Project SOPHIA

PhotoVoltaic European Research Infrastructure

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Data Beneficiary

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Activity NA02

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1 Introduction

The scope of this deliverable is to summarize the activities by the expert groups in the second year of the SOPHIA project. An expert group has been formed for each of the 8 technical topics of the project during the first reporting period (see D2.1, month 12). Within the context of the Strategic Research Agenda and the Implementation Plan, their role is to plan the actions to be undertaken in the coming years for each topic, in relation with the use of the relevant research infrastructures.

The structure of the deliverable thus follows the eight SOPHIA technical topics and will summarize for each topic:
- The current activities performed,
- barriers, needs and gaps,
- on-going activities

and (if applicable) give recommendations

2 Activities performed by each expert group

2.1 Topic 1 : Si-material

In the frame of the continuing coordination activity concerning upcoming specialist workshops in the field, an important project is a dedicated material workshop planned at ECN for 2013 (G. Coletti, ECN, in co-operation with ISE).

The research infrastructures and capabilities as reported in detail in the last Yearly Progress Report were actively used within the project in the Si-material related round robins running in work package 11 (JRA 03) and supervised by the expert group, which were completed in part within the reporting period. These dedicated round robin efforts were run aiming at elaborating differences between the participating infrastructures concerning characterisation of material and cell properties. To evaluate such possible differences was seen as a basis for any exchange of results.

Under the aspects, which parameters are mostly needed in order to describe the performance and quality of a material, and then which methods are the best capable to measure these parameters, the first of the three round robins was focussing on the impurity content, which is brought into the material by the feedstock or the crystallisation process. From the survey and discussion within the expert group (NA02), it was clear that agreement about accurate and reliable determination of impurity content is a fundamental issue for the development of new material types. The ICP-MS measurement emerged as a technique which is both, promising as an important technique to determine impurity content, and available at more than one of the participants, namely CEA INES and IMEC. Thus, a special ICPMS analysis intercomparison was run and completed between IMEC and CEA-INES. The result demonstrated that impurity concentration values obtained at CEA INES and IMEC correlate within the given uncertainty limits. Details are available in a separate report. Shortcomings of the technique are firstly, that the uncertainty limits still allow deviations of more than one order of magnitude and that the sensitivity is not sufficient to quantify levels of impurity concentration, which are still of detrimental effect in solar cells. Up to now, these concentrations are accessible best on the wafer and solar cell level with techniques, which rely on the electrical activity of the impurities.

One of the most widely used and most direct routes to quantify the impact of material quality on the PV-performance is the analysis of the loss channels in a finished solar cell. A wide range of techniques which are used by partner institutions in order to separate and extract different material related properties (as opposed to solar cell processing related loss factors) on the wafer and solar cell level had been collected and compared already earlier in the project within JRA3 (see results reported in Deliverable D11.1). Still it turned out in discussions within the material expert group that there was the need to have a common basis established for the determination of the most central performance parameters of a solar cell, i.e. the parameters determined from the light current to voltage (IV) curve and the spectral response. Especially if the part of the material related losses in solar cells with advanced architectures as e.g. bifacial solar cells, shall be evaluated, already an agreed measurement of the spectral response and the IV-curves is a non-trivial issue.

As a first step, an IV and spectral response-measurement-round-robin was performed for state of the art standard type industrial cells between 7 partners (CREST, ECN, ENEA CASACCIA, ENEA PORTICI, ISE, IMEC, INES), led by ECN. It was aimed to enable the participants to verify their measurement facilities and procedures for IV-measurements on "classic" Silicon solar cells by comparing their measurement data with the data of other participants.

It turned out that, taking into account the stated measurement uncertainties, the differences in determined cell parameters between the partners are not significant. Only for spectral response the curve of one partner deviates significantly from the other partner's data. The results of the round robin exercise on IV-measurements of classic Silicon solar cells were sent as report "ECN-E--12-050 SOPHIA" to the partners. A contribution to the next EU-PVSEC conference on "Round robins of solar cell measurement systems from European research institutes" by Manshanden et al. will disseminate the results.

For a quantitative extraction of the material quality contribution to the solar cell performance, the long wavelength internal quantum efficiency gives a good access. The internal quantum efficiency can be determined from the external one, equivalent to the spectral response (the comparison of measurements of this property is reported in the previous section). Additionally needed for this is a measurement of the reflection losses. Thus, a further intercomparison, also led by ECN, has been successfully conducted between

6 institutes (ECN, IMEC, ISFH, ISE, ISC Konstanz, Univ. Konstanz). Again, the exercise has a positive outcome: Between 500-1000 nm, the reflection measurements of the participants deviate less than 1 % from each other on the primary systems; outside this measurement range the deviation is less than 4 % (±2 %). A more detailed document is available for the SOPHIA partners.

2.2 Topic 2 : Organic material

The partner institutes at present active within NA2.2 - organic PV (OPV) and the respective representatives had been at the start of the project as listed in the following:

Partner	Key contact	Area of expertise
DTU	Peter Sommer-Larsen	OPV general
	Suren Gevorgyan	Test and characterization
ECN	Jan Kroon	OPV general
CEA-INES	Stephane Cros	Module
IMEC	Tom Aernouts	OPV general
TECNALIA	Oihana Zubillaga	Test and characterization
VTT	Jukka Hast	OPV general
	Tommi Vuorinen	Processing
	Sanna Rouso	Processing
ENEA	Francesco Roca	OPV general and testing

The detailed expertise in OPV represented by the participants is mainly derived from and related to the research infrastructure and the measurement and analysis capabilities at the respective institutions. These current research infrastructures and capabilities are at the same time actively used within the project in the device round robins running in work package 11 (JRA 03). The research infrastructure related to OPV at the different institutions has been already summarized in the month 12 version of D2.1.

2.3 Topic 3 : Thin film material

Currently the core thin film expert group consists of members from HZB, AIT, FZJ and ECN. This group has started work on a strategic vision for PV research infrastructure (RI) with respect to thin film devices and transparent conductive Oxides (TCOs) with a first meeting in Freiburg during the 2012 SOPHIA general assembly (GA). The emphasis there was to define the research infrastructure necessary to reach the goals as defined in the EU PV Technology Platform (Strategic Research Agenda and Implementation Plan). Based on the current implementation plan a list was compiled that contains the RI, which the expert group regards as necessary to support significant advances in the different fields of PV as outlined in the Implementation Plan (IP). To give just one example, in the IP one sub-topic is: "Understanding material and devices". There, important goals for all thin film materials are defect characterization and control. The expert group has concluded that in order to reach these goals, appropriate RI has to be available. This includes e.g. setups for electroluminescence (EL) and thermography analysis for module sized samples. So far, most of these setups are available only for small samples in the laboratory. Another requirement is a fast, in-situ partial analysis of roll to roll samples by optical methods.

Following a discussion during the SOPHIA meeting in Brussels on 4 October 2012 about the PV research infrastructure, a questionnaire was prepared by ECN (M. de Bruijne) and EUREC (G. Arrowsmith). This was circulated among the members of the expert group on thin films and the results were sent back to M. de Bruijne.

A few answers specific for thin film PV stated that module efficiency improvement and module price reduction are still valid goals and more so than in the field of crystalline Si PV. The downfall of PV production in Europe has especially affected thin film PV, where most companies are small and often not backed by large investors, therefore the current demand for thin film RI from companies is low. But, for thin film PV there is still demand for advanced characterization techniques for disordered (amorphous and microcrystalline) semiconductors and advanced interface characterization techniques.

A training course organised by HZB in October/November 2012 was held to increase awareness on the available RI at HZB and to offer training for two specific RIs (for details see 3.4.3 of the M24 report). The discussion during this workshop has emphasized the need for specialized characterization RI in the field of thin film PV like EPR (electron paramagnetic resonance) and x-ray based spectroscopy. Since these RIs require large investments and/or special know how and experience, they will always be available only at a small number of research centres.

2.4 Topic 4 : Concentrated PV

There has been no change in partner organization and representatives in comparison to the first reporting period. Main objective of NA2 is the planning and surveillance of the activities within JRA2.5. Here the focus was on the organization of the CPV module round robin and the formation of a spectral network. The spectral network has been established and data will be collected throughout the year 2013 at different sites in Europe. Additionally partners participated in an intercomparison activity for spectrally sensitive sensors in Catania Italy. This activity is mainly related to the EC project APOLLON, however it was decided that bringing together the two projects in this activity is of benefit for all partners and both projects. The success of this activity led to the agreement to hold a joint intercomparison again in 2013. This time the activity will take place in Puertollano in Spain which is a location far away from the sea in order to have a completely different location compared to the last event (Catania, directly at the sea).

The module round robin is just about to be kicked off – CPV modules provided by Soitec are under characterization at Fraunhofer ISE at the moment and will be distributed to the partners afterwards. Additionally to the full size modules also so called mono modules, comprised of one lens and one cell will be shipped. These mono modules have been manufactured in the frame of the project and will serve as irradiance sensors. The partners are in close contact to the International Electrotechnical Commission, technical committee 82, working group 7 (IEC TC82 WG7) responsible for the development of international standards for CPV. Some partners are also official members of the WG7. The CPV module round robin will be used as practical test for the power rating procedures under discussion for implementation in IEC 62670-3 (power rating of CPV modules and systems). Partners are participating actively in the WG7 telephone conferences in order to assure the findings of the round robin will help the further improvement of the standard. Additionally to the involvement of the WG7 also the manufacturer of the modules (Soitec) is involved in the specification of the test procedures for the modules. Andreas Gombert from Soitec could be won as external expert, additionally also Tobias Gerstmaier from Soitec is involved. At Soitec he is working on the rating of CPV modules and he is also member of the WG7 and the partners are also in close contact with him. One main input from Soitec was for example the recommendation also to take the lens temperature into account when analysing the round robin data, as the optical efficiency of the silicone on glass lenses in use in the Soitec modules show a stronger dependence on temperature as other concentrating optics like e.g. mirrors or acrylic lenses.

Main event in respect to CPV in 2012 was definitely the CPV8 conference that has been held in Toledo, Spain. SOPHIA partners were also involved in the organization of this event. Directly after the conference also a meeting of the IEC WG7 took place in Toledo were many of the partners were participating.

2.5 Topic 5 : Cell modelling

The partner institutes at present active within NA2.5 and the respective representatives are the following:

Partner	**Key contact**
Jülich	B. Pieters
ECN	E. Bende
ISE/IWES	W. Sprenger
CEA/INES	W. Favre

IMEC	I. Gordon
HZB	M. Schmidt
JRC	B. Werner
ENEA	M. Celino
AIT	S. Abermann

Several software tools have been developed to a high level. However, those activities are usually isolated, do not interact with other software tools and often are not available for user access. Thus we initiated a collection of modelling activities at various partners. The questionnaire to collect the available software tools, their applications, users, providers, and contact persons at the respective institutes has been updated. Regularly the questionnaire is sent out to scientists worldwide. The most recent list is available on the MyndSPHERE platform at https://www.myndsphere.com/gm/folder-1.11.121739.

The result of this questionnaire will be published on the SOPHIA website, thus enabling the dissemination of the available expertise.

Furthermore, in conjunction with JRA 2 and JRA4, we organized the "1st European Workshop on PV performance modelling" at CEA Ines in Chambery that took place on 21-22 February 2013. In several parallel and general sessions recent results were spread within the consortium. The interaction between work packages and partners especially in the JRAs has been strengthened.

2.6 Topic 6 : Lifetime prediction

The partner institutes which are active within NA2.6 and the respective representatives are listed in the following:

Partner	**Key contact**
ECN	Ian Bennett
IMEC	tbd
CREST	Ralph Gottschalg
CEA-INES	Eric Gerritsen, Philippe Malbranche
JRC	Tony Sample, Barbara Werner
EPIA	Manoel Rekinger
AIT	Shokufeh Zamini

Most effort has been focused on coordinating JRA01. The goal of JRA01 is to develop new module tests and relate the results of these tests to expected lifetime of modules. This should lead to an adaptation or update of IEC61215 to be more relevant to lifetime. Meetings were organized at the GA in Freiburg February 2012. Regular conference calls were held relating to the work being performed in JRA01.

It was intended to include two industrial partners within the expert group. Two of the largest module manufacturers in Europe were approached as potential candidates. Their inclusion as partners has proved impossible due to the economic climate and ceasing of activities in crystalline silicon PV. No attempt has been made to find replacement partners also due to the economic climate.

An overview of test and characterization facilities at the partners has been made and reported in D9.1. This document will be regularly updated during the course of the project. Further to this, new test methodologies outside IEC61215 have been defined (see D9.2). Examples of these tests include higher relative humidity and higher temperature, combined UV and damp heat, and mechanical load at sub-zero temperatures. These tests have been carried out on a set of three different types of module including a reference module with crystalline cells and EVA as the encapsulant, a module containing heterojunction cells and a module encapsulated with a thermoplastic. The modules and their initial characteristics are described in D9.3. The aim is to compare the degradation rate of the three types of modules under different conditions to identify any differentiation in degradation mechanism. This will allow suggestions for adaptation of the IEC standard to be made. The results of the test plan are described in D9.4.

The next step is to analyse the test data to determine the dominant degradation mechanisms for the modules and to calculate activation energies for these mechanisms. These results can then be used as input for the adaptation of the test sequences in the current standard. A set of the three types of module will be subjected to the proposed sequence and the results compared to testing according the standard test sequence. A relationship with outdoor testing will also be investigated.

2.7 Topic 7 : Module and system performance

The PV Module and System Performance Expert Group aims to develop a strategic vision and roadmap concerning European PV R&D infrastructure. The group comprises the following organisations and experts:

JRC	Nigel Taylor
ISE-IWES	Siwanand Misara, Michael Köhl
ECN	Nico Dekker
CEA-INES	Jens Mertens
ENEL	Francesco Aleo, Paola Maria Pugliatti, Antonluca Loteta
RSE	Fabrizio Paletta
CREST	Ralph Gottschalg, Tom Betts
TECNALIA	Eduardo Roman

EUREC Greg Arrowsmith
EPIA Scalett Varga
AIT Stepha Abermann, Shokufeh Zamini
Derlab Vincent Helmbrecht
ENEA Giorgio Graditi
Industry representative (nominated by EPIA): open

In late 2011 the NA2.7 group performed a survey on R&D issues for module and system qualification and qualification of balance of system components. The resulting recommendations were presented to the General Assembly in February 2012. The discussions led to the following conclusions:

- JRA2 will address guidelines for long-term outdoor testing (DERlab document) and work on performance ratio.
- JRA1 will look at issues regarding PID (Potential Induced Degradation) and reverse current
- Safety issues are considered out of scope of SOPHIA
- No possibility seen to address MPPT (maximum power point tracking) and shading issues in SOPHIA - a different platform is needed.

In general, SOPHIA should focus on R&D infrastructure issues up to module level but not beyond to system level.

2.8 Topic 8 : Building integrated PV

The BIPV expert group activities have started with 9 partners: CEA INES, AIT, TECNALIA, ISE/IWES, HELIOTOP, JRC, EPIA, and ENEA.

At the end of the M1-M12 period, an action plan was validated by the NA2.8 Expert Group during the General Assembly Meeting in Freiburg from 8th to 9th February 2012.

As a reminder, the first action is to make a document for the state of the art of BIPV products and technologies and BIPV R&D activities and projects. Secondly, each country has to give the definition and the vision of “BIPV” (Italia, Spain, Germany, France, Austria, others). Thirdly, partners have to make a list of functions that could be done by BIPV products. Fourthly, the description of the BIPV test facilities has to be updated. The fifth action consists in making a list of existing practices in order to characterize BIPV taking into account the energy production and the global energy balance of BIPV and building.
Some of these actions will be realized in the JRA2.6 subtask.
During the M13-M18 period, the state of art on BIPV performance was proposed in the M18 deliverable (D10.14) by CEA, AIT, Fraunhofer ISE and IWES and Tecnalia. It concerns the electrical and thermal behaviours and the performance of BIPV system (non ventilated PV system): numerical models, availability conditions, PV modules performance and experimental studies. The report comprises an optical analysis part, a thermal behaviour part and an electrical behaviour part.

The action plan of JRA2.6 validated by the partners during the General Assembly Meeting in Freiburg has been detailed lately.

The first method is to realize a state of art of the BIPV systems by taking into account the energy (electrical and thermal) performance of PV modules in BIPV systems. The second method consists in performing a benchmark of all the partners' available models. Partners decided to use steady state models, as a first step. Later, if necessary, dynamic models could be considered. This method will start with a benchmark considering that the width of the insulation layer is infinite. Then, a second benchmark will be done taking into account the interior temperature of the building. The third method is to realize studies in ICT test conditions which mean setting the BIPV component in extreme operating conditions such as an infinite insulation layer or high irradiation. The last method is to perform a comparison between measurement and simulation results in order to evaluate the discrepancies. The case studies chosen could be based on the second method.

The joint abstract sent by JRA2.6 partners for the EUPVSEC 2012 conference in Frankfurt (authors: CEA-INES, AIT, ISE-IWES, and ENEA) was accepted. The topic of this abstract is the numerical estimation of the impact of environmental conditions (wind, locations, weather…) on the behaviour of PV modules in BIPV systems. An article was written and published in the conference proceeding and a poster was presented.

A questionnaire sent by CEA permitted to provide an overview of JRA2.6 partners' infrastructures, numerical models and measured data on BIPV. In order to realize the benchmark between the partners' models, two or three cases could be selected in this questionnaire answers.

3 Barriers, needs and gaps

3.1 Si-material

For the global strategic vision on the required research infrastructure, different aspects are important: (i) long term expectation concerning the environmentally most benign Si-material production, but at the same time (ii) the medium term requirements of the market have to be taken into account. In view of (i) and in alignment with the European Energy Research Alliance (EERA) a major focus was put at the start of the project on the requirements related to the development of "solar grade" feedstock due to expected lower cost, but especially also expected lower energy use in production and the related benefit for the environment. In 2011 the situation concerning material demand and supply for Si-photovoltaic underwent a change in focus due to the general oversupply of modules. In the course of a dramatic price decrease for modules on the market, the availability also for high quality and high efficiency products, modules, cells and also high grade silicon starting material was extremely high. Consequently, the attempts to lower costs of modules by the use of lower grade starting material were strongly under pressure, since the actual gap in costs to be utilized was shrinking. Under environmental aspects this may well be a temporary effect. In 2012, the oversupply and related very low prizes continued throughout the year. Only in January 2013 a slight increase in feedstock prizes occurred. On the other hand, there were indications of further progress of the metallurgical silicon route towards lower costs at still improved impurity content. Thus, the necessary research base to support this route in the future appears still promising.

On the other hand, this development affects the initially defined central aim of this expert group, i.e. creating an overview of actual feedstock sources and expected development in this area. Essentially, at present feedstock sources on the market are still dominated by virgin poly silicon, either from the Siemens or the Fluidized Bed process. Alternative feedstock is rarely found.

As a consequence, a second focus on the development and production of silicon material for high efficiency solar cell technologies is included. Here several areas of research needs are identified:

Firstly, the material technology, linked to the requirements of solar cell processing, for n-type silicon should be included. This topic is important as a link between the efficient use of material from the “solar grade” production route, which tends to have higher residual phosphorous content and the requirements for high efficiency solar cell technology. Although the topic did find attention in previous calls, this phase of initial exploration actually appears to lead into a phase of broad industrial interest with the associated necessity for more focused research activities. Consequently, already a proposal for a specific call in this direction has been formulated within EERA in 2011. This is seen as a starting point for a broader effort.

Secondly, the development of directionally solidified material of quality and/or crystal structure as close as possible to single crystalline silicon is important. Industrial activity in this area has grown very strongly in recent years. An adequate increase of research capabilities, especially covering the specific problems encountered here as especially the input of distributed line defects has not grown adequately. As outcome from the first overview, means to investigate and modify the properties of dislocated areas and the related defect engineering in crystal growth and solar cell processing are lacking. The presently running material intercomparison is expected to reveal a first evidence of this view.

3.2 Organic material

Organic photovoltaic include several technologies where organic molecules or polymers constitute all or parts of the photoactive components. These technologies are either on an early commercial or pre-commercial state where applications depend on their special features like flexibility, ease of integration and semi-transparency. Wide spread use rely on maturing the OPV technologies to a level comparable to thin film PV. It requires a continued improvement of performance, lifetime, and high speed low cost processing methods. Three KPI's (key performance indicators) are defined for the technical performance:

1) Power Conversion Efficiency (PCE) > 10% on module level
2) Lifetime > 10-15 years
3) Production speed > 10 m/min in continuous roll-to-roll production for e.g. polymer solar cells.

Small molecule PV and dye-sensitized solar cells (DSSC) use other processing routes and hence have other KPI's. The need for research infrastructure is driven mostly by the needs of R&D institutions and R&D groups in companies and not yet by a production industry.

The needs for infrastructure relate to those developments are:

- Materials development: There is a need for a paradigm shift in R&D away from using PCE as the dominant KPI towards the development of a real world technology:
  - Materials that can be synthesized in large amounts at low cost with little environmental impact.
  - Materials that can be used in scalable processes.
  - Materials that allow for long lifetimes.

  In order to develop real world materials, it is still necessary to develop the best performing materials – the premium molecular motifs for e.g. new active layer low band gap polymers with ultimate performance in term of PCE – even though tenths of synthesis steps and huge amounts of solvents are used in their synthesis. It is anticipated that focused projects among many partners will subsequently utilize the premium molecular motifs to develop and select the real world options. The RI needs here is identified as fast screening instrumentation – see below under materials testing - and processing methods that
  - allow for using small amounts of newly synthesized materials (typically 100 mg)
  - and emulate large scale production methods – see below under processing.

- Materials testing: there is a clear need for advanced materials test methods that give insight in structure, the photo properties, chemical and morphological changes during operation, and the chemical degradation mechanisms both for isolated materials and for materials in device configurations. Much of the instrumentation is relevant for a general materials science purpose but nanoscale chemical and morphological characterization techniques like X-ray microscopy with nm resolution is thought for. There is a need for addressing methods for fast screening of materials. Such RI is planned to be identified in e.g. materials round robin projects.

- Processing: depends strongly on the OPV technology. Laboratory processing is based on batch processing through wet chemical or physical deposition techniques i.e. spin coating, thermal evaporation and CVD (chemical vapour deposition). A trend towards more processing RI is seen in the OPV R&D community: a growing number of groups employ continuous processing methods like Roll-to-Roll coating (R2R) and the field is characterized by a multitude of technical options. In particular for polymer solar cells, Roll-to-roll printing machinery is installed at an increasing number of sites. The competences in advanced processing techniques are slowly building up. Two needs are identified:
  - -A need for developing process machinery and processing methods for fast processing of solar cells - increasing speed will reduce resource use in general (materials, solvents, power, heating) – and it will also strengthen the high volume advantage of OPV.
  - Bridging the gap between materials development and processing through instrumentation that allow for printing solar cells with small amounts of material in scalable processes. Examples of e.g. slot-die mini roll coaters exist but as large scale processing has several options, more RI in this area is requested.

- Lifetime and stability: is a field with much on-going collaboration among the OPV groups. Harmonization of test procedures, test equipment and development of common standards is an area where a special effort is needed for OPV because a number of the general PV standard test conditions are too hush for today's level of OPV. A project like SOPHIA and a forum like EERA are excellent hosts for further work along these lines. With the maturing of OPV technologies an increasing need for test centres focused on OPV are envisaged.

3.3 Thin film material

A main obstacle in thin film PV research in Europe today is the rapid decline of industrial production, partly due to a combination of cheap crystalline Silicon imports, mainly from Chinese manufacturers and feed-in tariff reductions, especially in Germany. Several large producers have gone bankrupt or withdrawn operation from Europe within the last 2 years, leading to a decline in industrial partners for thin film research. Furthermore, governments become more reluctant to finance research in this field, given the unclear perspectives of the industry. The immanent need for the entire field is the increase of efficiency in order to become competitive with crystalline silicon. Some experts put the limit at 15 % standard reporting condition efficiency for the production average. Currently, however, efficiencies of production modules are rather in the range of 11-13 %. Therefore, research has to aim at increasing the module efficiency and quickly transfer the respective technology into production.

3.4 Concentrated PV

CPV is like all PV technologies suffering from the declining market for photovoltaics in general. Times like that are tough for a new technology to enter the market. In addition – as has been already pointed out in the last report – the lack of international standards in the field of CPV is another decelerator. Thus the CPV activities in SOPHIA also strongly concentrate on supporting especially the standardization processes for CPV in order to help the technology to gain acceptance on the market. Work has already been focussing on the reliability of tracking units and is now more related to the rating of CPV modules and systems.

3.5 Cell modelling

Even though, the separate software tools are merging due to the work in JRA4, closer cooperation is required to profit from full expertize along the modelling chain. In some areas data with sufficient reliability are lacking as input parameters for modelling. This means that errors may expand during modelling and the final result is questionable. If data have been measured and when software tools are available, possible users do not know about these, so a database with meta data is required to raise the awareness and provide access to these data or software tools. For intellectual property conservation, contracting and guidelines could accelerate the access by users to the data, simulation tools, or any modelling service.

3.6 Lifetime prediction

A large number of modules (> 90) were required for the testing in JRA01, and also a large number of climate chambers to perform the tests. Clearly, the extent of the test plan could not be performed by one institute alone. In this joint research, three barriers were encountered:

It was anticipated that the modules would be supplied by industry partners in exchange for access to the results. However, after long negotiations this proved to be impractical, as the industrial partners demanded too much control over the tests and dissemination of the results. The solution was to purchase modules covering a range of different technologies.

It appeared that nearly all climate chambers at the partners are used for standard IEC testing. This makes implementation of the test plan at the institutes impossible. The tests were performed at commercial test centres, at additional costs.

The weight and dimensions of modules are much larger than wafers and cells. Although this is obvious, it does have large implications for the logistics of the test plan. This added time and costs to the research activity.

In summary, the execution of a large test matrix on large solar modules outside of the standard IEC61215 tests has shown that there is a need for more flexibility and capacity in test facilities within Europe. It has also shown that there is a need for joint research independent of industrial partners, to push the standards beyond what is currently accepted.

3.7 Module and system performance

The input for the SRIA questionnaire at the end of 2012 highlighted several technical issues including:

- Durability, ageing and system lifetime management: this is to an extent already addressed in NA2.6, but efforts are also needed on advanced monitoring methods at both module and system level, on module-integrated and module-oriented inverters and on reliability databases. Such information can support long-term operation (> 30 years) with integrated maintenance and component replacement strategies.
- Energy and power prediction for different applications and regarding innovative products and systems. Such tools also need to be integrated with solar radiation predictive models to support large scale grid integration.
- Increased cooperation on standards and associated pre-normative R&D.

These complement the results of the survey conducted by this expert group in 2011 and will be further discussed at the JRA2 1st European workshop on PV Performance Modelling workshop on 21-22 February 2013 and at the General Assembly in April 2013.

3.8 Building integrated PV

No major barriers were encountered. The main difficulty was the deadline for M18 deliverable which matched the holiday departure for some partners.

4 Ongoing activities

4.1 Si-material

Under the aspect of a correct evaluation of the Si-material impact in final solar cells, an important topic, which needs coordination activity has been identified in correlation with NA04. Within the participation of some of the partners (ISE, ECN, IMEC) at a specialist workshop on bifacial solar cells held in 2012 in Konstanz the urgent need of a standardized measurement technique for bifacial cells came up. An expert group established among participants of the workshop extending outside the SOPHIA consortium is after some discussion planned to be followed up and supported.

The first round of material characterization intercomparisons with support of WP 11 (JRA 3.1) was addressing already different aspects as outlined in Section 2, where further development needs of infrastructure and specific measurement techniques is envisaged. Material of different origin, covering actual development directions, was included: Silicon crystals from upgraded as well as virgin poly silicon, (all p-type), and in addition n-type silicon. As a result of this broadly laid-out exercise an overview was compiled of the most prominent mainly imaging techniques and delivered. Analysis, exchange and discussion of results were done intensively in the second project year and are on-going. On the basis of the results delivered by the individual labs a focused experimental plan had been anticipated, which should address specific differences, unclear results or lacking information on material parameters. One of the conclusions which were drawn from the discussions of this overview was an emphasis of the importance of majority as well as minority charge carrier mobilities for a valid evaluation of measured results especially if new, e.g. umg silicon (upgraded metallurgical-grade silicon) sources are included. It is still not sufficiently clear, how this basic property varies for different silicon materials and how these differences can be understood and described. Widely used techniques need mobilities as input data in order to draw valid conclusions on material quality. Therefore, as the next activity, a comparison of the techniques and approaches to gain access to these data is presently in detail worked out between the partners. Discussions are on-going, how this activity will be performed in detail, if e.g. investigation of further material aspects should be integrated.

4.2 Organic material

An ongoing characterization inter comparison with support of WP 11 (JRA 3.2) aims at improving and harmonizing the test procedures, parameters and equipment in order to increase the interoperability of cell and module tests between European partners in EERA and SOPHIA. The status for the study is reported under JRA 3.2. Another study concerning the characterization of materials and device fabrication was initiated at a project meeting in September 2012 with the ambition to improve characterisation/prediction methods and procedures for OPV materials, performance and lifetime studies and clarify the relations between materials properties and performance. The objective is to establish the data for developing materials screening protocols and aging models that allow for inter-operability between laboratories.

The broader infrastructure's expert group will evaluate the state of infrastructure status and needs within OPV and input to the questionnaire on PV infrastructure has been given.

A round robin study for studying inter-operability and inter-comparability of testing OPV stability will be initiated. The performance round robin study finalized in the present reporting period can be viewed as a pre-study for the demanding life-time tests planned for the next study. All tests will be in controlled laboratory settings. Protocols will be prepared with the aim to support the on-going ISOS (International Summit on Organic Photovoltaic Stability) work on OPV stability by testing the ISOS protocols for stability testing. Also the study will run in parallel with a non-SOPHIA initiated international outdoor inter-laboratory test presently being arranged. A number of the EERA/SOPHIA partners are also expected to participate here.

Execution of the stability round robin is planned for Q1-Q2 2013.

A materials round robin study is being planned with the objective to establish the data for developing materials screening protocols and aging models as part of sub-task 3.2.1. Planning in Q1 2013. Execution will be in Q2 2013.

The feasibility of an OPV encapsulation study / round robin is being evaluated in Q1/Q2 2013.

4.3 Thin film material

The questionnaire from ECN and EUREC was returned by the participants and is now used to write a first draft for the strategic vision on PV research infrastructure. During the SOPHIA GA in April 2013 the thin film PV expert group will meet for a working session to add to the current draft and discuss the future of thin film PV research in the light of the current situation in the thin film PV industry.

4.4 Concentrated PV

As mentioned in the chapter "current situation" the spectral network has been initiated and data recording is on the way. Additionally a spectroradiometer intercomparison is taking place in Puertollano, Spain, in May 2013. This activity corresponds to the reissue of the campaign in Catania, Italy, 2012. Also the initial measurements for the module round robin are just being performed so that the round robin will fill most of the year 2013.

In April 2013 the CPV9 conference and an additional standardization meeting of the IEC WG7 will take place in Miyazaki, Japan. Unfortunately the M24 meeting of SOPHIA will take place at the same time, which will prevent some of the partners from participating both events.

4.5 Cell modelling

The collection of software tools is regularly updated. Expert discussions are initiated occasionally at several meetings on modelling. The results are provided to the partners via e-mail, the MyndSPHERE, or the public SOPHIA website.

4.6 Lifetime prediction

The test plan as described in D9.2 is being carried out at the partner institutes using the module described in D9.3. The test plan included thermal cycling and damp-heat at conditions different to those described in IEC61215 and 61730. This includes higher and lower temperatures and relative humidity and combination of stress factors such as UV and damp-heat. Pre-conditioning for mechanical testing is also being studied. The results of the test plan are being collected in D9.4. It is expected that the results will be completed in Q1 of 2013 although some testing has been delayed by the availability of test facilities at the partners able to operate at the conditions defined in the test plan. Post-test analysis of the module by non-destructive and destructive means will take place once the test plan has been completed.

The results of the test plan will be used to define an adapted test sequence possibly specific to a cell or module technology. This will be tested on a set of three modules used for the main test plan. Determination of the dominant failure mechanism for the modules and the activation energy will be compared with results of field testing of similar modules. This will be used to adjust the proposed sequence to make it more relevant to degradation seen in the field.

In addition to this, a recommendation for development of the research infrastructure will be made based on the experiences in this project. The main item that has been identified is a lack of capacity for testing at conditions outside the current IEC61215 and 61730. This limits the capability of the partners to investigate the effect of conditions outside the standard. These conditions will become more and more relevant as the industry grows and modules are installed at different location with different climatic conditions. The introduction of new module concepts, new cell technologies and new module materials is also predicted to require testing under different conditions than currently used.

4.7 Module and system performance

For the reporting period the main focus has been on:

a) monitoring and supporting the JRA2 activities

b) preparation of input to the questionnaire on Europe's PV infrastructure trends, to help provide a basis for SOPHIA's Strategic Research Infrastructure Agenda (SRIA) for PV.

For the latter, following a video/telephone conference held 9 November 2013, six organisations provided detailed input: CREST, JRC, TECNALIA, IWES, DERLAB, INES and RSE. The replies were collated into a common "NA2.7" questionnaire, which was submitted to the organisers (ECN/EUREC).

4.8 Building integrated PV

The upcoming activities will consist in attending the JRA2 workshop on PV module modelling from 21st to 22nd of February at INES CEA in Chambéry. It will comprise 3 sessions including a BIPV session.

During the Brussels meeting in October 4th 2012, some workshops and training sessions about BIPV were proposed as next activities for years 3 and 4. First discussions were realized between the partners in order to decide about the number, the topics and the participants (for SOPHIA project partners and industries) of these workshops and training sessions. A first workshop could be organized from 29th and 30th August during IBPSA World conference in Chambery. Further discussions will permit to validate this proposal.

The activities will also consist in realizing other points of the action plan.

5 Recommendations

5.1 Topic 1 : Si-material

None at this point.

5.2 Topic 2 : Organic material

A strong selling point of polymer solar cells is that capital costs of printing production machinery are a factor 100 lower than the costs of a similar silicon PV production capacity. Despite of that, the development of processing methods and machinery that are linked intimately to development of materials and efficient barriers still requires large R&D investments. The main recommendation is to focus both R&D and RI needs on bridging the gap between materials development and large scale processing:

1) Focus on materials development apt for processing and develop methodology and instrumentation for fast screening of materials

2) Instrumentation and processing methods that allow for using the small amounts of newly synthesized materials and emulate large scale production methods

3) Strengthen the collaboration on utilizing and defining protocols for performance and stability of OPV and develop methodology to fast screen stability

4) Strengthen the synergy between materials development and up-scaling through consortia among able partners in industry and academia.

5.3 Topic 3 : Thin film material

For the research infrastructure, up to now, there are fewer requests than expected. To foster the usage of the RI of SOPHIA it could probably help to better advertise the excellent possibilities offered. Another barrier might also be the administrative effort, necessary to be awarded with the possibility to use the RI. Also the long assessment times should be reduced to make the offered RI more appealing for applicants.

5.4 Topic 4 : Concentrated PV

The CPV module round robin to be performed within SOPHIA is the first of its kind for CPV modules. The expert group recommends investing sufficient time in the preparation of the activity in order to assure that measurement procedures are well defined and all needed equipment is shipped together with the modules. Thus it is recommended to concentrate on this activity before e.g. thinking of including other kind of modules from other manufacturers.

5.5 Topic 5 : Cell modelling

During the PV performance modelling workshop guidelines for research infrastructure in PV modelling were formulated and concluded in the questionnaire sent out by EUREC last year.

Main results are:

Important tasks	Related WP
• Reliable and good measurement to calibrate the models	JRA2, JRA3
• Meta database with description of available data and contact person	JRA2
• Availability of data and corresponding rules/contracts	NA ?
• Software tool database and interface standards	JRA4

Some of these activities are already followed in the JRAs. The contracting and rules to handle such access service is not yet directly covered by the SOPHIA work plan.

5.6 Topic 6 : Lifetime prediction

For the work performed in JRA01 it has become clear that the capacity for testing outside the standard conditions as defined in IEC61215 and 61730 is limited. Expansion of this capacity is thought to be necessary due to the expected implementation of PV in different location and in different climates than has traditionally been done. In addition to this, the implementation of new cell and module technologies and materials may require adaptation of test sequences to make it more relevant to degradation mechanisms seen in the field. Examples of such technologies include heterojunction cells and thermoplastic encapsulants as are being tested in the module used in JRA01.

5.7 Topic 7 : Module and system performance

The expert group should use the results of the SRIA (Strategic Research and Innovation Agenda) survey and the discussions at the JRA2 European workshop on PV Performance Modelling on 21-22 February 2013 to establish priorities for further activities. Consideration also needs to be given to supporting initiatives for the NA3 (databases, standards) and NA4 (education/training) work packages.

5.8 Topic 8 : Building integrated PV

None.

6 Conclusion

The actual work of the expert groups is mainly related to the steering and control of the corresponding JRA activities like e.g. round robin tests that are performed for different SOPHIA topic groups. Additionally research infrastructures available have been identified and summarising lists were comprised.

Main barriers identified were related either to the strongly decreasing demand and thus also decreasing prices for PV and the lack of international standards especially for new technologies. The first can lead to either disappearing industrial partners or the lack of willingness (or ability) to cooperate with the SOPHIA partners. The latter is also a chance for SOPHIA to support the standardization processes for new technologies. Based on these facts some recommendations were also given.

Project SOPHIA

PhotoVoltaic European Research Infrastructure

GA N° 262533

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NA2: Expert groups on a PV infrastructure Strategic Vision

D2.1 – Yearly progress report

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Table of contents

1 Executive summary 28
1.1 Description of the deliverable content and purpose 28
1.2 Deviation from objectives, corrective action 28
1.3 Technical progress 28
1.4 Impact of the results 28
1.5 Dissemination activities carried out, planned 28
2 Technical section 29
2.1 Current situation 29
2.1.1 Si-Material 29
2.1.2 OPV 31
2.1.3 Thin Films 33
2.1.4 Cell Modelling 33
2.1.5 CPV 34
2.1.6 Lifetime prediction 35
2.1.7 Module and system performance 35
2.1.8 BIPV 36
2.2 Barriers, needs and gaps 38
2.2.1 Si-Material 38
2.2.2 OPV 39
2.2.3 Thin film 40
2.2.4 Cell Modelling 40
2.2.5 CPV 40
2.2.6 Lifetime prediction 41
2.2.7 Module and system performance 41
2.2.8 BIPV 42
2.3 Ongoing activities 42

2.3.1 Si-Material 42

2.3.2 OPV 43

2.3.3 Thin film 43

2.3.4 Cell modelling 45

2.3.5 CPV 45

2.3.6 Lifetime prediction 45

2.3.7 Module and system performance 45

2.3.8 BIPV 45

3 Conclusions 46

4 References 46

1 Executive summary

1.1 Description of the deliverable content and purpose

The objective of this deliverables is to summarize the work done by the experts groups regarding the eight technical topics addressed within the networking activities of the SOPHIA project:

- Si material
- Organic material
- Thin Film Technology
- Concentrated PV
- Cell Modelling
- Lifetime prediction
- Module and system performance
- BIPV

1.2 Deviation from objectives, corrective action

N/A

1.3 Technical progress

N/A

1.4 Impact of the results

N/A

1.5 Dissemination activities carried out, planned

N/A

2 Technical section

2.1 Current situation

2.1.1 Si-Material

The partner institutes at present active within NA2.1 and the respective representatives had been at the start of the project as listed in the following:

Partner	Key contact	Area of expertise
ISE	W. Warta	Imaging (defects, cell parameters)
ECN	G. Coletti	Feedstock specification / effect on cells
CEA/INES	A. Jouini	Feedstock / crystallisation
IMEC	F. Dross	Effects on cells / low level contamination / Si on substrate
SINTEF	B. Rynigen	Feedstock / crystallisation (mono/mc) / wafering / material characterisation
ENEA	F. Roca	

The changes which had occurred during the first year as updated up to the status at the General Assembly Meeting in Freiburg on February 8./9. 2012 were:

Elkem, represented by B. Sandberg, with strong expertise in all aspects concerning silicon feedstock could be won as an industry representative. For the second industry representative foreseen in the work program, intensive discussions with Wacker Silicon finally did not succeed. I. Gordon replaced F. Dross as the expert representing IMEC, likewise T. Pettersen assumed the key contact for SINTEF. The detailed expertise in silicon material characterization represented by the participants is mainly derived from and related to the research infrastructure and the measurement and analysis capabilities at the respective institutions. These current research infrastructures and capabilities are at the same time actively used within the project in the material round robins running in work package 11 (JRA 03). The research infrastructure at the different institutions is compiled in the following.

Fraunhofer ISE

- a broad variety of carrier lifetime measurement techniques. These are Photoluminescence (PL)-Imaging, Quasi-Steady-State-Luminescence (QSSL, both electro and photoluminescence), Quasi-Steady-State Photoconductance (QSSPC), Mikro-Photoluminescence (µPL)-Spectroscopy, resistivity (4PP, Hall)
- determination of defect element concentration (FTIR, Fe-Imaging, Cr-Imaging, EDX)
- crystal status and crystal defect analysis (EBSD, EPD, µRaman-Spectroscopy)
- advanced defect characterisation (Thermography, Trap-Imaging, Defect-PL, EBIC)
- cell processing for material qualification.

CEA-INES

- Chemical Analysis using ICP-MS (ppb)
- DTA/TG/DSC analysis (1700 °C)
- 3D Wafer measurement tool
- SEM-EDX NanoSem 630 (resolution 1.6 nm) including EBIC
- Optical microscopy analysis Zeiss Axio2M (Including 1500 °C in-situ heating furnace)
- IR Silicon Brick inspection
- Lifetime measurement µ-PCD, QSSPC; Diffusion length LBIC
- Resisitivity measurement RT100, WT2000
- FTIR (RT)
- I(V) : Voc, Isc, FF, Rsh, Rs

IMEC

- Access to a number of material analysis techniques: SEM, TEM, XRD, (T)XRF, Raman spectroscopy, (TOF)-SIMS, SRP,...
- Including detection of very low surface/bulk contamination
- Including morphology measurements (roughness, bowing, residual stress, etc.)
- Solar cell fabrication facilities; possibility to screen materials on solar cell level

SINTEF

- Crystallisation of mc- and Cz-silicon in various furnaces
- Minority carrier lifetime: Quasi Steady State Photo Conductance (QSSPC) and Carrier Density Imaging (CDI)
- Resistivity: Four Point Probe (FPP)
- Dislocation Density Mapping by PVScan
- Micro structure: Field Emission Gun Scanning (FEGSEM) /Transmission Electron Microscopy (TEM)
- Impurities: Glow Discharge mass spectrometer (GDMS)
- Interstitial Oxygen and substitutional Carbon: Fourier Transform Infrared (FTIR)
- Mapping of recombination active defects: Electron Beam Induced Current (EBIC)

In order to disseminate the available expertise in a useful structure, the idea was that reviews should be prepared as joint review papers intended for publication. One responsible person per review should collect the contributions from all partners. Initially an extensive list of topics was created, which was seen to be of considerable usefulness. At present, the discussion is continued, how to focus within this wide scope. Generating all the anticipated content will most likely exceed the available resources; also a possible publication venue is open.

2.1.2 OPV

The partner institutes at present active within NA2.2 and the respective representatives had been at the start of the project as listed in the following:

Partner	Key contact	Area of expertise
Risoe DTU	Peter Sommer-Larsen	OPV general
	Suren Gevorgyan	Test and characterization
	Torben Damgaard Nielsen	Market and applications
ECN	Jan Kroon	OPV general
CEA-INES	Stephane Cros	Module
IMEC	Tom Aernouts	OPV general
TECNALIA	Oihana Zubillaga	Test and characterization
VTT	Jukka Hast	OPV general
	Tommi Vuorinen	Processing
	Sanna Rouso	Processing
ENEA	Francesco Roca	OPV general and testing

The detailed expertise in OPV represented by the participants is mainly derived from and related to the research infrastructure and the measurement and analysis capabilities at the respective institutions. These current research infrastructures and capabilities are at the same time actively used within the project in the device round robins running in work package 11 (JRA 03).
The research infrastructure related to OPV at the different institutions is compiled in the following.

CEA-INES

- Permeameter/ Ca test
- DTA/TG/DSC analysis
- Climatic chamber with solar simulator
- Optical microscopy analysis
- FTIR, UV/vis
- I(V) : Voc, Isc, FF, Rsh, Rs
- Processing

Risoe DTU

- R2R processing
- TGA/DSC analysis
- Life time test chambers, controlled atmosphere and temperature
- Outdoor testing
- Indor/outdor concentrator setup
- SIMS
- Spectrocopic ellipsometry
- AFM
- Gracing incidence SAXS/WAXS line
- LBIC
- I(V) : Voc, Isc, FF, Rsh, Rs

- R2R characterization IPCE
- Climate chamber test

Tecnalia

- SEM-EDS, AFM, XPS, FTIR, RAMAN, UV-VIS, DSC, TGA
- Adhesion, Hardness, Scratch Resistance
- Gloss and Colour
- UV ageing, Temperature and Humidity Cycling, Salt Spray, voltage/current cycling
- Abrasion Testing
- Barrier properties

VTT

- R2R processing
- IV characterisation
- FTIR, UV-Vis spectroscopy
- Ca testing
- TGA
- DSC
- AFM
- SEM (EDS)

ENEA

- Realization of polymer solar cells using commercial materials and innovative polymers
- Inkjet printing
- Inorganic and polymeric Trasparent conductive oxide
- synthesis of II-VI semiconductor compound nanocrystals and core-shell nanocrystals functionalization of nanocrystals and ligand exchange to coordinate the nanocrystals surface;
- Material (FTIR, TEM, XRD, AFM, SE, TGA, DTA) and device characterization (I-V, Qyield,etc)
- Quantum chemical study of electron acceptors for polymer-fullerene solar cells
- Facility for encapsulation and degradation test against U-V, humidity, thermal and mechanical stress

IMEC

- Imec is present in the fields of OPV and c-Si
- Access to a number of material analysis techniques: SEM, TEM, XRD, (T)XRF, Raman spectroscopy, (TOF)-SIMS, SRP,...
    - Including detection of very low surface/bulk contamination
    - Including morphology measurements (roughness, bowing, residual stress, etc.)
- Access to a number of device analysis techniques: a number of PV-oriented analysis tools (including some under inert environment), c-AFM, PL, IR mapping/imaging
    - Including lifetime measurement systems (QSSPC, CDI, PL)
- Solar cell fabrication facilities; possibility to screen materials on solar cell level
    - c-Si, OPV

2.1.3 Thin Films

The partner institutes at present active within NA2.3 and the respective representatives are the following:

Partner	Key contact	Area of expertise
HZB	I. Lauermann	Thin film solar cells, surface and interface analysis
FZ Jülich	J. Hüpkes	Thin film solar cells, TCO, modelling,
AIT	S. Abermann	Silicon and compound thin film solar cells
JRC	D. Polverini	Thin film solar cells
ENEA	F. Roca	Silicon thin film solar cells
SINTEF	T. Pettersen	Silicon thin film solar cells
EPIA	M. Rekinger	PV business facilitator
EUREC	G. Arrowsmith	European energy strategy
ECN	P. Pex	Thin film solar cells
CEA	Anis Jouini	c-silicon casting
ISE	Wilhelm Warta	Characterisation and simulation / CalLab

In thin film PV technology very different materials, device structures and deposition methods are employed. Therefore there is only limited overlap in the research fields of the individual SOPHIA-Partners. One of them is TCO-technology, with all aspects of deposition, characterisation and application on small and medium-sized substrates. A database (see below) was started to give an overview of the different infrastructures available within the consortium.

Another common topic is the device characterization with problems specific for the individual thin film technologies like light-soaking effects, temperature-induced healing and other metastabilities. These effects make reliable characterisation of devices difficult. Therefore the development of common procedures is an important part of this work package in conjunction with NA03 and JRA2.

2.1.4 Cell Modelling

The partner institutes at present active within NA2.5 and the respective representatives are the following:

Partner	Key contact
Jülich	B. Pieters
ECN	E. Bende
CEA/INES	P. Thony
IMEC	K. van Wichelen
HZB	M. Schmidt

Within and also outside the consortium there are many software tools in use for modeling of cells. To collect the available expertise we therefore initiated, in conjunction with the activities in JRA4, a questionnaire to collect the available software tools, their applications, users, providers, and contact persons at the respective institutes. The result of this questionnaire will be published on the open

Sophia website, thus enabling the dissemination of the available expertise. Furthermore, also in conjunction with JRA4, we organized a workshop on PV modeling, open for everyone to attend.

2.1.5 CPV

The partner institutes at present active within NA2.4 and the respective representatives are as following:

Partner	**Key contact**
ENEA	Michele Pellegrino
RSE	Paolo Morabito
ENEL	Paola Maria Pugliatti
ENEL	Francesco Aleo
CEA-INES	Mathieu Baudrit
UPM	Ignacio Anton
Tecnalia	Eduardo Roman
FhG ISE	Gerald Siefer
JRC	Robert Kenny

The main objective of NA 2.4 is the planning and surveillance of the activities that will be performed within JRA 2.5. The partners involved in NA 2.4 represent an almost complete roundup of the concentrator photovoltaic research expertise in Europe. Main expertise of the partners involved is related to the outdoor characterization of concentrator photovoltaic (CPV) modules. Expertise on characterization and assessment of tracking units is also available. Moreover experience in indoor characterization is available at several partners, involving indoor characterization of CPV modules, characterization of concentrator optics and measurement of concentrator cells.
The partners form a close network and have established continuous exchange via telephone conferences. Besides this partners have met and contributed to the following conferences/meetings held in 2011:

- CPV 7 conference and IEC TC82 WG7 meeting in Las Vegas (April 2011)
- IEC TC82 WG7 meeting in Cologne (September 2011)
- European photovoltaic conference in Hamburg (September 2011)

The main activities planned within JRA 2.5 and thus to be supervised and planned within NA 2.4 are:

- Round robin of CPV modules
- Formation of a spectral network
- Assessment of tracker stability

The involvement of external experts from industrial partners is a key component to assure the practical usability of the work and results performed within the JRA. In this context Andreas Gombert from Soitec could be won as external expert for the planning and realization of the CPV module round robin. Soitec will provide CPV modules to be used for the round robin and will give technical support if needed.

2.1.6 Lifetime prediction

The partner institutes which are active within NA2.6 and the respective representatives are listed in the following:

Partner	Key contact
ECN	Ian Bennett
IMEC	tbd
CREST	Ralph Gottschalg
CEA-INES	Eric Gerritsen, Philippe Malbranche
JRC	Tony Sample, Barbara Werner
EPIA	Manoel Rekinger
AIT	Shokufeh Zamini

Most effort has been focused on coordinating JRA01. The goal of JRA01 is to develop new module tests and relate the results of these tests to expected lifetime of modules. This should lead to an adaptation or update of IEC61215 to be more relevant to lifetime. Besides the GA kick-off meeting, meetings in Berlin (March 2011) and Hamburg (September 2011) were organized to discuss these issues.

It was intended to include two industrial partners within the expert group. Two of the largest module manufacturers in Europe were approached as potential candidates. As of yet, they have not joined the expert group, mainly due to the current economic climate.

An overview of test and characterization facilities at the partners has been made and reported in D9.1. This document will be regularly updated during the course of the project. Further to this, new test methodologies outside IEC61215 have been defined. Examples of these tests include higher relative humidity and higher temperature, combined UV and damp heat, and mechanical load at sub-zero temperatures.

2.1.7 Module and system performance

The PV Module and System Performance Expert Group aims to develop a strategic vision and roadmap concerning European PV R&D infrastructure. The group comprises the following organisations and experts:

Partner	Key contact
JRC	Nigel Taylor, Barbara Werner
ISE-IWES	Norbert Henze, Siwanand Misara, Michael Köhl
ECN	Nico Dekk
CEA-INES	Christophe Mangeant, Eric Gerritsen, Jens Mertens
ENEL	Francesco Aleo, Paola Maria Pugliatti, Antonluca Loteta
RSE	Fabrizio Paletta, Mattia Giussani
CREST	Ralph Gottschalg, Tom Betts
TECNALIA	Eduardo Roman, Ricardo Alonso
EUREC	Greg Arrowsmith
EPIA	Manoël Rekinger

AIT	Shokufeh Zamini
Derlab	Vincent Helmbrecht
ENEA	Giorgio Gra
Industry	Phoenix Solar (Thomas Schwarz)

The expert group held two face-to-face meetings in Year 1, at the project kick-off in February 2011 and in a joint NA2.7 & NA2.8 meeting at Chambery in May 2011.

In the SOPHIA workprogramme the topics to be addressed by NA2.7 are:

- Energy prediction: standardized procedures for PV-modules and systems
- PV module and system qualification
- Qualification of BOS components (fuses, overvoltage protection devices, cables,)
- Recycling of modules and BOS components
- Qualification of support structures
- Best practice in PV-system design.

At the kick off meeting in Amsterdam February 2011 it was noted that the JRA1 and JRA2 projects already address a range of issues regarding module qualification and energy prediction respectively. Concerning the proposed topics on recycling, support structures and system design involve competences outside this expert group and hence no work is planned in the immediate future.

2.1.8 BIPV

The partner institutes and their respective representatives had been at the start of the project as listed in the following:

Partner	Key contact
CEA INES	Ya Brigitte Assoa, Philippe Malbranche, Benjamin Boillot
AIT	Shokufeh Zamini
TECNALIA	Jose M. Campos, Eduardo Roman
ISE/IWES	Siwanand Misara, Norbert Henze, Wendelin Sprenger, Tilmann Kuhn
HELIOTOP	Volker Hinrichs
JRC	Nigel Taylor, Hans Bloem
EPIA	Manoël Rekinger
ENEA	Michele Pellegrino, Franco Roca

The existing infrastructures for this topic are:

CEA INES: BIPV platform

In INES, the research activities consist in developing methods to determine the BIPV performance and also in developing the innovation of new BIPV concepts. The list of equipment and facilities made available are:

- BIPV roof test benches: Ten experimental benches built early 2010 to test and characterize building integrated photovoltaic for roof. These benches can support 35 m^2 of roof elements. The orientation of these benches can vary between 0 to 50°.

- BIPV roof test benches coupling with building: Three roof test benches built in 2010 to test and characterize roof elements which have energy coupling with the building. These benches could permit INES to characterize, for example, hybrid PV/T elements.

Fraunhofer IWES: PV test lab
At two outdoor test facilities, the Fraunhofer IWES is in a position to provide large capacities for outdoor tests. A well proven outdoor location is situated on the roof of the institute building. Enlarged capacities offer a new spacious test field – SysTec. At this location, modules are installed upon field mounted systems, tracked or building-integrated. The technical parameters of photovoltaic modules are determined under genuine operating conditions, with simultaneously recording of all relevant meteorological data. The electrical data and the I-V curve of the modules are measured with the ISET-mpp meter®. PV test lab as the equipment for all meteorological data and usually gives full meteorological data set with all measurements: ambient and module temperature, irradiance on module level, global irradiance, diffuse irradiance, direct irradiance, wind velocity and direction, rel. humidity and precipitation.

Fraunhofer ISE:
BIPV curtain wall test bench installed in the main building and permitting to estimated the g value.

TECNALIA: KUBIK
KUBIK is an international outstanding and unique experimental facility for R&D that provides a real live test bed for building technologies, specially focused on energy uses, aiming for the development of new concepts, products and services to improve energy efficiency in buildings.
The main characteristic of KUBIK is the capability to build realistic scenarios (residential, office, schools) to analyze the energy efficiency obtained from the holistic interaction of the constructive solution for the envelope, the intelligent management of the HVAC and lighting systems and the supply from renewable energy.

AIT: PV modules and system lab
The photovoltaic lab facilities of the Austrian institute of technology are mainly for measuring performance of PV devices and systems. Moreover, equipments for characterizing thermal, mechanical and electrical properties are available.
Equipments and devices permit to carry out module lifetime analyses indoor as well as outdoor long-term measurements and investigations on effects of weather and spectral conditions on different PV technologies.

During the General Assembly Meeting in Freiburg from 8^{th} to 9^{th} February 2012, a meeting of NA2.8 permitted to validate the action plan proposal. In order to disseminate JRA2.6 results, an abstract was sent for the EUPVSEC 2012 conference in Frankfurt. The topic of this abstract is to estimate numerically the impact of environmental conditions (wind, locations, weather…) on the behaviour of PV modules in BIPV systems. The authors are CEA INES, AIT, Fraunhofer IWES, Fraunhofer ISE, and ENEA.

2.2 Barriers, needs and gaps

2.2.1 Si-Material

For the global strategic vision on the required research infrastructure, different aspects are important: (i) long term expectation concerning the environmentally most benign Si-material production, but at the same time (ii) the medium term requirements of the market have to be taken into account. In view of (i) and in alignment with the European Energy Research Alliance (EERA) a major focus was put on the requirements related to the development of "solar grade" feedstock due to expected lower cost, but especially also expected lower energy use in production and the related benefit for the environment. In 2011 the situation concerning material demand and supply for Si-photovoltaic underwent a change in focus due to the general oversupply of modules. In the course of a dramatic price decrease for modules on the market, the availability also for high quality and efficiency products, modules, cells and also high grade silicon starting material was extremely high. Consequently, the attempts to lower costs of modules by the use of lower grade starting material were strongly under pressure, since the actual gap in costs to be utilized was shrinking. Under environmental aspects this may well be a temporary effect. However, an extension of the previous focus on "solar grade" material appears necessary.

This development affects the initially defined central aim of this expert group, i.e. creating an overview of actual feedstock sources and expected development in this area. Essentially, at present feedstock sources on the market are dominated by virgin poly silicon, either from the Siemens or the Fluidized Bed process. Alternative feedstock is rarely found.

As a consequence, a second focus on the development and production of silicon material for high efficiency solar cell technologies is included. Here several areas of research needs are identified: Firstly, the material technology, linked to the requirements of solar cell processing, for n-type silicon has to be included. This topic is important as a link between the efficient use of material from the "solar grade" production route, which tends to have higher residual phosphorous content and the requirements for high efficiency solar cell technology. Although the topic did find attention in previous calls, this phase of initial exploration actually appears to lead into a phase of broad industrial interest with the associated necessity for more focused research activities. Consequently, already a proposal for a specific call in this direction has been formulated within EERA in 2011. This is seen as a starting point for a broader effort.

Secondly, the development of directionally solidified material of quality and/or crystal structure as close as possible to single crystalline silicon is important. Industrial activity in this area has grown very strongly in recent years. An adequate increase of research capabilities, especially covering the specific problems encountered here as especially the input of distributed line defects has not grown adequately. As outcome from the first overview, means to investigate and modify the properties of dislocated areas and the related defect engineering in crystal growth and solar cell processing are lacking. The presently running material intercomparison is expected to reveal a first evidence of this view.

2.2.2 OPV

Organic photovoltaic include several technologies where organic molecules or polymers constitute all or parts of the photoactive components. These technologies are either on an early commercial or pre-commercial state where applications depend on their special features like flexibility, ease of integration and semi-transparency. Wide spread use rely on maturing the OPV technologies to a level comparable to thin film PV. It requires a continued improvement of performance, lifetime, and high speed low cost processing methods. Although the lab-scale efficiency for a multijunction polymer solar cell reached 10.6% recently, it still takes a persistent effort to unify high performance, long lifetime, and ease of processing into a product apt for bulk electricity generation.

The needs for infrastructure relate to those development needs:

- Materials development: typically takes place within academic groups or industrial entities and the results are shared after proprietary rights are handled. The value of a superior material or materials class will be immense. However it is simply not very likely that such a material will develop through a quantum leap by a single entity or group - compare to i.e. the efforts of the pharmaceutical industry to develop one truly new drug. Hence a sharing of knowledge in wider consortia would benefit the development. No needs in term of infra structure is presently identified.
- Materials testing: there is a clear need for advanced materials test methods that give insight in structure, the photo properties, chemical and morphological changes during operation, and the chemical degradation mechanisms both for isolated materials and for materials in device configurations. Much of the instrumentation is relevant for a general materials science purpose but nanoscale chemical and morphological characterization techniques like X-ray microscopy with nm resolution is thought for.
- Processing: depends strongly on the technology. Laboratory processing is based on batch processing through wet chemical or physical deposition techniques i.e. spin coating, thermal evaporation and CVD. A growing number of groups employ continuous processing methods like Roll-to-Roll coating (R2R) but the field is characterized by a multitude of technical options. A strong selling point of i.e. polymer solar cells is that capital costs of printing production machinery are a factor 100 lower than the costs of a similar Si-PV production capacity. Despite of that, the development of processing methods and machinery that are linked intimately to development of materials and efficient barriers still requires large R&D investments. A structure with physical and virtual knowledge centers will be most beneficial for further progress in processing.
- Lifetime and stability: is a field with much ongoing collaboration among the OPV groups. Harmonization of test procedures, test equipment and development of common standards is an area where a special effort is needed for OPV because a number of the general PV standard test conditions are too hush for today’s level of OPV. A project like SOPHIA and a forum like EERA are excellent hosts for further work along these lines. With the maturing of OPV technologies an increasing need for test centers focused on OPV are envisaged.

2.2.3 Thin film

The WP had a slow start because of lengthy CA negotiations and other administrative issues within the topic leader organisation. A Round Robin test of is currently being organised and some of the main issues to be addressed are the preconditioning procedures of thin film tandem cells and the peak power measurements. The first TNA call including 4 research infrastructures at HZB has one application so far and TNA apparently needs more promotion by the consortium.

2.2.4 Cell Modelling

The increasing complexity of the used models and software makes validation and comparison or results exceedingly difficult. For this reason it is important that input parameters for simulations and simulation results are shared to enable validation and comparison. This sharing of data may be achieved by creating an open database.

We are discussing how to initiate interaction on modelling tasks and how to create a platform for interaction between technology and simulation. We are considering to create a map of PV contributors (who does what), and how can we utilize experts outside PV sector (e.g. specialists in materials simulation).

2.2.5 CPV

One main barrier to a widespread application of CPV is the lack of international standards. For an upcoming industry it is important to have international accepted standards. A promising example in this context is the standard IEC 62108: *Concentrator photovoltaic (CPV) modules and assemblies – Design qualification and type approval*. This standard helped the CPV companies a lot when communicating with potential customers, as it provides guidelines for minimum requirements to CPV modules for long-term operation. Unfortunately this is still the only international standard specifically devoted to CPV. There is a strong need especially for standards dealing with the rating and safety of systems and modules as well as guidelines for the specifications of trackers. Here the main focus is on the power and energy rating of CPV systems and modules. The power rating provides a rated power of a module or system under certain standard testing conditions. This is an important number especially when comparing modules and systems installed at different sites. Moreover the power rating is an important instrument for the performance of an acceptance test on site for an installed system. Besides the rated power of a system the expected yearly generated electrical energy is of highest importance for both, the manufacturer as well as the customer. Consequently, two of the main activities planned within the CPV part of the SOPHIA project also focus on supporting the development of rating procedures for CPV that can be applied to international standards that are under development in the IEC TC82 WG7 at the moment. On the one hand this is the application and testing of procedures for a power rating of CPV modules currently being discussed within the TC82 WG7 in the frame of a module round robin. On the other hand a spectral network will be formed in order to gain experiences on how the complex parameter "spectrum" can be implemented in an energy rating procedure for CPV modules.

A major reservation against a reliable operation of CPV is the lack of confidence in the trackers that are needed to assure optimum alignment of the CPV modules to the sun. In contrast to flat plate modules that are mounted on tracking units the failure of the tracker leads to a total breakdown of the electrical output in the case of a CPV system. In order to overcome the prejudices against the

tracking units the third major activity within the CPV part of SOPHIA deals with the assessment of the tracking units involved in the systems. Again input to the standardization processes is intended.
The main objective of NA 2.4 is to steer and control the activities in JRA 2.5 also with guidance by external partners (especially CPV manufactures). One major output of the activities within SOPHIA should be a substantial input to the standardization process for CPV, as the lack of international standards is recognized to be one of the major threads for a fast and widespread application of CPV.

2.2.6 Lifetime prediction

A large number of modules (> 90) are required for the testing in JRA01, and also a large number of climate chambers to perform the tests. Clearly, the extent of the test plan could not be performed by one institute alone.

In this joint research, three barriers were encountered:

- It was anticipated that the modules would be supplied by industry partners in exchange for access to the results. However, after long negotiations this proved to be impractical, as the industrial partners demanded too much control over the tests and dissemination of the results.
- It appeared that nearly all climate chambers at the partners are used for standard IEC testing. This makes implementation of the test plan at the institutes impossible. The tests will be performed at commercial test centers, at additional costs.
- The weight and dimensions of modules are much larger than wafers and cells. Although this is obvious, it does have large implications for the logistics of the test plan. This will add time and costs to the research activity.

In summary, the execution of a large test matrix on large solar modules outside of the standard IEC61215 tests has shown that there is a need for more flexibility and capacity in test facilities within Europe. It has also shown that there is a need for joint research independent of industrial partners, to push the standards beyond what is currently accepted.

2.2.7 Module and system performance

At its meeting in Chambery May 2011, the group identified a number of potential issues relating to module and system qualification and to qualification of BOS components. To determine priorities and timescales a questionnaire was prepared by IWES and Tecnalia and circulated on the group in October 2011.

The analysis of the replies received lead to the following recommendations:

- SOPHIA should collaborate with DERlab to finalise a guideline for outdoor measurements of PV module energy yield
- A round robin and/or intercomparison tests should be organised on real systems with defined shading characteristics and using different MPPT algorithms, in order to arrive at best practice guidelines for such tests.
- Guidelines should be developed for calculation of performance ratio, considering both assessment of operating systems and prediction of planned system performance. Such guidelines should also consider uncertainties in the input parameters and the impact on the

final PR value. The requirements for the inclusion of degradation rates should also be considered, in conjunction with JRA1 (module degradation).

- A dialogue should be opened with DERlab and/or DERri to establish what actions are already in progress or can be undertaken on inverter, integrated storage and other power management issues.
- A joint study should be organised on the different approaches used to estimating BOS losses to support the PR calculation guideline work.

2.2.8 BIPV

For the global strategic vision of NA2.8, a summary of identified BIPV barriers was the starting point. The action plan validated by the NA2.8 Expert Group during the General Assembly Meeting in Freiburg from 8th to 9th February 2012 consists in five activities.

The first action is to make a document for the state of the art on BIPV products and technologies and BIPV R&D activities and project. Secondly, each country has to give the definition and the vision of "BIPV" (Italia, Spain, Germany, France, Austria, others). Thirdly, partners have to make a list of functions that could be done by BIPV products. Fourthly, the description of the BIPV test facilities has to be updated. The fifth action consists in making a list of existing practices in order to characterize BIPV taking into account the energy production and the global energy balance of BIPV and building. Some of theses actions, especially the state of art are realized in the JRA2.6 subtask.

The action plan of JRA2.6 was modified and validated by the partners during the General Assembly Meeting in Freiburg. The first method is to realize a state of art of the BIPV systems by taking into account the energy (electrical and thermal) performance of PV modules in BIPV systems. The second method consists in performing a benchmark of all the partners' models available. Partners decided to use steady state models, as first step. Later, if necessary, dynamic models could be considered. This method will start with a benchmark considering that the width of the insulation layer is infinite. Then, a second benchmark will be done taking into account the interior temperature of the building. The third method is to realize studies in ICT test conditions which consist in setting the BIPV component in extreme operating conditions such as an infinite insulation layer or a high irradiation. The last method is to perform a comparison between measurement and simulation results in order to evaluate their difference. The case studies chosen could be based on the second method configurations or on TECNALIA KUBIK experimental results.

2.3 Ongoing activities

2.3.1 Si-Material

The ongoing characterization intercomparisons with support of WP 11 (JRA 3.1) is addressing already in the first round the different aspects as outlined in Section 2, where further development needs of infrastructure and specific measurement techniques is envisaged. Material of different origin, covering actual development directions, is included: Silicon crystals from upgraded as well as virgin poly silicon, (all p-type), and in addition n-type silicon. Mono-like directionally solidified material will be successively included into the running trial due to availability issues. The analysis, exchange and discussion of results will be a major task of the second project year. First conclusions derived by the expert group in a workshop planned for Mai/June 2012 will be reported in the interim report and used for the definition of the second intercomparison round. On the basis of the results delivered by the individual labs a focused experimental plan is anticipated, which addresses specific differences, unclear results or lacking information on material parameters.

2.3.2 OPV

An ongoing characterization inter comparison with support of WP 11 (JRA 3.2) aims at improving and harmonizing the test procedures, parameters and equipment in order to increase the interoperability of cell and module tests between European partners in EERA and SOPHIA. The project will carry through the first round robin study of stable organic solar cells at a range a laboratories. The study will identify differences in measurements methodology, instrumentations, and capabilities of the involved laboratories by characterizing both the OPV cells and a Si-reference cell. Subsequently, an ambitious inter laboratory test scheme for characterizing OPV lifetime will be set up. Delivering laboratories will fabricate 6-10 similar cells to be tested at each receiving test side. The large number will statistically even out the inevitable scatter in properties among OPV cells/modules and high light the test results. The scientific merit of the study is the larger diversity in tested cells and modules compared to previous studies. In particular the larger number of each cell/modules gives a statistical dataset that exclude or minimize random differences during test and handling of the cells.
The first part of the study is progressing in the first half of 2012.

2.3.3 Thin film

PV-EERA Workshop on Innovative Thin Film Device Structures

The workshop took place from 10. to 11. October 2011 on the premises of the Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) in Berlin, Germany with a total of 27 participants from 20 different institutions and companies. It was organised by Volker Hinrichs and Iver Lauermann from HZB and Jürgen Hüpkes from FZ Jülich. The first morning of day 1 was devoted to key note talks on current developments in thin film PV and on the potential and limitations of the most today's technologies (see agenda). In the afternoon a brain storming session and parallel working groups followed, where new ideas on the improvement of current devices and possible new concepts in thin film PV were discussed. These ideas were then worked out in more detail during the second day in separate working groups and written down as five proposals for the WP2013 within the FP7 of the European Commission. These proposals covered the topics encapsulants, light management, low cost processes, multifunctional materials, and new materials. They were submitted to the EC as part of a larger package of proposals from all EERAs in October 2011.

During the second half of day 2 of the workshop there was a meeting of the Cluster 2 – Thin film PV cells. (for information: http://ec.europa.eu/research/industrial_technologies/pdf/photovoltaics-nano-b5-27102011_en.pdf), where the status of current European projects in thin film PV was presented (see agenda) and discussed. The presentations during this meeting will be made available online as soon as all presenters have cleared them for publication. A brochure containing the abstracts was published by CEA. The co-organiser of this meeting was Bertrand Fillon from CEA (bertrand.fillon@cea.fr).

Meeting of the expert group on a strategic vision for PV infrastructure

The expert group meeting took place in Freiburg during the SOPHIA GA on 8.2.2012. Participants were Iver Lauermann (HZB), Stefan Abermann (AIT), Andreas Gerber (FZ Jülich), and Maarten de Bruijn (ECN). The purpose of this meeting was to collect ideas on the future requirements for a research infrastructure regarding thin film PV. It was started with a brainstorming based on the SRA Implementation Plan of the PV Technology Platform. The results will be used as a base for the work on the final document for the PV RI. Summary of outcome:

- Pilot plants for technology transfer (example PV Tec at ISE, PVcomB at HZB, ….) are important tools to help new technologies get into industry, should be supported further when needed.
- New technologies need specific infrastructure for preparation and characterization of materials and devices; these should be clustered to make best use of synergies and know-how. Barriers have to be avoided (e.g. IP barriers due to industry participation, lack of knowledge about the facilities, restrictions for safety reasons etc.)
- Many new technologies need similar RI and can profit from the same installations

Training workshop for TNA participants

In October 2012 a one week training workshop, mainly for prospective TNA participants at the HZB but not limited to these, is planned. It will cover synchrotron-based surface and interface analysis as well as EPR characterisation of thin film PV materials. The contact person for this workshop is Volker Hinrichs at HZB (hinrichs@helmholtz-berlin.de)

Round robin experiments

2 round robin campaigns involving thin film devices are currently being prepared:

1. Thin film tandem cells
   (leader HZB, Volker Hinrichs and Björn Rau (bjoern.rau@helmholtz-berlin.de)).
   The current participating institutes participants are:

Jürgen Hüpkes	FZ Jülich
Volker Hinrichs	HZ Berlin
Wilhelm Warta	ISE
Lucia Mercaldo	ENEA
Stephan Abermann	AIT
Anis Jouini	CEA
Nigel Taylor	JRC

Details on the round robin on thin film tandem cells can be found in the report on JRA 3.3.2.

2. Thin film modules, JRA 2.3 (leader Jake Bowers, Loughborough University, (J.W.Bowers@lboro.ac.uk)

These activities are all in a stage of preparation and definition of measurement conditions. Detailed information is available from the respective leaders.

Survey on TCO preparation and characterisation within SOPHIA (ongoing)

Leader: J. Hüpkes, FZ Jülich (j.huepkes@fz-juelich.de)

2.3.4 Cell modelling

We we have established contacts to JRA2 to utilize the database developed there for simulation results and input data. We still need to define the exact data to be stored in such a database (material properties, modelling tools, standard spectra, spectra for different locations, etc.).

2.3.5 CPV

At the moment the planning of the CPV module round robin and the formation of the spectral network are underway. These activities will start in 2012. Also the assessment of the influence of trackers is under way. Additionally it is planned to introduce the CPV activities within SOPHIA during the next IEC TC82 WG7 standardization meeting which will be held in April after the CPV 8 conference in Toledo, Spain. The intention is to make these activities known to the CPV experts involved in the standardization processes and to receive their input to the planned tasks

2.3.6 Lifetime prediction

Further discussions on the implementation of the test plan are ongoing. Thirty modules of three different types have been purchased and will be tested. Input for IEC TC82 WG2 will depend on the results of these tests. The first results are expected Q4/2012.

Once the tests have started, the required research infrastructure for lifetime testing will be defined in more detail. These will be related to existing strategic agendas. Contact will be made with the partner institutes to arrive at the definite composition of the expert group.

2.3.7 Module and system performance

In the second year the expert group will:

- work for the implementation of the above recommendations
- seek to identify further priorities in areas not directly considered so far, also considering the priorities identified PV Technology' Platform's 2011 Strategic Research Agenda.
- contribute to the SOPHIA strategic road map for PV infrastructure

2.3.8 BIPV

The ongoing activities are to realize the state of art on BIPV system. Then, the questionnaire has to be analyzed with all the responses of partners. This will permit JRA2.6 to select two or three cases for the benchmark. Then, some first ICT test conditions studies has to be done numerically or experimentally. The various available experimental data should be sent by the partners. Some results of these three steps will be presented in the M18 deliverable. A workshop on JRA2 has been proposed to the participants in order to discuss and to clarify the work to be done. It should take place at CEA-INES in Chambery.

3 Conclusions

During the first year, the expert groups per topic were set-up and the first recommendations were given.
More frequent interaction between partners is required to ensure speedy continuation of the project.

In the second year the expert groups will follow-up the implementation of these recommendations via SOPHIA networking and joint research activities, as well as contributing to the strategic roadmap for related R&D infrastructure.

4 References

N/A