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End-of-Life Management of Photovoltaic Modules

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Abstract: End of Life Management (EoL) of photovoltaic modules will be, because of the estimated life time, important in some years. Currently PV modules have a reasonable low ratio of efficiency. Therefore in the next years new production technologies with new materials will come up.

After a short introduction in EoL and the importance, in this paper the state of the art of PV modules as well as the currently available EoL strategies are shortly described. For a quantitative evaluation of the economy of EoL 10 indicators are defined. Based on these, according to the scope of TECIS, the preferences of three groups involved namely the users, the producers and the recyclers are estimated. Clearly they are quite different. Therefore it is necessary in the future to close this gap by taken into account this fact for the development of new PV cells.

Keywords: Photovoltaic cells, End of life management, Social impacts, Society.

1. INTRODUCTION

Recycling procedures for photovoltaic modules are quiet similar to recycling methods of some of electrical and electronic equipment with a large proportions of glass like LCDs and screen glass. Due to the fact that the large volumes of end-of-life photovoltaic modules would enter the market in years 2025 or 2030, currently the recycling of photovoltaic modules is not economically viable (European commission, DG ENV 2011).

Based on the data on these scenarios and their assessments, the following conclusion is definable: including photovoltaic modules in the WEEE Directive would reduce the potential negative environmental impacts of improper disposal and would generate economic benefits. Limiting the quantity of the photovoltaic modules improperly disposed; has the positive environmental impacts of avoiding lead and cadmium leaching and avoiding potential recourse loss due to non-recovery of valuable conventional recourses and rare metals in photovoltaic modules.

In 2010 the PV industry has reached a significant growth. The total capacity installed in 2010 around the whole globe is approximately 40 Gigawatt (GW), which shows a sustainable growth from 1.5 GW in 2000 to 39.5 GW in 2010 (EPIA, 2011).

2. END OF LIFE MANAGEMENT

End-of-Life (EoL) management describes the systems and processes that take place at the end of the life cycle of a product, i.e. after a product is used as initially proposed. Due to economic and ecologic reasons, these products are no longer seen as a useless amount of waste that has to be disposed. Old products represent interesting resources that can be used for various new products. Additionally, the awareness of ecological questions is rising. According to various regulations, hazardous materials have to be collected and treated in a special way in order to minimize the negative effects on the environment.

In EoL management, basically four different strategies can be chosen. These are (the 4-R): Reduce, Reuse, Recycle and Recover (Fig. 1). The least favorable strategy is landfilling. In this pyramid, the various strategies are ordered top-down. The best strategy is situated to the top.

Fig. 1: End-of-Life pyramid

Reduce: The first and most favourable strategy is the reducing of the amount of primary material that is used for a product. Therefore, this strategy is the most favourable for

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EoL. This implies that reduce has to be taken into account during the design phase of the product.

Reuse: The second best option is reusing the whole product, modules or single parts of it. In this case, the produces value can be won for a second life-cycle, without (significant) modifications of the device that is reused. If not the whole product, but just some modules or parts can be reused, the device has to be disassembled in a way, that at least the parts, which are envisaged for reusing, are not destroyed during the process.

Recycle: The third best alternative is the recycling of the material that can be extracted from a device. These materials can be used as starting material for new products. When the new products are of a better quality than the origin device, the process is called "upcycling", while "down cycling" describes the process of producing new products of a lower quality than the origin device.

Recover: The forth "R" used in this model stands for the energy recovery of the waste devices. During this process, non-hazardous materials are combusted, which has two goals. The first one is that the generated heat can be used to produce e.g. electric power, which can be used or sold. The second advantage is that the amount of waste is reduced.

Landfill: The least and worst strategy is landfilling, devices are deposited at landfills after their life-cycle. This alternative is costly due to several reasons. A high amount of ground is necessary, and a lot of resources are needed for maintaining a landfill. On the other side, there are no positive returns coming from a landfill. Therefore, the main goal for the present and future development is to reduce the share of products that end on a landfill to zero.

3 PHOTOVOLTAIC CELLS

Photovoltaics converse the sunlight into electricity with the use of layers of semiconductors. When the light shines on the PV cell, an electric field across the layers would be created. This electric field would cause the electricity to flow. The higher the intensity of the light rays, the higher the flow of electricity is. The most common semiconductor used in the construction of photovoltaics is silicon. The silicon would be extracted from quartz and there is no limitation to its availability.

Materials used in PV cells are glass, metals (Aluminium, Indium, Germanium, Silver), plastics and silicon for the semiconductors. In polycrystalline thin films PV cells copper indium selenide and cadmium telluride is used.

There are two main technologies, involving in producing solar cells; crystalline silicon technology, which is known as the "first generation" technology and thin-film technology as the "second generation" technology.

3.1 Crystalline Silicon PV cells

Crystalline silicon cells represent about 90% of the market. Crystalline Silicon cells could be categorized into three main categories as follow:

- Monocrystalline silicon (mono c-Si)
- Multicrystalline/Polycrystalline silicon (multi c-Si)
- Ribbon- technology (ribbon sheet c-Si)

What makes distinguishes between these three types is mainly related to the characteristics of the silicon, which has been used and also the process of producing.

3.2 Thin film PV Cells

Photovoltaic (PV) technology is undergoing a transition to a new generation of efficient, low-cost products based on thin film of photoactive materials. In this method, thin layers of semi-conductor material are deposited on a substrate.
Currently, there exist several different categories of thin film solar cells. These modules, which are described below, can be distinguished according to their type of semiconductors.

Amorphous silicon (a-Si)
Cadmium telluride (CdTe)
Thin-film polycrystalline silicone cells CIS/CIGS (Cu (In,Ga)Se2).

3.3 Other types of PV cells

In addition to the before mentioned main types of PV cells, they are some other types of PV cells available in the market.

Nano a-Si PV cells
Nano-crystalline dye PV cells
Concentrated PV cells
Flexible PV cells

The last cells are not included in the further observations.

4 EoL OF PHOTOVOLTAIC CELLS

At the time of decommissioning of PV cells, modules may be reused, recycled or disposed. The PV cells may contain small amounts of materials like Cd, Pb and Se, which make their disposal in landfills questionable and also landfill is the least optimal treatment of EoL in any kind of industry. That means, basically out of the five EoL strategies, which have been described in the EoL pyramid in Fig.1 we found out that there are only two - reuse and recycling - of the strategies applicable for photovoltaic.
Beside aluminum, glass, and semiconductor materials, photovoltaic modules contain other materials for reuse. In Table 1 a list of valuable materials that photovoltaic contains is presented:

4.1 Reuse

Reuse relates to the further use of a worn out or damaged PV module or parts of it. The reasonability of such a reuse is strongly bounded to the (expected) life time of a module or a part of a module. If for example a house with a roof including PV cells should be destroyed for any reason, it might be