Recycling and Reuse potential of NICE PV-Modules

Roland Einhaus(1), Frédéric Madon(1), Julien Degoulange(1), Karsten Wambach(2), Julius Denafas(3), Francisco Rodríguez Lorenzo(4), Samuel Costas Abalde(4),Tamara Delgado García(4), Axier Bollar(5)

(1)Apollon Solar, 69002 Lyon, France; (2) bifa Umweltinstitut GmbH, 86167 Bamberg, Germany; (3) UAB Soli Tek R&D, Vilnius, Lithuania; (4)AIMEN, Laser Applications Centre, 36418 Porriño-Pontevedra, Spain; (5) INGESEA Automation SL, Elgoibar, Spain

***Abstract* — In difference to laminated state-of-the-art PV modules, major components of Apollon Solar's proprietary NICE ('New Industrial Cell Encapsulation') modules are not physically attached to each other due to the absence of soldering and lamination. This allows for an efficient and low-cost disassembly of end of life NICE modules into their original components, such as glasses, copper connectors, solar cells. The fact that these components can be recovered as entire pieces opens up a more sustainable and high value recycling and reuse potential, in terms of waste management towards a circular economy.**

This work reports results from feasibility studies on the disassembly of NICE modules and recycling/reuse of their components, carried out in the frame of the European H2020-FOF-13-2015 'ECOSOLAR' project.

I. Introduction

The continuous strong global growth of the PV industry, with a compound annual growth rate in the order of 40% in the past years and with an installed capacity close to 100 GW in 2017 has a strong, positive impact on securing current and future electricity requirements worldwide, at a reduced environmental impact. However, to be fully sustainable as a technology the increasing amount of future waste streams from decommissioned end-of-life PV modules needs to be assessed as well.

According to projections published by IRENA (International Renewable Energy Agency), the cumulative PV module waste amounts to 1.7 to 8.0 million tons in 2030 and to 60 to 78 million tons in 2050. The corresponding potential economic value creation related to recovered raw materials from this module waste is estimated to 450 Million US$ in 2030 and to 15 Billion US$ in 2050 [1]. As end-of-life management for PV modules is likely to become an increasingly important element of the PV value chain in the near future, it becomes important to develop and implement sustainable and cost-effective recycling and reuse technologies for end-of-life modules. On the legal side, waste regulations and directives such as the European WEEE (Waste of electrical and electronic equipment) directive, which applies to PV modules, act as an additional driving force for end-of-life management of PV modules.

Overviews on recycling technologies, including challenges, for current state-of-the-art crystalline Silicon based modules can be found in the literature. As pointed out for example in [2], today's PV module recycling technologies are rather destructive for module components and energy intensive, once the Aluminum frame and the junction box have been removed. The architecture of all major state-of-the-art crystalline Si modules includes lamination of the solar cell strings, using organic products (such as EVA), between a glass front and an organic or glass backsheet, as well as soldering of the interconnecting tin coated copper tabs to the solar cell contacts to establish solar cell strings. Since all major module components are physically linked these links need to be broken in order to disassemble the modules into its components.

Apollon Solar's NICE modules are frameless glass/glass modules that use an underpressure to establish contacts between solar cells and pure copper tabs instead of soldering. The inner volume of NICE modules is filled with neutral gas and sealed from the outside by a double edge seal, consisting of poly-iso-butylene (PIB) and silicone. Solar cells and copper tabs are fixed to the rear glass by an adhesive such as PIB, to keep these components in place during the module manufacturing. A detailed description of the NICE technology can be found in literature [3].

The absence of soldering and lamination in NICE modules allows for a simplified disassembly and the potential recovery of module components as entire pieces, which present an increased value for recycling and reuse. This point has been explored by feasibility studies in the frame of the European H2020-FOF-13-2015 ECOSOLAR project [4] that has as overall objective an increased resource and energy efficiency by introducing recycling and reuse technologies along the entire PV value chain.

The module workpackage of the ECOSOLAR project aims at increasing the resource efficiency, production yield and remanufacturing options for PV modules. This paper reviews results obtained in subtasks related to the disassembly of PV modules with diagnosed production failures or end-of-life modules, focusing on Apollon Solar's NICE modules. In addition to the disassembly remanufacturing and reuse options of major module components, directly in the PV industry or outside of the PV sector are investigated.

II. NICE MODULE DISASSEMBLY PROCESS

In order to maximise the recyling and reuse value of recovered module components the following requirements are regarded to be important:

- Recovering of components as entire pieces
- Absence of contamination by other materials
- Clean residue free surfaces

As part of the project work program, disassembly runs have been carried out on 5- to 8-year-old, industrial NICE modules that were used during the ramp up of the first industrial NICE assembly lines. These modules are typically 60 (mono- or multi-crystalline Silicon) cells modules with STC powers up to 250W.

During the project different disassembly techniques have been tested and developped by Apollon Solar and project partners INGESEA, Bifa Umweltinsitut and AIMEN. The process starts by penetrating the combined PIB/Silicone edge seal by cutting through the seal around using industrial thermo-cutters, or standard cutters combined with a hot air gun. The local heat impact was found to be important to soften the organic sealing material for a more efficient cutting action. By this step the underpressure inside the module is released at the same time. Figure 1 shows a sequence of photos from a manual disassembly run of an old NICE module at Apollon Solar.

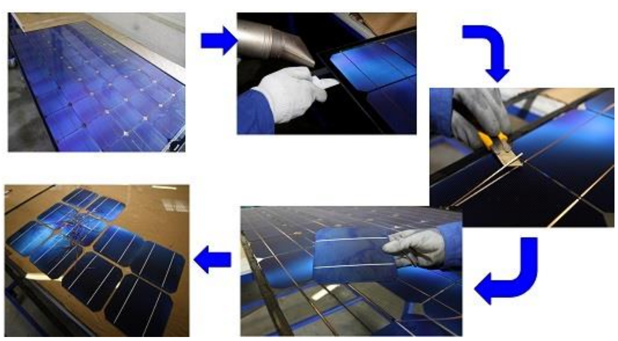

Fig. 1. Manual disassembly sequence of an industrial size NICE module.

After this step the front glass can be released as entire piece as shown in Figure 2.

The release of the pure copper tabs from the cells is relatively straightforward due to the absence of soldering and allows to recover the copper tabs as entire pieces as well, as shown in Figure 3.

Fig. 2. Recovered front glass from a disassembled NICE module

Fig. 3. Recovered copper tabs from discarded NICE modules.

The detachment of the cells from the rear glass, including the copper tabs from the cell rear surfaces presents a challenge due to the strong adhesion of the PIB that is used for fixation of both, cells and copper tabs onto the rear glass. Cells often break during this detachment process, that so far combines localised heating and mechanical gripping/twisting. Collaboration with the project partners bifa, INGESEA and AIMEN has allowed to progressively optimize the disassembly process, in particular concerning the removal of PIB from glass, copper tabs and cells.

AIMEN demonstrated the detachment of PIB using a pulsed nanosecond IR laser and bifa the use of heat and different chemicals, including solvolysis and reacting agents.

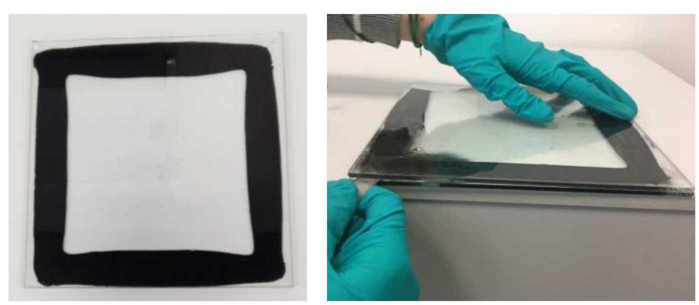

Fig. 4. a) Glass-glass sample sealed with PIB, b) opened corner after being processed with an IR nanosecond laser.

As a proof of concept, AIMEN has employed an IR nanosecond pulsed laser with a fundamental wavelength of

1064 nm and an average power of 16W in order to eliminate the PIB used to seal glass-glass samples (see Figure 4).

In addition, alternative fixation materials for the cells and copper tabs, with a less strong adhesion and easier release potential, are also investigated.

As a final outcome of the project, INGESEA works on a study and design of an automated disassembly line for NICE modules, integrating the above-mentioned disassembly process. Combined with diagnostic systems such as EL or IR imaging, such a tool can be used in module production for direct repair or reuse of components from production reject modules (for example due to cell breakage).

A second application would be the disassembly of end-of-life NICE modules for recycling.

III. RESULTS: CHARACTERISATION AND RECYLING/REUSE

a) Glasses

Recovered module glasses are optically inspected and characterized. Figure 5 shows one of the corners of a recovered fully tempered, extra white, 3mm module glass without antireflective coating from an old NICE module. It can be seen that the glass is relatively clean and transparent, only a few dots of residual PIB can be identified.

Fig.5 . Corner of a recovered front glass sheet from a discarded NICE module.

Project partner AIMEN has worked on optical characterization methods to analyse the quality of the recovered glasses, focusing on photoelasticity imaging (diagnosis of mechanical stress and other failures) and transmission spectroscopy (diagnosis of degradation of the AR-coating).

As an example, photoelasticity images of unstressed and stressed glass samples are presented in Figure 6 showing characteristic fringe patterns. Comparisons between undamaged and intentionally damaged samples, with a laser-imposed crack, have shown qualitatively more important stress patterns with higher optical contrast in damaged areas.

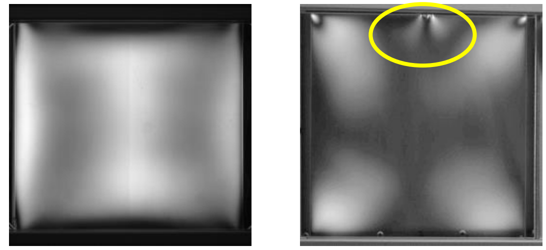

Fig.6. Photoelasticity images of an unstressed (left) and an intentionally stressed glass (right).

Project Partner Soli-Tek reused recovered front glass sheets from discarded NICE modules to assemble new laminated glass/backsheet modules on their industrial module line, using Al-BSF multi-c Solar cells. From a technical point of view the reuse of these glasses worked perfectly. The STC IV data of two of these modules are shown in Table 1.

TABLE 1

STC IV-data of 2 industrial laminated modules by Soli Tek reusing recovered front glasses from discarded NICE modules

Module ID	*Isc [A]*	*Imp [A]*	*Voc [V]*	*Vmp [V]*	*Pmp [W]*
ECOSOLAR old glass #1	8.87	8.29	38.26	30.27	250.88
ECOSOLAR old glass #2	8.92	8.33	38.35	30.30	252.53

Taking into account that the old recovered glass sheets did not have an AR coating, the obtained Isc and power are in the expectable ranges. The modules have been subjected to degradation tests, in particular a PID test protocol (96h at 60°C and 85% r.H.), which resulted in a power degradation of 0.58%. However, an observed delamination of the backsheet on the module edge gave an indication of a non-perfectly cleaned glass surface.

b) Copper tabs

Recovered copper tabs from discarded NICE modules have been chemically analysed by ICP OES at bifa, showing a copper concentration of 99,93 %. Other elements were below the detection limit, giving rise to a high recycling and reuse potential and taking into account the total mass of approximately 60g of copper per 60 cells module.

IV. DISCUSSION

In order to arrive at an optimised and high value waste management scenario for end-of-life or production reject PV modules each module component needs to be evaluated on an individual basis, for their optimum recycling and reuse potential, either directly within the PV industry, or outside. Regarding the case of NICE modules of this study, the highest potential in terms of technical feasibility and economics is attributed to the glasses and pure copper tabs provided that they are free of cross contamination by other materials.

In case of glasses from end-of-life modules after 20 and more years of outdoor exposure the direct reuse in new modules seems questionable due to potential corrosion and degradation. However, the recycling for reuse in the glass industry shows a high potential due to the clean aspect and absence of lamination products.

In case of production reject modules a direct reuse of glasses for new NICE modules can be envisioned however, resulting in a higher material yield in production.

Solar cells from discarded PV modules present a more limited reuse potential as entire pieces, as the cell technology constantly progresses. However, solar cell materials such as Silicon or Silver have a recycling potential from a pure material point of view and based on separation techniques as for example described in [4].

Other components such as junction boxes have a low recycling and reuse potential from end-of-life modules as they are difficult to detach without breakage or damage and likely occurred degradation over the years in use.

IV. CONCLUSION

The recovery of entire and intact glass sheets as well as copper tabs from discarded NICE modules has been demonstrated, which opens up higher value recycling and reuse scenarios in terms of PV waste management.

In case of the glass sheets a reuse in new PV modules has been demonstrated, which could be an industrial solution for production reject modules.

V. ACKNOWLEDGEMENTS

This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No. 679692.

REFERENCES

[1] IRENA (International Renewable Energy Agency), *“End of life Management – Solar Photovoltaic Panels”, 2016,* p.13, ISBN 978-92-95111-98.

[2] W-H. Huang et al.: “Strategy and technology to recycle wafer-silicon solar modules”, *Solar Energy 144 (2017), p.22.*

[3] J. Dupuis et. al.: “NICE module technology – from the concept to mass production – a ten year’s review”, *Proceedings of the 38^{th} IEEE PVSC, 2012.*

[4] M. P. Bellmann et al.: “ECOSOLAR Factory: 40% plus Eco Efficiency gains in the Photovoltaic value chain with minimized resource and energy consumption by closed loop systems” *Proceedings of the 32^{nd} EU-PVSEC, 2016, p. 175*