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EU-RES	Classified Information: RESTREINT UE (Commission Decision 2005/444/EC)	
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Abstract

This deliverable deals with the re-use of NICE Module components being investigated at bifa. The experiments carried out verify the feasibility of damage-free disassembly. The recovery and re-use of components are assessed. The repair of recovered components such as defective solar cells and subsequent re-use are taken into consideration. In addition, the quality requirements are checked. In addition, bifa takes a closer look on the waste regulations concerning the NICE Module. The analysis of the samples and the NICE Module is finished.

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. Our target is that 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.

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

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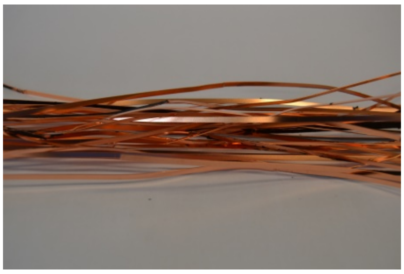
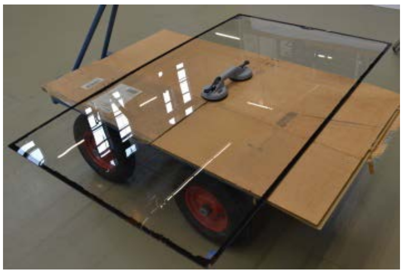
1 INTRODUCTION

The laboratory and disassembly tests of the retrieved NICE Module components verify the feasibility of a damage-free disassembly and furthermore, the re-use and recyclability of the components. The quality of the material recovered is remarkably high; however, an automatic treatment of the end-of-life NICE Module is needed to exploit the value of the fractions. Below, the recovered NICE Module components are shown in pictures 1 - 6.



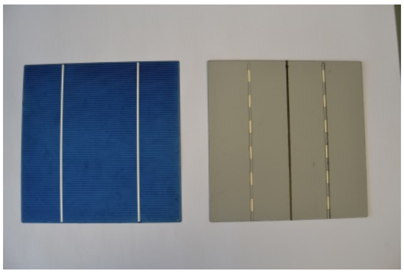
Picture 1 and 2: copper wire (left) and copper wire with Sn-layer (right)



Picture 2 and 3: Glass sheet (left)/cullet (right**)**

Picture 4: Al-frame

Picture 5: PIB retrieved from NICE Module



Picture 6: solar cell

2 LABORATORY TESTS

2.1 NICE Module Recycling

2.1.1 Properties of NICE Module

The solar power is pollution-free during use, however, the production of PV-modules demands considerable energy and natural resources. Under the assumption that the PV-industry is growing steadily, hence it follows that the resource consumption is increasing enormously, too. Moreover, recycling is hardly factored during module production resulting in a need of efficient recycling techniques as well as a recycling-friendly module design with regard to the growing PV-industry. The NICE Module offers the opportunity to re-use module components within the solar industry and other applications due to the design which enables a damage-free extraction of the components. Furthermore, the purity of the retrieved components is comparably high with respect to standard modules.

Two NICE Modules are being examined at bifa. At first, a composition analysis takes place. Therefore, the compounds are listed and properties are recorded. In addition, the feasibility of damage-free disassembly was assessed. The results are presented below.

Table 2.1: Properties of NICE Module

property [unit]	value
mass of module with frame [kg]	30.0 ± 0.5
length of module with frame [cm]	167.5
width of module with frame [cm]	100.0
height of module with frame [cm]	5.0
mass of module without frame [kg]	26.12 ± 0.5
length of module without frame [cm]	166.5
width of module without frame [cm]	99.0
thickness of module without frame [mm]	6.14
mass of frame [kg]	4.02
thickness front sheet [mm]	3.2
thickness back sheet [mm]	2.9
number of cells [-]	60
mass of a cell [g]	10.89 ± 0.5
total mass of cells [g]	653.4 ± 0.5
thickness of a cell [mm]	0.121
mass of used module busbars, Cu with Sn-layer (interconnection) [g]	18.43 ± 0.5
mass of used module busbars, Cu-tabs [g]	58.52 ± 0.5

bifa has conducted disassembly experiments and based on these, developed a preliminary recycling path of an end-of-life NICE Module. Figure 2.1 depicts the possible recycling way.

Inspection

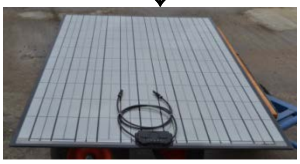
→ **Repair**

↓

Recycling

↓

Intermediate Storage



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Removal of Frame

→ metal industry (Al extrusion)

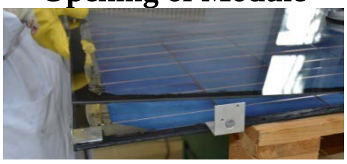
↓

Removal of Junction Box

→ plastic and metal recycling
thermal treatment

↓

Opening of Module



Separation of Front Glass with hot blade

→ reuse as glass pane, e.g. as PV glass
(flat) glass industry for cullet

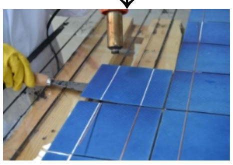
←

Optical Sorting

Removal of PIB

↓

Re-use of Cell Fragments

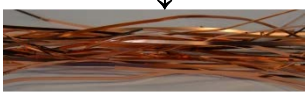


Cell Separation/Cell Laser Cutting

→ reuse of laser cut cell fragments for solar applications,
solar cell production
metallurgy,

↓

Cu Interconnectors for Cu Recycling



→ metal industry,
cable & wire recycler
electronics industry/recycling

Figure 2.1: NICE Module Recycling

2.2 NICE Module: Composition Analysis

2.2.1 Analysis of Solar Cells

In order to analyse the solar cells, they are removed from the NICE Module. Afterwards they are analysed by ICP-OES. The values of the analysis are in the table 2.2. The results reflect the tested module with its cell, the cell technology is under development in the project and the composition may change (e.g. reduction of Ag content).

Table 2.2: Results of ICP-OES (example cell)

element	wavelength [nm]	average value of mass [mg/cell]
Tl	190.801	6.4
Cd	228.802	not detectable
Ag	338.289	205.8
Al	396.153	934.7
Cu	327.393	0.4
Pb	220.353	4.4

It is desired to replace the silver on a large scale by a more cost-effective metal like copper.[2] This replacement still demands a lot of research and development and is expected to be introduced step by step in the next years. By the time being, silver remains the most widely used metallization material in the solar cell production.

Nevertheless, as a further step for the reduction of Ag consumption on solar cells, a second series of mini NICE Modules have been produced using busbar free bifacial solar cells that have been acquired externally from an industrial cell producer. The performance of the cells has not been available, yet, this time due to difficulties of contacting busbar free cells for testing in a solar simulator. There is a risk of a certain mismatch and lower performing modules again.[3]

2.2.2 Analysis of Used Copper Wire

The purity of the used copper wire is 99.93%. Other elements are below the limit of determination and therefore not detectable. The copper wire is analysed by ICP-OES. Copper is the dominant interconnector material but its market share will decrease in the next years due to alternative cell interconnector materials like conductive adhesives which shows lower thermal stresses[4]. These thermal stresses, due to the soldering process, are an issue concerning a direct re-use of extracted copper wires in a new solar module. This material does not fulfil the quality demanded. Concerning the NICE Module this has to be checked.

[2], International Technology Roadmap for Photovoltaic (ITRPV), 2016 Results, Eighth Edition, March 2017
[3] Referring to Apollon Solar's M24 Technical Report

2.2.3 Removal of PIB from NICE Module Compounds

The removal of the PIB residues from the NICE Module components after disassembly is necessary with regard to the re-use opportunities. The thermal treatment of the module components is an option but this process has got a high energy demand. Therefore, the removal of PIB with a non-polar solvent is a possibility to replace this kind of treatment. Some samples of module compounds are put in a vessel filled up with a solvent for a certain time. Afterwards it is examined if the PIB residues are removed by the solvent.

It is observed that only the treatment with n-hexane shows an effect. All other substances with a higher polarity do not react with the PIB apparently. The summary of the results are shown in the table 2.3

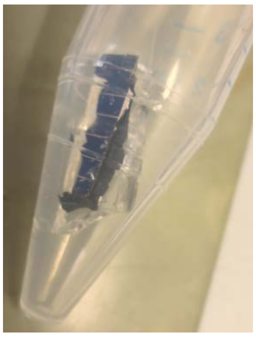
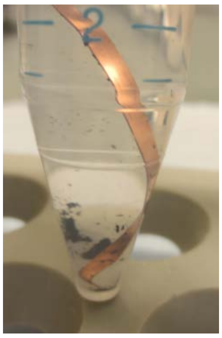
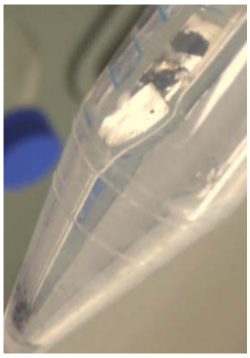
Table 2.3: Results of chemical treatment experiments with several solvents

	substance	**PIB**	**silicone**	**compound (glass, cell, PIB)**	**copper with PIB**	**copper / tin with PIB**
polarity increases from top to bottom	n-Hexane (5 ml)	high solubility after some minutes	high solubility after some minutes	PIB dissolves	PIB dissolves	PIB dissolves
	n-Butanol (4 ml)	no reaction	no reaction	no reaction	no reaction	no reaction
	Dimethyl sulfoxide (4 ml)	no reaction	no reaction	no reaction	no reaction	no reaction
	PEG 200 (4 ml)	no reaction	no reaction	no reaction	no reaction	no reaction
	1,2 Propylene glycol (4 ml)	no reaction	no reaction	no reaction	no reaction	no reaction

Table 2.4: Chemical dissolving of PIB (Polyisobutylene) and silicone with n-hexane

PIB	**Silicone**	**Compound**	**Copper with PIB**	**Copper / tin with PIB**



Taking this into account, tests of new chemical and mechanical approaches for the removal of PIB residues from glass and copper connectors have to be conducted. In addition, tests of alternative fixation material to easer separate cells from NICE Modules are made by Apollon Solar. They are testing acrylic foams as a substitute of PIB glue, but experiments with a real PV Module are outstanding. A first test showed that these foams were easy to remove from the glass.

2.3 Waste Regulation Assessment of the NICE Module

The waste regulation assessment is based on the data of the NICE Module delivered by Apollon Solar as well as on the disassembly experiment and the subsequent separation of the compounds at bifa. The definition of appropriate waste streams is the main goal for further considerations concerning recovery/recycling routes and reuse opportunities. Furthermore, the waste streams have to be analysed with respect to hazardous waste criteria. Referring to the state of art modules, some module compounds can be seen as hazardous waste, for instance Cd-containing bus bars or polymers. Identifying the share of the several compounds and allocating the waste key numbers to them is fundamental for the assessment. The table 2.5 shows the waste streams.

Table 2.5: Different waste streams of the NICE Module

no.	waste streams	main material	containing/adhering substance(s)
1	**Al-frame**	Al	aluminium alloy ($AlMg_3$) polyisobutylen (PIB) silicone product
2	**glass**	soda-lime glass	PIB silicone product
3	**solar cells**	mc/sc-Si	Ti, Ag, Sn, Pb, Cu, Ni, Pd PIB
4	**composite material**	PPE PS	-
5	**junction box**	PPE/PS flame-retardant V-0/5V	-
6	**wires**	Cu HDPE	-
7	**electrical connector**	Cu, Sn, diode, lead	-
8	**NICE Module**	BOM	-

		given by Apollon Solar	

The next table presents the different, preliminary recycling possibilities of the NICE Module compounds.

Table 2.6: NICE PV Module compounds and possible recycling ways (non-exhaustive)

module compound	material	percentage by mass [%]	possible use of output
glass	soda-lime glass	30-65	reuse as solar glass (flat) glass industry horticulture building industry
composite material	Acrylate PU	5-10	thermal treatment separation
rear side covering	polyester Aluminium steel glass	0-10 (without glass)	plastic recycling metal industry glass industry thermal treatment (polymers)
frame	aluminium steel PU PC	0-20	metal industry plastic recycling thermal treatment (polymers)
junction box	ABS, PC, PPO, PET	0-5	plastic recycling thermal treatment
wire	Cu polyolefines synthetic rubber	ca. 1	metal industry cable recycler electronics industry/recycling plastic recycling thermal treatment (polymers)
sealant	silicone polyacrylate PE – foam PU	0-10	thermal treatment
filler materials	Al_2O_3, TiO_2, $CaCO_3$, SiO_2, C	ca. 1	Fillers, mineral additives
solar cells	Si, Ti, Ag, Sn, Pb, Cu, Ni, Pd	5-10	Reuse of laser cut cell parts metallurgy solar cell production
electrical connector	Cu, Sn, Pb, Al, Ag	ca. 1	metal industry electronics industry

In compliance with EWC (2014) Annex III of the regulation 2008/98/EG the threshold values do not refer to solid metal alloys in general. Exceptions are marked in this regulation.

The Al-frame consists of an aluminum/magnesia-alloy which is not be classified as a hazardous waste. It is been taking into consideration if the residues of PIB and silicone have an influence on this classification (PVA 200 Comp. A und PVA 200 Comp. B.The assessment of the Al-frame waste stream is shown in table 2.7.

Table 2.7: Assessment of the waste stream Al-frame

CAS no.	material	percentage by mass in the original product [%]	relevant R-phrases	H-phrases
-	aluminium alloy ($AlMg_3$)	13,5404 %	non-hazardous	non-hazardous
	polyisobutylen (PIB) consists of			
1407-96-6	talcum	0,0652 %	non-hazardous	non-hazardous
9003-27-4	polyisobutene polymer	0,0652 %	non-hazardous	non-hazardous
25895-47-0	polyolefine polymer	0,0326 %	non-hazardous	non-hazardous
1333-86-4	Carbon black	0,0326 %	non-hazardous	non-hazardous
	Kömmerling PVA 200 Comp. A: silicone product consists of			
471-34-1	calcium carbonate	0,4400 %	non-hazardous	non-hazardous
9016-00-6	polydimethylsiloxane	0,5134 %	R52 R53	H413
	Kömmerling PVA 200 Comp. B consists of			
471-34-1	calcium carbonate	0,0293 %	non-hazardous	non-hazardous
1333-86-4	carbon black	0,0220 %	non-hazardous	non-hazardous
9016-00-6	Polydimethylsiloxane	0,0147 %	R52 R53	H413
682-01-9	Tetrapropylorthosilicate	0,0147 %		H315, H319, H335
1067-25-0	Trimethoxypropylsilane	0,0037 %		H226, H315, H319, H335

The development of a competitive disassembly to decompose an end-of-life NICE Module is necessary. The current mechanical treatments are compared in order to set the commercial boundaries. The results are presented in table 2.8 and figure 2.2.

Table 2.8: Comparison of mechanical treatments

no.	kind of mechanical treatment	recovered materials	specific potential value [€/t]
1	laminated glass recycling plant, incineration in municipal waste incineration plant	Al, glass, Cu	122
2	laminated glass recycling plant, incineration of mono	Si, Al, Ag, glass, Cu	316
3	laminated glass recycling plant, incineration	Solar Si, Al, Ag, glass, Cu	476

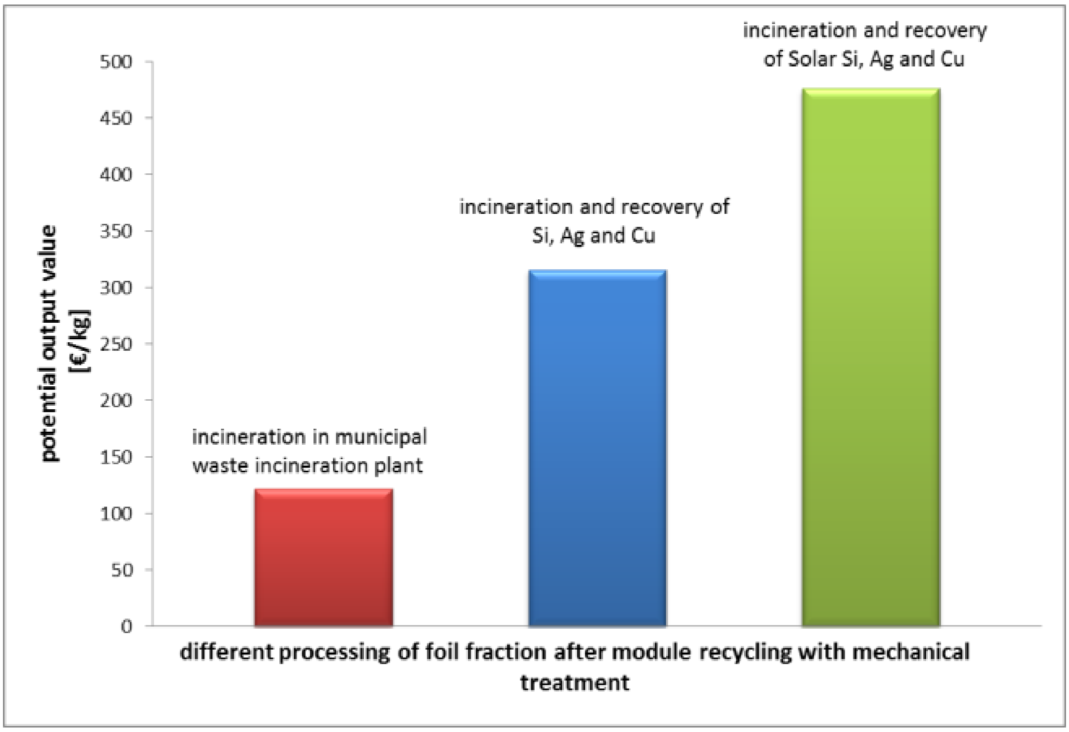


Figure 2.2: Potential material values after different recycling processes of PV modules with polymer incineration

The comparison of mechanical treatments indicates that highly pure outputs of the recycling treatment will increase significantly the value of the secondary raw materials obtained. Moreover, the re-use of secondary raw materials within the solar industry can decrease the cost of solar panels making this kind of renewable energy source even more attractive. In addition, the establishment of a cost-effective treatment may have a positive impact on the eco-efficiency, too.

The development of a cost-effective treatment of the disposed NICE Modules is still a challenge. The expectation has to be considered that the capacity of installed PV modules is assumed to increase remarkably in the near future. Hence it follows, that the amount of possibly recovered material increases significantly, too. Thus the conditions of a recovery or re-use route become a demanding task. Further research and input from project partners are necessary. The benefits of recovered secondary raw materials from discarded solar panels are described in table 2.9.

Table 2.9: Exploitation considerations about the recovery of solar panel compounds

solar panel components	description
target	using the state of art solar panel recycling systems in order to generate commercial benefits and to increase the eco-efficiency
result	recovery of solar panel compounds: high yield and high purity desired; secondary applications shall be easily enabled
unique selling point	equal quality for a lower price in comparison to raw materials
product market size	global market size [5] about 43,000 Mt/a
product positioning	industrial application: metal industry, metal recycling, metallurgy, solar cell/panel producer, glass industry, building industry, Si-production
requirements	material has to be modified in order to fulfil the needs of customers
competitors/ incumbents	raw material suppliers, recycling companies
foreseen product price	about 350 €/t
external experts/partners to be involved	laminated glass recycling plant owner, silicon smelters, metal industry, metal recycler, metallurgy, solar cell/panel producer, glass industry, building industry, Si-production
sources of financing foreseen	proceeds from the separated and purified solar panel compounds, using an established laminated glass recycling plant, savings from landfill costs

[5] IRENA and IEA-PVPS (2016), "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems

3 CONCLUSION

The NICE Module was investigated by bifa. The experiments verify the feasibility of damage-free disassembly. The specifications for an automatic disassembly process and equipment to decompose an end of life NICE Module into its different components is recommended in order to be competitive with respect to new raw materials. The recovery and re-use of intact components seem to be possible. The repair of recovered components such as defective solar cells and subsequent re-use are thinkable but the viability strongly depends on the current cost of new components in comparison with the recovery costs. A fast screening, non-contact diagnosis techniques to detect failure modes of module components, including repair function if possible, is planned to be implemented. In addition, the quality requirements will have to be met if a direct re-use is targeted. It is planned to take a closer look on this as a next step.

The removal of PIB by means of a chemical treatment is neither regarded as cost- nor as eco-efficient. A thermal treatment requires a high energy demand which is undesirable.
Therefore the glue to fix the solar cells might be replaced by acrylic foams. In despite of the slightly increasing costs, the removal of this foam would take less time. This would support the recommended automatic disassembly process.

The compounds of the NICE Module are already allocated to different waste streams. The assessment of each waste stream has been started. It is expected that the new European waste regulation will not be an issue inhibiting reuse and recovery options.