the English version will follow.

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Annual Report 2005

Photovoltaic Energy Statistics of Switzerland 2005

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Project- / Contract Number	
Duration of the Project (from – to)	

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 2005, about 200 new PV plants were connected to the grid in Switzerland; 100 more than last year. The Swiss PV Market's installed peak power (4.3 MWp) more than doubled the 2004 results. This was mainly due to two projects: a 1 MWp installation in Geneva and an 0.85 MWp installation in Bern.

On account of 5% higher irradiation in 2005, compared to that of the last 20 years, the annual yield of all Swiss PV installations reached 820 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.

Annual Report 2005

Solarstrom vom EW

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Project- / Contract Number	17067 / 73481
Duration of the Project (from – to)	from 1996

ABSTRACT

"Solar electricity from the utility" is the name of an action within the Swiss National Action Programme SwissEnergy, aimed at providing customers of utilities with the service of solar electricity. The action is supported by SwissEnergy since 1996. The fundamentals of the action can be described as a marketing approach towards both utilities and their customers in order to deploy the market for solar electricity for customers willing to buy this product at generation costs. After eight years of operation, this action has achieved remarkable results: More than 150 utilities participate in the action in the year 2005, more than half of the Swiss population now has access to this service, more than 8 MWp of photovoltaic power systems have been installed within this concept and around 6 GWh of pure solar electricity are subscribed annually, nearly 3 GWh PV is contained in other "green" products.

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