Project no.:
679692

Project acronym:
Eco-Solar

Project full title:

Eco-Solar Factory: 40%plus eco-efficiency gains in the photovoltaic value chain with minimised resource and energy consumption by closed loop systems

Research and Innovation Actions (RIA)

FOF-13-2015

Start date of project: 2015-10-01
Duration: 3 years

D27/D 6.4
Scientific Workshop

Due delivery date: 2018-07-31
Actual delivery date: 2018-07-31

Organization name of lead contractor for this deliverable:
bifa

Project co-funded by the European Commission within the Framework Programme Horizon 2020 (2014-2020)		
Dissemination Level		
PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	
EU-RES	Classified Information: RESTREINT UE (Commission Decision 2005/444/EC)	
EU-CON	Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC)	
EU-SEC	Classified Information: SECRET UE (Commission Decision 2005/444/EC)	

Deliverable number:	D27/D6.4
Deliverable name:	Deliverable 6.4 Scientific Workshop
Work package:	WP6 Dissemination and Exploitation
Lead contractor:	bifa Umweltinstitut GmbH

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Abstract

This deliverable summarizes the results of the scientific workshop held in Munich on 10 April 2018 on the topics: Kerf-recycling, Quartz re-use / recycling, Graphite re-use, Defect / broken cells, Polymer materials for PV, Glass recycling and Metal recycling. Stakeholders from industry of the different sectors and consortium members of the H2020 project Cabriss were invited. 35 participants discussed the topics in 8 working groups. The results were summarized and distributed. A report was uploaded to the project website.

Public introduction[1]

Europe wants to reduce its needs for raw materials and raise the level of recycling of resources in the solar power industry. After the successful completion of this project the greenhouse gas emissions from solar panel manufacturing will be reduced by 25 to 30 % and the waste generated will be decreased by 10% minimum. Therefore, the re-use and recycling of PV module components are targeted including the PV industry as well as other industrial sectors. The tests results and/or feedback received about the recycling and reuse of the selected waste and by-products as e.g. silica/quartz crucibles, hot zone graphite, diamond wire and components of (NICE)-modules such as solar cells, copper ribbon or glass are presented. Samples of the wastes were prepared, characterized and their recycling and reuse potential was discussed with stakeholders from the value chain during a scientific workshop with 35 participants. The feasibility of the recycling and reuse processes was investigated for material quantity, quality, and commercial value/demand. Potential customers/users in existing industries were identified in accordance with the quality of the output materials of the recycling processes.

[1] All deliverables which are not public will contain an introduction that will be made public through the project website

TABLE OF CONTENTS

Page

1 INTRODUCTION

ECO-Solar aims overall resource efficiency in the photovoltaic cell industry by implementing a closed recycling economy by reuse of cell components. If the utilization within the photovoltaic cell industry is not feasible, other industries will be taken into account. As the global photovoltaic module production is going to grow in the next years and with the production being highly energy and natural resources consumptive, there is need for a recycling concept.
Within the framework of the *ECO-Solar* project a workshop with 35 participants on "How to create value from PV waste" has been conducted by bifa and BCC. Representatives of H2020 project "CABRISS" were also invited to present as well as to discuss the project results and synergies with ECOSOLAR. Possible buyers of the selected waste-streams, potential sellers of the selected waste-streams, potential technology providers that can turn the waste stream into economically viable products and recyclers of PV modules have discussed how to turn waste streams from the solar value chain into valuable products. The following waste streams have been identified to be most promising and valuable ones:

- Kerf-recycling
- Quartz re-use / recycling
- Graphite re-use
- Defect / broken cells
- Polymer materials for PV
- Glass recycling
- Metal recycling

The topics were discussed in 2 x 4 separate groups and the results were collected on canvas. After the workshop the results were distributed to the participants and a summary was published on the ECOSOLAR website.
During the workshop several ideas for the utilization of every kind of waste stream have been collected. Moreover some groups have agreed on further cooperation in order to develop a market for the wastes and convert them into products again.

2 WORKSHOP PROGRAM

The program of the workshop was as follows:

"How to create value from PV waste"
10th of April 2018 - Workshop programme
Maritim Hotel Munich, Goethestraße 7, 80336 München, Germany

09:30	Registration and coffee
10:00	Opening and introduction of the Eco-Solar project (Martin Bellmann / coordinator)
10:30	Purpose of the round tables (Karsten Wambach, WP-leader)
10:45	First parallel sessions: **Silicon, ingots and wafers** ***Kerf recycling*** ***1. CABRISS project results**:* Topic leader Terje Halvorsen (Resitec) presenting potential of their product so far ***2. GARBO**:* Topic leader Guido Fragiacomo (Garbo) presenting upgraded kerfs-loss for hydrogen fuels and sodium silicate ***Reuse potential of crucibles and their consumables*** ***3. Quartz reuse / recycling:*** Topic leader: Otto Paans (Boukje.com) Imagining concepts to recycle quartz in horticulture ***4. Graphite reuse:*** Topic leader: Karsten Wambach (bifa) Bifa to show some recycling techniques resulting in material interesting for SiCarbide and alloying additive / metallurgy
12:00	Feedback from the 4 topics (Topic Leaders to give a brief summary)
12:30 – 14:00	Lunch
14:00	CABRISS project overview
14:30	Short recap of purpose of the round tables
14:45	Second parallel sessions: **Cells, modules and components** ***5. Defect / broken cells:*** Topic leader: Wolfram Palitsch (Loser Chemie) ***6. Polymer materials for PV:*** Topic leader Imco Goudswaard (DSM) ***7. Glass:*** Topic leader: Karsten Wambach (bifa) ***8. Metal recycling:*** Topic leader: Oliver Friedrichs (Take-e-way)
16:00	Feedback from the 4 topics (Topic Leaders to give a brief summary)
16:30 – 18:00	Closing of the workshop with drinks and nibbles

3 PROCEDURE INSTRUCTION AND TASKS OF THE TOPIC LEADER

For each topic one topic leader was appointed from project participants and stakeholders prior to the meeting. A preparatory meeting took place in the afternoon of the day before the workshop to instruct the topic leaders about the methodology, applied processes and expected results. Guidelines for moderation were agreed on as well. The moderator information is presented below.

Procedure of the workshop rounds:

1st	2nd	
10:45	14:45	Welcome and introduction to the table topic (10 minutes).
10:55	14:55	Work in pairs (15 minutes): • Each participant builds a pair with one seatmate. • Each seatmate-group will get one canvas for notes. Together they will discuss the questions and write down their thoughts and results.
11:10	15:10	Group work - Poster 1 (25 minutes) • The group will discuss the questions of poster 1 based on their notes. • The group will fill in Poster 1 together. (Lead: Topic Leader).
11:35	15:35	Group work – Poster 2 (25 minutes) • The group will work out the market prerequisites (on Poster 2).
12:00	16:00	Presentation of the results in the plenary session.

Your tasks:

- Welcome the participants at your table.
- Give a short introduction to your topic.
- Work in pairs: Distribute the canvas for notes (each pair will get one canvas) and give an introduction, what to do.
- Lead the discussion on your topic table. Be sure to handle all questions from the poster and try to get detailed answers.
- Document the results on the poster or choose someone to help you.
- Present the results based on the poster in the plenary session.
  Optional: Choose a second round participant for presenting together.

4 RESULTS OF THE WORKSHOP

Workshop: How to create value from PV waste? on 10th April 2018 in Munich, Germany.

ECOSOLAR organized this workshop in cooperation with the H2020 project CABRISS. During the workshop, 35 participants from industry and institutes lively discussed the valorization potential of 8 different kinds of waste selected from the value chain of photovoltaic production. Several creative solutions were identified and collected on canvas. Some groups already agreed on follow up meetings to elaborate deeper on cooperation potential to market the wastes.

The topics, their major outcomes and market prerequisites are:

Topic 1: Kerf Recycling In Metallurgical Applications
Si-kerf can be purified to 5N quality and utilized as feedstock blended with other solar grade silicon. Impurities are water, glycol, oil, SiC, Diamonds, Fe, Ni, glass, oxidation products etc. Poorer qualities can be used e.g. in metallurgical applications. The major market for selling this technology is in Asia as the amount of kerf available in Europe is moderate.

Topic 2: Kerf Recycling for hydrogen fuels and sodium silicate
Si kerf can be purified and used for hydrogen fuels by oxidation of the Si particles in water with chemical additions. The material is converted to sodium silicates by reaction with sodium hydroxide. Storage and transportation of kerf is difficult for its high reactivity with oxygen and moisture generating hydrogen, therefore it is preferable to have the conversion process implemented at the same location where the wafer cutting is performed.

Topic 3: Quartz Reuse or Recycling (In Horticulture, Additives, Construction Materials etc.)
Crucibles that are used for melting and crystallization of silicon ingots are manufactured from high purity quartz or silica. After use, the crucibles break during cooling due to a partial phase transition of the glassy phase to β-cristobalite. The fragments may contain silicon, SiC, Si3N4 or SiO_x on their surface. The material can be used in horticulture or as milled quartz for additives (polymers, construction materials).
Other material can be used as SiO_2 source for cement, concrete, inorganic fillers etc. Horticultural applications or decorative tile manufacturing will require more time for market development. The market size in Europe for silica and quartz crucibles is small.

Topic 4: Graphite Reuse
Graphite is used for heaters, crucibles and heat insulation, in silicon crystallization furnaces and Czochralski pullers. It may react with Si and SiO_x vapor to SiC and CO. Si may also be deposited on the surface and in the pores of the graphite together with SiO_x. The mechanical properties may change. Potential applications of the graphite would be SiC, activated carbon, soot, electrodes, additives etc. Time to market could be 1 year for abrasives and around 4 years for more complex products.

Topic 5: Recycling/ Reuse of Defect and Broken Cells
The solar cells may be cut to smaller pieces and used in solar powered gadgets. Another option is to remove the metal layers, antireflective coatings and dopant layers with selective etching, so that the silicon can be used as solar grade silicon again. The application of recovered solar grade silicon has to be seen on long term, and strongly correlates with the poly silicon price and availability on the world market.
Alternatively, the metals can be recovered for use as Ag or aluminum compounds (e.g. for use as water chemicals). Poorer silicon qualities can be used in metallurgical applications.

Topic 6: Polymer Materials for PV
Most polymers are used energetically after recycling. Thermoplastics can in principle be melted and recycled, chemical recycling is under investigation as well. Development of recycling solutions for PVF, PVDF and other will require at least 1 year of R&D.

Topic 7: Reuse of Glass
Glass recycling is well established but due to the level of contamination, the glass from solar modules is mainly used as fiber or foam glass. Reuse in the flat glass or container glass industry is desired but requires high purity of the fractions. Implementation of new technologies can increase output quality within the next ten years.
Separate treatment of the polymer fraction during module recycling e.g. by thermal treatment allows high purity and yield of Si, Ag, Cu outputs.

Topic 8: Metal Recycling

During the recycling process the metals are separated with metal separators after crushing and/or milling of the modules. Al from the frames can be reused for remelting, Cu with Sn/Pb coatings can be recycled at Cu smelters, Ag from the solar cells can be removed via etching or melting of the solar cells. Cables go to cable recyclers. The existing metal recycling technology seems to be sufficient.

5 CONCLUSION

Several ideas on the utilization of the waste streams kerf, quartz, graphite, defect/broken cells, polymer, glass, metal have been collected with stakeholders of interested firms.

Si-kerf can be used for the production of Si-ingots again. First examinations show that ingot with an acceptable quality for PV modules can be created. The Si-kerf can also be used for production of silicon nitride (Si_4N_3) crucibles. First evaluations show that crucibles with good mechanical and physical properties can be manufactured with up to 20 % Si-kerf. Furthermore, the Si-kerf can be used in metallurgical application or for the production of hydrogen.

Currently there is no interest of quartz manufacturers in taking back the material. A possibility for utilization is given by the horticulture. Quartz can be used as filling material for gabions or in the production of terrazzo like tiles. Furthermore, utilization as decorative glass cullet is under investigation. Cooperation between a glass recycler and the quartz supplier has been established.

The use of the graphite is strongly dependent on its purity. While high grade graphite can be used for the production of metal carbides, low grade graphite can be used as recarburizer in the steel industry or in industrial felts.

The recovery of solar cells is quite difficult. A complete separation of individual components is mandatory. Only functional cells may be cut in smaller pieces and used in solar powered gadgets.

Polymers like thermoplastics can be melted and brought in the virgin market. Chemical recycling methods are under investigation. However, the polymers can be used for energy recovery.

The glass can be mainly used for fibre glass or foam glass production. By removing the contamination from the glass the utilization in the flat glass or container glass industry is also feasible. Intact glass sheets can be reused for PV module manufacturing in ideal cases.

The metals can be segregated by metal separators from the cullet. Aluminum from the frames can then be reused or remelted. Copper with coatings of tin and lead can be recycled at copper smelters. The silver from the solar cell can be removed by etching or melting. The cables can be utilized by cable recyclers.