Repairing of Photovoltaic Wafers and Solar Cells by Laser Enabled Silicon Processing – REPTILE

Grant Agreement nº 286955 - FP7-SME-2011-1

Final Report

Publishable Summary

Project Funded by the European Commission under the Programme "Capacities".

Research for the Benefit of SMEs

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Executive summary

REPTILE project ("Repairing of Photovoltaic Wafers and Solar Cells by Laser Enabled Silicon Processing") developed a laser-based technique for automatic repair of defective silicon cells and wafers, within the manufacturing line. The main aim is to improve the yield and competitiveness of the European PV manufacturing, representing an opportunity for European SMEs for the reuse of defective PV cells to produce custom low cost modules, covering a growing demand for small format, semi-transparent or custom shape PV cells.

The project resulted in the realization of a fully functional prototype system, able to automatically select and cut or isolate non-defective areas in defective cells and wafers, with computer based calculation of the best geometry for maximum efficiency and minimum waste of material. Proof-of-concept modules will be then built, installed and tested to assess the market potential.

Summary description of project context and objectives

REPTILE has provided the technology and methodology to transform a cheap and yet available material (scrapped cells and wafers) into small, customized and efficient PV cells and modules that can be installed on architectural solutions or in any other kind of solution as requested by the final customer.

The REPTILE project have demonstrated the viability of the repairing methodology developed within the project, for reusing defected solar cells and wafers to manufacture customized solar modules with higher efficiency than those manufactured with defected solar cells and even higher than solar modules manufactured with standard solar cells.

The project objectives as included in GA-Annex I are as follows:

- O.1. Definition of characteristics to be detected to identify damaged areas of the cells and silicon wafers which will be used throughout the project. (Achieved in month 12)

Related with deriverables: D3.2, D4.2, D6.1

- O.2. Selection of process parameters and requirements of the laser system to isolate and cut the areas selected by the system characterization. (Achieved in month 12)

Related with Milestone MS2 and deriverables: D2.1, D2.2, D2.3, D2.4, D2.5, D2.6

- O.3. Development of an automated characterization system, so that it will be able to identify the defective areas. Computing algorithm to isolate the optimal areas for higher efficiency depending on the initial state and desired final cell shape. (Achieved in month 17)

Related with Milestone MS3 and deriverables: D3.1, D3.3, D3.4, D4.1, D4.3

- O.4. Automation of laser process for cutting and isolation of defective areas. (Achieved in month 12)

Related with Milestone MS2 and deriverables: D2.7, D2.8, D2.9

- O.5. Integration of both systems (characterization and processing system) in a prototype which can fulfill the ultimate objective of the project. (Achieved in month 18)

Related with Milestone MS4 and deriverables: D3.1, D3.3, D3.4, D4.1, D4.3

- O.6. Development of laser based processes based to increase the added value of the final product (recovered cells and wafers). (Achieved in month 21)

Related with Milestone MS5 and deriverables: D7.2, D7.3

- O.7. Evaluation of the overall ecological footprint and economical issues of the complete developed methodology, market opportunity and replication potential. (Achieved in month 24)

Related with Milestone MS6 and deriverables: D7.1, D7.4

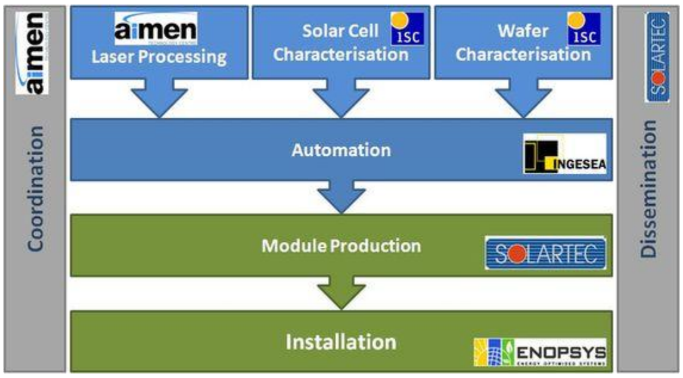
The whole defined project objectives were accomplished within the second project period. In GA-Annex I, the objectives are directly related with most of project deliverables, which allows to assess and measure the accomplishment of objectives and evaluate the project status for the second period, at the end of the project.

During the last period of REPTILE project, the work has been developed without any significant deviation in terms of technical and scientific development. All the tasks have been developed timely and delivering the expected results, so, the objectives of each particular task have been successfully achieved and reflected in the deliverables.

Following the recommendations from the first periodic review, some additional tests on multicrystalline silicon were performed and summarized in the project deliverables.

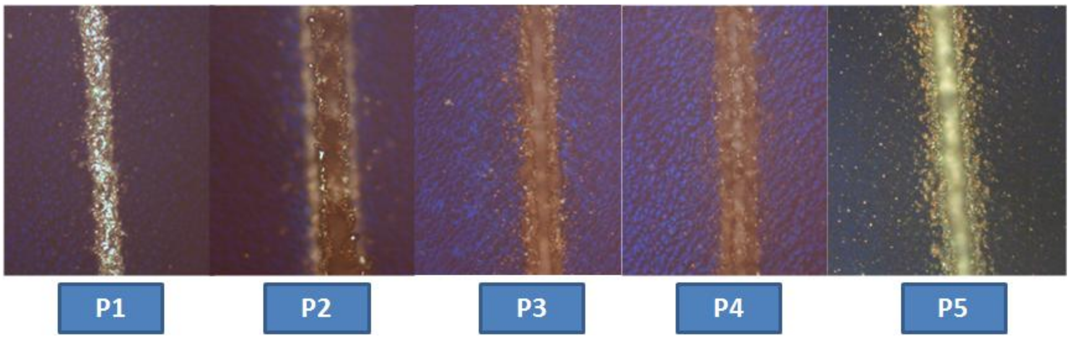
Description of work performed and main results

The work plan followed in REPTILE project is structured into eight Work Packages (WP) divided into different tasks, each one having a distinctive role towards the accomplishment of the project objectives.



Interdependences of Work Packages

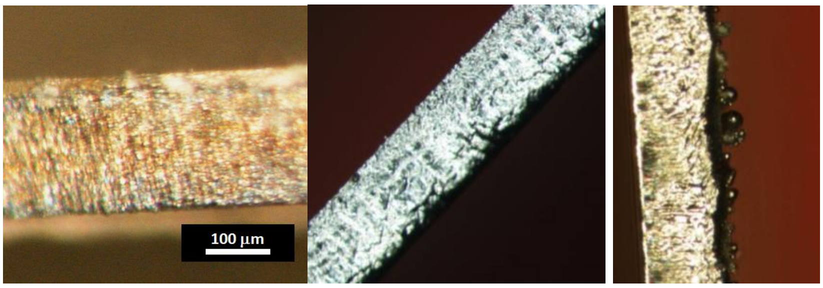
During the first period of the project, the main research activities leading to an automatic system design were accomplished. In terms of laser processing, contactless laser cutting (multipass remote cutting) and laser isolation were developed on several grades and qualities of silicon PV cells, by using Nd:YAG and Nd: YVO_4 pulsed lasers at ISC and AIMEN. The most relevant specifications involve the ability to perform scribing grooves of 30-40 microns in depth with a single pass, which impose strong requirements to the laser source: pulse width under 20 ns, high average power, high beam quality, and short wavelength.



Laser grooves on ARC coated silicon PV cells, optical micrographs for different parameter combinations

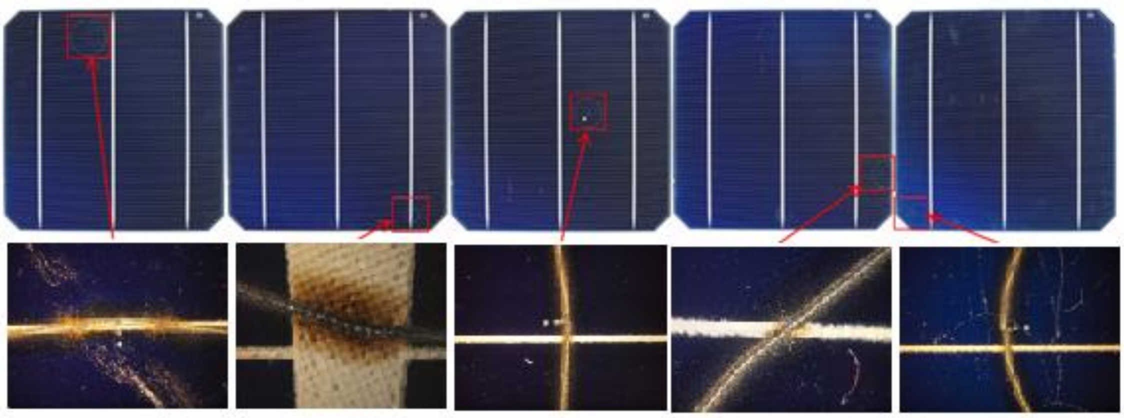
According to the performed experiments, the main technical limitation in scribing arises when trying to groove over the front metallization. Thus, the required fluence values and scan speeds to obtain consistent quality, leading to the need of high quality green or UV Q-switched lasers.

Silicon cutting of complex shapes has been determined as a critical process due to the brittle behaviour of silicon. Laser can induce defects by heat generation, melting, redeposition and shock waves: debris, recast, and microcracks. A series of experiments with fibre and vanadate sources was performed to allow the optimal selection of the laser source and beam guide elements, to bring a compromise between quality, cost-efficiency and productivity.



200 microns thick Si wafer cut with: Multipass 12 W 10 ns pulsed green laser, and single pass IR fibre laser

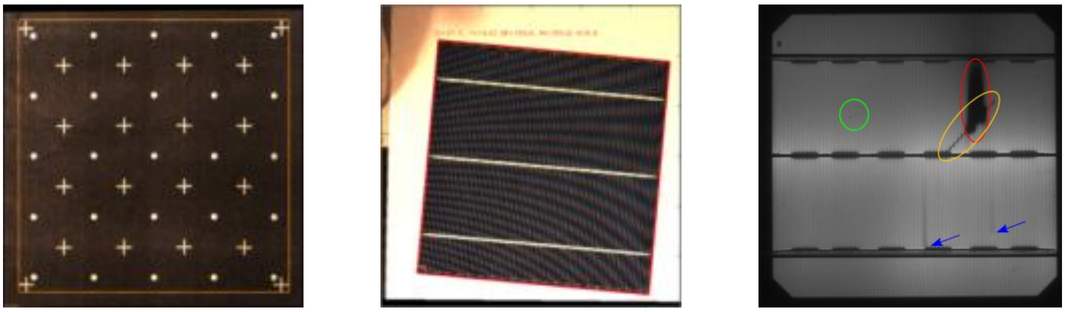
In second periodic, previous work during the first period of the contactless laser cutting (multipass remote cutting) and laser isolation, have been updated and optimal parameters have been obtained to optimize the process. Thanks to these tests, the laser requirements for the repairing system have been defined like the required laser source, optics and auxiliary equipment.



Through metal laser isolation paths with different parametric settings.

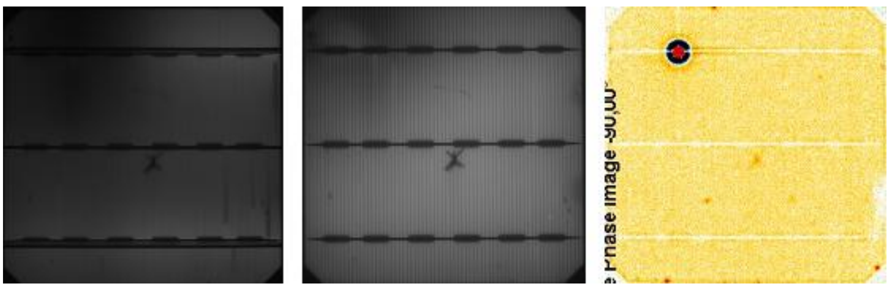
A first overall concept of the integrated automatic system was accorded among the partner in the first period, consisting on a single moving holder which transfer the cell between three stations: characterization, processing and sorting. The system will gather the information from the plant regarding general characterization of the cell (IV-curve, flasher, visual aspect), through the envisaged plant-level communication interface (OPC client-server based technology enabling multi-vendor data exchange).

A vision system and software has been developed for detecting the defects and to provide the laser repairing system with the required degree of automation and flexibility to ensure a proper operation of the whole REPTILE repair unit.



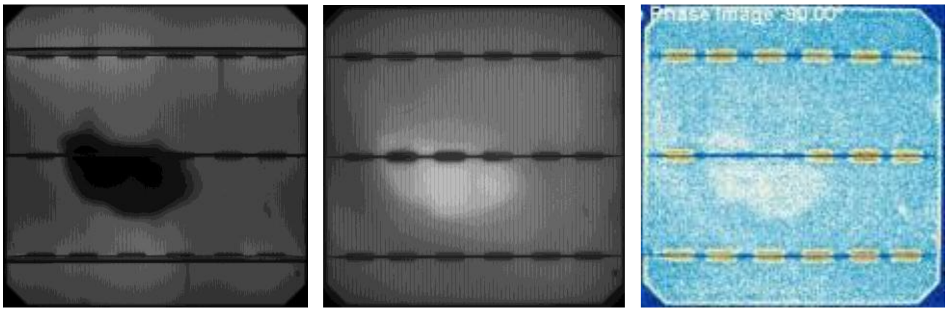
Components of the vision system: calibration pattern, shape recognition module and defect tagging module.

Complementary characterization methods will be applied. The main methods identified for this task are electroluminescence, photoluminescence, lock-in thermography and infrared transmittance, all oriented to the detection and spatial location of microcracks, recombination centres, shunts and hot spots.



Over 500 commercial (sorted out from production) and unconventional (manufactured for the project) cells were tested to detect different kinds of defects during the first period, allowing a reasonable prediction on the categories of different kind of cells depending of their reparability: cells needing laser isolation, needing area separation, needing multiple cuts, combination of them, or not repairable cells (3% of class D, less than 0.25% of the total production). A powerful combination of luminescence and thermography was tested to be able to detect all significant defects with enough spatial resolution to feed the repair system.

These characterization methods have been analyzed, selected and improved, including the hardware, software and analysis models, to obtain a characterization tools for wafers and solar cells to include in the final prototype. First tasks included the classification in wide defect families of major flaws in industrial rejected cells, to choose the optimal characterization method that allows the defect identification, quantification and geometrical tagging. PL and EL measurements were used to detect defects such as cracks, holes, shunts, etc. On the other hand, IV curves were obtained to measure the electrical parameters for the tested samples. Afterwards, a characterization line for wafers and solar cells was proposed to be included in the final prototype. Finally, such characterization equipment was built.



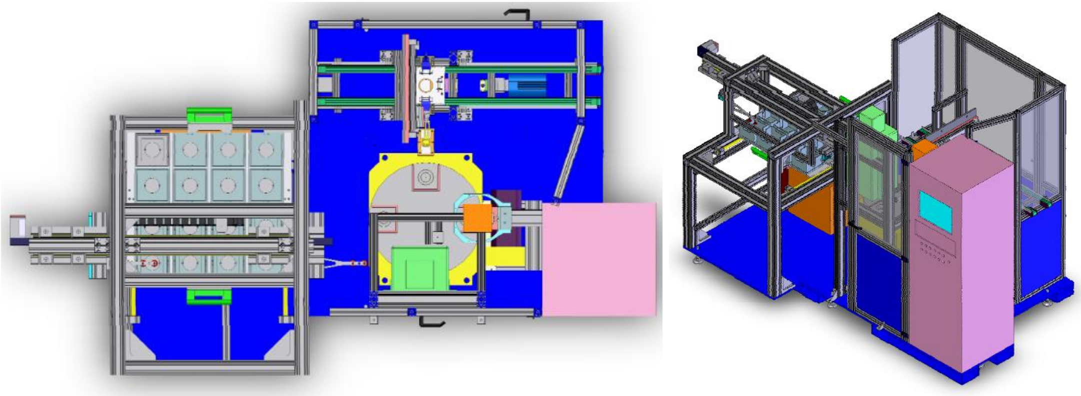
Back metallization defect under EL, PL and ILIT imaging.

Based on an analysis of the possible scenarios, the technical requirements for the processing in a real industrial environment were determined. In a modern production line with a particularly high percent of damaged cells, the target cycle time is over 10s. After an analysis of the available technologies and alternatives, generic specifications were determined to enable the performance of scribing and cutting of cells with a single laser source within the cycle time.

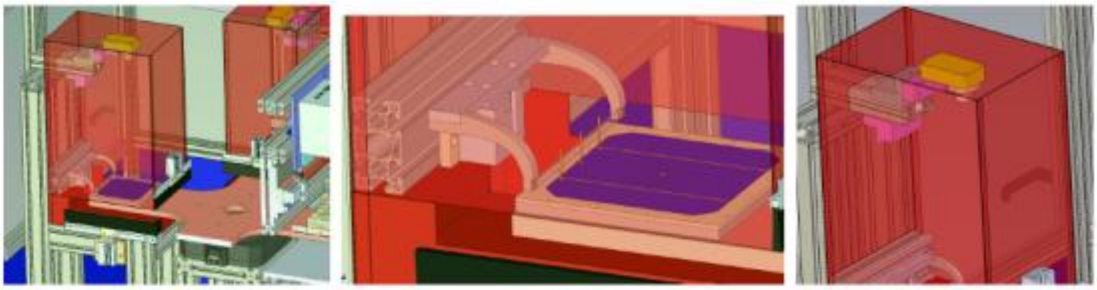
Besides choosing the proper laser source, the beam delivery path was designed in order to achieve the required quality and flexibility. In the case of REPTILE project, the right choice the focal lens is a key factor to assure the process energy density, precision, detail size. Given the working area size (typically 156x156mm) and restricted cycle time, scanner optics provide the best combination of features, while they are less accurate and repeatable than other optical arrangements. So a self-calibrating system will be developed based on vision.

REPTILE solution will take into account the inherent limitations given by the use of the scan head like the speed limit achievable by the chosen scan. It will be a key factor in some processes, mainly in cell singulation for cells with cracks or large inactive areas.

Two possible approaches are usually considered in the first period: the full multipass cutting and the scribe-and-cleave method: scribe down to 60% depth with subsequent mechanical snapping. A new method of multipass cutting with focal spot shifting was developed (effective cutting speed of 120-150 mm/min), together with a hybrid cutting strategy of close-to-full cutting. These innovations will couple with a brand new design of zonal cell handling system which will allow the automatic separation of the cells during the sorting phase.

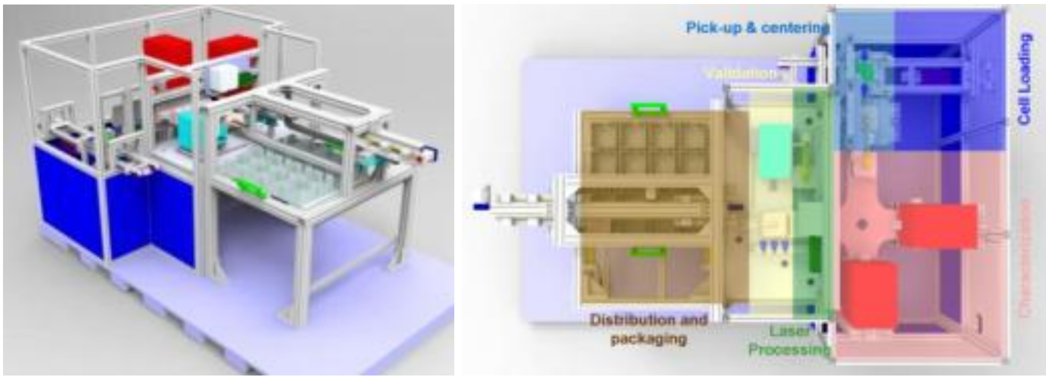


In WP5 developed during the second period, the components for the automation of the prototype processing system were conceived, defined and designed. The development of all the technology needed to fit all handling, diagnosis and processing operations in a single automatic system have been designed in this workpackage.



Details of the automated EL/IR system including automatic contacting system and carrousel positioner.

Prior to the assembly of the prototype system, the needed information to develop the required components to design and develop the prototype system was studied. The key element of the prototype is the integration between laser and characterization techniques. For this reason, the individual designs made in the laser processing and solar cell and wafer characterizations methods have been integrated into a unique machine, where other automation tools have been included to obtain a complete cell and wafer repairing machine. Several interlinked components have been defined: cell loading, pick up and positioning, characterization and laser processing, cleaning and final classification.

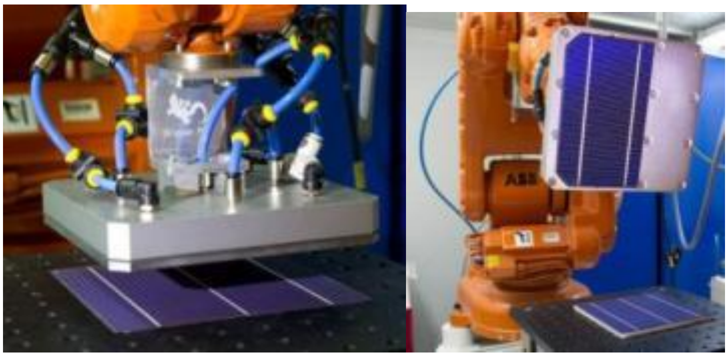


3D and plant designs for a full scale automatic cell repairing machine for in-line operation.

A novel design of gripper was developed for the sorting, as it is a critical point in the automation of the whole process to feed the repaired and modified cells again in the manufacturing line. The gripper is based on the Bernoulli gripper concept. A multisection integrated Bernoulli gripper with selectable active vacuum areas. This improves the gripping in broken cells and also allows to perform an automated sorting of custom cells cut-out from standard defected cells.

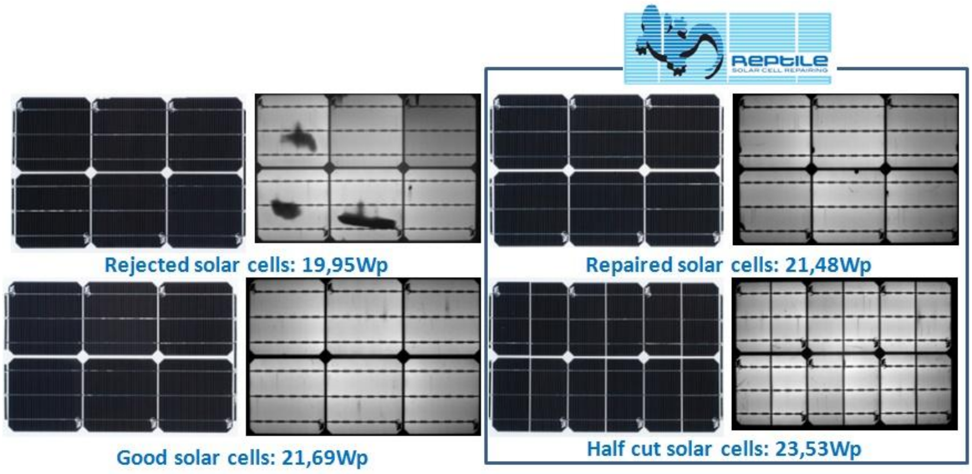
The characterization, laser process, handling device and data managing have been concurrently designed with the system layout, to enable an integrated repairing process which will be incorporated in a single prototype machine during the next project activities.

A special design of a gripper for the handling of the new sizes of solar cells has been developed and the gripper was manufactured.



Robot operated REPTILE gripper, showing selective holding of one cut half.

Demonstrators of solar modules were manufactured using the solar cells repaired by using the project prototype. These modules have been characterized to evaluate the effectiveness of the repairing process, achieving the following results:



The DEMO modules assembled with commercial, rejected and repaired cells, with their power outputs.

- Solar modules manufactured with GOOD SOLAR CELLS: 21,69Wp
- Solar modules manufactured with REJECTED SOLAR CELLS: 19,95Wp
- REPTILE solar modules manufactured with LASER REPAIRED SOLAR CELLS: 21,48Wp
- REPTILE solar modules manufactured with HALF LASER CUT SOLAR CELLS: 23,53Wp

Several demonstrators of different nature have been produced: solar cells, wafers and solar modules made out of laser processed rejected cells. These modules have been installed in two real applications: electrical powered tricycles and a carport. Characterization techniques have been applied in these demonstrators to check the quality of the resulting products. An economical evaluation of the viability of the machine as a business opportunity for its fabrication, and as a valuable asset for the user, has been elaborated and the potential end-users have been defined.

The last work packages focus on the dissemination of the results. Among other activities, a video and a Wikipedia page was made for the public dissemination.

Expected final results and potential impacts

The main aim of REPTILE project is to develop an automated method for repairing and reusing silicon wafers and solar cells, based on the interlinking of luminescence-based characterization and laser-based processing, by means of computer data processing in a single system.

To achieve this goal, some requirements need to be defined from the technical point of view, which should be met during the course of REPTILE project, including:

- Definition of characteristics to be detected to identify damaged areas of the cells and silicon wafers.
- Selection of process parameters and requirements.
- Development of an automated characterization system.
- Automation of process for isolation of defective areas.
- Integration of both systems (characterization and processing system).

Due to the nature of the wafers and solar cells selected to develop the REPTILE project, the end product (photovoltaic panels) will have an added value because of using waste and rejections of conventional industrial production of photovoltaic modules as raw material.

With the method developed within REPTILE project, an economic raw material will be obtained from discards of conventional photovoltaic industry to generate modules with customizable geometry that could be installed on architectural solutions (buildings, infrastructure, signalling, etc.) or in any other kind of solution as requested by the final customer.

REPTILE project aims to automate the repairing of silicon wafers and solar cells, based on the interlinking of luminescence-based characterization and laser-based processing, by means of computer data processing in a single system. Specific results are described in the following list:

1. Laser processing of silicon was optimized to perform wafers and PC cell defect repair operations.
2. Required characterization techniques have been defined for each raw material.
3. All components of the automatic processing system have been developed.
4. A fully operational prototype for repairing system have been designed and assembled.
5. Demonstrator solar modules were built for real applications and their performance assessed.

The performance of the modules built with REPTILE repaired solar cells was shown to be equivalent or even better than those of standard A class cells. Particularly, modules produced from halved cells (where the defect free half is automatically selected) perform better than conventional modules due to higher fill factor. Even if the EL image from repaired cells show some inactive areas, the result of this project show their excellent performance even in difficult conditions (like in the Solar Race competition), and comply all requirements for its use in all environments. This set of tests is very valuable to introduce a new product like the REPTILE modules in a very competitive market, and show the customers their potential benefit.

With a market of damaged, nonprime or rejected cells of over 1 GW currently identified, the demonstrated possibility of automatic repairing resulting in high quality modules can have enormous economical impact with minimal effort, as shown in the economic studies performed during the project.

Project public website address

www.reptile-project.eu/