IMPLICATIONS OF EUROPEAN ENVIRONMENTAL LEGISLATION FOR PHOTOVOLTAIC SYSTEMS

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ABSTRACT: An overview is given of European environmental legislation which is effective now or proposed and which may have implications for the photovoltaic industry. The focus will be on legislation, which has been implemented already in national law, like the ***WEEE*** (waste electrical and electronic equipment)- and ***ROHS*** (restriction of the use of certain hazardous substances)- directives. Photovoltaic modules are presently excluded from the WEEE- and ROHS- directives, but this situation may very well change in the future. As a common European waste policy the producer will be responsible for its end-of-life collection and "treatment" of his products. When PV modules are included in the ROHS regulation, it will be prohibited to put lead- or cadmium-containing modules on the EU-market, above the regulatory limits for hazardous metal contents. Therefore an overview is also given of repair, recovery and recycling technologies for PV modules, design-for-recycling concepts and the replacement of lead and cadmium.
A number of other proposals for future legislation may have an impact on photovoltaic products as well. Among these are ***Reach*** (Registration, Evaluation, Authorisation and Restriction of Chemicals), ***F-gases*** (regulation on certain fluorinated greenhouse gases) and ***EuP*** (eco-design requirements for energy-using products).
A change of the module design, with the research, development, implementation and certification necessary to be able to produce photovoltaic systems that comply with such legislation, may be very time-consuming and expensive. Therefore a pro-active approach by the PV community is desirable.
Environmental life cycle thinking and eco-design is becoming increasingly important as part of the European product and waste policy and will have its impact on the PV industry as well. Design-for-recycling must be encouraged to allow for an easy, cost-effective disassembly, with a high retrieval of for instance the precious crystalline silicon solar cells.
A closed production cycle, i.e. guaranteed take back system, would probably prevent the commission as well as member states to impose legislative measures.

Keywords: legislation, collection, recycling, disassembly

1 INTRODUCTION

The stream of post-consumer waste and its environmental impacts form an increasing burden for our society. Also waste streams often contain valuable and/or scarce materials that might be recovered so that material cycles can be closed. In order to address these problems most national governments have in the past issued regulations concerning waste management. More recently the regulation issued by the European Union is becoming more and more important. For example within the European *6th Environment Action Programme* the promotion of an **Integrated Product Policy** (i.e. environmental life cycle thinking) and **a strategy on the prevention and recycling of waste** are key elements.

The PV industry, as any other industry, will have to deal with consequences of these regulations, especially if its wants to keep intact its image of a “sustainable technology”.

In order to raise awareness about the topic of life-cycle thinking and waste management among the PV industry, a special workshop was organized and a number of presentations were given at conferences [1-3]. Also we should mention that a report was published recently by the German Environmental Agency [4], which addresses the topic of EU regulations and their consequences for the PV industry.

In this paper we will give an up-to-date overview of European environmental legislation, which is effective now or has been proposed and which may have implications for the PV industry. Consecutively the WEEE, RoHS, REACH, F-Gases and EuP directives will be discussed. Also we will look at actions that have already been taken by the industry and make recommendations for further actions.

2 WEEE

The directive on Waste of Electrical and Electronic Equipment (WEEE) [5] regulated that from 13 August 2005, producers shall provide at least for the financing of the collection, treatment, recovery and environmentally sound disposal of WEEE. Depending on the product category, the minimum rate of recovery that is required ranges from 70-80% by weight. The corresponding reuse and recycling ranges from 50-75% by weight. Recovery includes recycling, reuse and the use as a fuel.

2.1 Implications of WEEE for PV

At this moment photovoltaic products, i.e. **solar panels** are *not* included in the WEEE directive, but amendments are possible to the Annex 1B (WEEE article 13). So future modifications to *include PV panels,* are possible, for example to curb the growing volume of this waste stream. It is foreseen in the regulation that before the Annex is amended the Commission shall consult the producers concerned. However in the case of solar powered calculators, telephones or radios the WEEE directive is applicable!

It is uncertain whether **inverters** are included in WEEE or not. There is a need for further clarification.

For PV modules, although they are still exempt from WEEE, the WEEE targets could be met by just recovering and reusing/recycling the encapsulation glass and aluminium frame. In other words high value recycling, i.e. reuse of silicon wafers, is not especially encouraged by the present WEEE legislation.

2.2 Existing recycling activities

The PV industry has already started some activities to promote collection and recycling of PV components.

Figure 1: Disposed PV modules collected at Solar Materials, Deutsche Solar AG in Freiberg (Saxony, Germany). Valuable materials like the silicon solar cells, aluminium frame and encapsulation glass are recovered.

Deutsche Solar is running a pilot line for the recycling of crystalline silicon solar cells and modules [6]. This process starts with a thermal processing step to burn off the polymers in the laminate. After recovery of the solar cells these are subjected to a chemical etching process to remove metallization, anti-reflection coating and p-n junction. The resulting wafers can be reprocessed in standard solar cell processes.

Another approach, developed in Japan, is to soak the panel in an organic solvent, resulting in easy removal of the ethyl vinyl acetate (EVA) [7,8]. A key problem with this process is the breakage of the cells by the swelling of the EVA. Some mechanical pressure is therefore needed to reduce breakage losses.

Sharp has also developed a recycling technology for crystalline silicon panels, but in this case the silicon is being remelted [9], thus avoiding the bottleneck of processing smaller wafers, but also reducing the potential energy credit [10].

Regarding thin-film modules several developments are underway. Showa Shell has developed a technology to recycle $Cu(InGa)Se_2$ based thin-film modules [11].

The subject of recycling CdTe and CIGS modules will be addressed by Fthenakis at this conference [12].

In the EU SENSE project the recycling of amorphous silicon, CIGS and CdTe modules is investigated [13].

2.3 Take back systems

An important element in EU environmental policy is the Extended Producer Responsibility, implying that the producer remains responsible for its product throughout its entire life-cycle. In this respect some PV companies have already taken the initiative to set up take back systems for EOL modules. One example is First Solar, which takes back its own modules and guarantees their recycling [14]. Their insurance policy assures funding of reclamation and recycling at the end of life [15].

Also Deutsche Solar AG is establishing a voluntary take back system for solar cells and modules [16].

2.4 Design-for-recycling

Looking at the future it must be encouraged that the design and production of PV components facilitates the EOL dismantling of components into parts that can be reused or recycled. Present-day module designs focus, quite understandably, on stability and long lifetimes, and of course this also beneficial from environmental point of view. However the same design makes EOL dismantling quite difficult and less economically attractive. Especially for thin film modules this is a problem as the value of recoverable cell materials is mostly much lower than for silicon wafer technology.

One simple example of design-for-recycling, is the use of special screws for securing the module frame made out of shape-memory-alloys, thus allowing for easy disassembly at the end-of-life [17].

In order to facilitate recovery of solar cells, and avoid the combustion step, attempts have been made to add an additional polymer layer with low adherence to the cell and to the laminate [17,18]. The disadvantage is that this generally increases optical losses. Another possibility is to replace the EVA by an alternative polymer, like a thermoplastic olefin resin [19].

3 ROHS

The ROHS directive [20] is applicable to electrical and electronic equipment falling under the WEEE categories 1-7 and 10 plus electric light bulbs, and luminaires in households. So category 9 "Monitoring and control equipment" is exempted, meaning that **inverters** at the moment are not included in the ROHS directive.

The ROHS directive regulates in article 4(1) that from 1 July 2006 electrical and electronic equipment put on the EU-market must not contain: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).

Exemptions to article 4(1) are listed in the Annex. Exempted is for instance: “Lead in glass of electronic components”.

Furthermore a draft decision [21] concerning the amendment of ROHS article 5(1)(a) has been proposed:

*"A **maximum concentration value** of 0.1% by weight in homogeneous materials for lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) and of 0.01% weight in homogeneous materials for cadmium shall be tolerated. Homogeneous material means a unit that can not be mechanically disjointed in single materials".*

The draft guidance document [22] defines some terms:

*The term "**homogeneous**" is understood as "of uniform composition throughout". Examples of "homogeneous materials" are individual types of: plastics, ceramics, glass, metals, alloys, paper, board, resins, coatings.*

*The term "**mechanically disjointed**" means that the materials can be, in principle, separated by mechanical actions such as for example: unscrewing, cutting, crushing, grinding and abrasive processes.*

Present-day photovoltaic systems may contain:

- **lead** in the solder of the tabs interconnecting cells,
- **lead** in the glass frit of the metallization paste,
- **lead** in the glass encapsulation,
- **lead** in inverter or other BOS components?,
- **cadmium** in CdTe solar cells or CIS cells with a CdS window layer
- **bromine-containing flame retardants** in the plastic housing of junction boxes or inverters

We will now discuss sources of RoHS substances in more detail.

3.1 Lead

To interconnect the solar cells copper with solder alloy layers is used.

Traditional solder is $Sn_{60}Pb_{40}$ with a melting temperature of 183°C. This compound has a lead content above the ROHS maximum concentration value. On the other hand several types of lead free tabbing material are available on the market, including Sn_{100}, $Sn_{97}Ag_3$, $Sn_{96.5}Ag_{3.5}$, $Sn_{96.5}Ag_{3.0}Cu_{0.5}$ and $Sn_{96}Ag_{3.5}Cu_{0.5}$ [23]. One drawback of these materials, however, is their higher melting temperature.

Some companies are already using lead free solder. RWE Schott Solar, for example, is using $Sn_{96.5}Ag_{3.5}$ a solder with a melting temperature of 221°C. The lead content of this solder is below the ROHS maximum concentration value. The company Mitsubishi is even claiming to sell completely lead-free modules.

As metallization silver or aluminium is used. It is applied by screen printing a paste onto the solar cell and subsequent firing. To enhance the process a lead containing glass frit is used.

Traditional front side pastes, as supplied by Ferro for example, contain about 3.4 weight% lead, while the front side paste DuPont PV145 contains 1-5 weight% of lead, according to the safety data sheet. The back side paste from Ferro contains about 3 weight% lead. Because of the loss of organics during firing process the lead content of the paste will increase. The traditional metallization paste has a lead content above the ROHS limit in the final product.

Lead-free metallisation paste is commercially available now for the back-side metallisation, but not yet for the front side. However, a lot of research and development is conducted in this area [24,25].

To encapsulate the solar cells, glass is used which may contain lead.

Lead in glass is exempted from ROHS at this moment and we think this is not likely to change. Moreover the type of glass used for PV modules is relatively pure because it is generally low in iron content. Lead is not added intentionally, but can be present in trace amounts of typically 0-10 ppmg (=0-0.001% by weight) as analysed in three different solar glasses produced in 2004. In the end the metal contents of glass depend primarily on the purity of the natural feedstock sources. So the lead content of present solar glass is well below the regulatory limits.

3.2 Cadmium

Presently the EU's Cadmium directive 91/338/EEC does not prohibit the use of cadmium containing PV modules, because in CdS and CdTe the cadmium is *non-metallic*.

However CdTe type of modules will need an exemption from the RoHS, since the cadmium is present in the basic components. According to this regulation exemptions may be given, when it is likely that the elimination or substitution of the cadmium causes an increase in the environmental, health and/or consumer safety impact. More information on cadmium in solar cells can be found on http://www.nrel.gov/cdte/.

Cadmium may also be used in CdS buffer layer of CIGS–type solar cells. Several research groups are developing Cd-free CIGS cells. Showa Shell is using $Zn(O,OH,S)_x$ buffer layer in its CIGS PV modules.

3.3 Bromine containing flame-retardants

Flame-retardants are used in products to delay the spread of fire. They may be present in cables, wires, casings and housings. Therefore junction boxes and other electrical Balance-Of-System components should be screened on this aspect.

According to the Bromine Science and Environmental Forum, **PBB** is no longer produced since 2000 [26].

Another EU directive [27] has banned the flame retardants **penta-BDE** and **octa-BDE** in all products from the EU market by August 2004.

The exemption from the ROHS directive of **deca-BDE** is not clarified yet.

4 REACH

REACH is a proposal for the Registration, Evaluation, Authorisation and Restriction of Chemicals [28]. It will simplify EU regulation in replacing 40 existing pieces of legislation and in creating a single system for all chemicals.

For substances that have already been manufactured or that already have been on the Community market for the last 15 years, a series of registration deadlines are established. The deadline for registration of CMR (Carcinogenic, Mutagenic and Reprotoxic) substances, like lead and cadmium, is 3 years after the date of entry into force. CMR substances are substances of very high concern and require authorisation for their use and their placing on the market. Applicants will have to demonstrate that risks associated with the use are adequately controlled. Their uses will not be banned by default. If the socio-economic benefits outweigh the risks and if there are no suitable alternative substitute substances or technologies, an authorization may also be granted.

The risks from the use of toxic substances in PV modules are limited because of their encapsulation between glass and/or plastic. This implies that there is very little chance of the release of such toxic materials during normal operation of the PV system. With regard to Cd-containing modules, Fthenakis [29] has demonstrated that during fire simulation tests on glass-to-glass encapsulated CdTe modules, there is no release of Cd because the Cd dissolves into the molten glass. For single-glass CdTe modules, however, risks are probably higher.

5 F-GASES

The proposed **F-gases** directive is a regulation on certain fluorinated greenhouse gases [30]. The objective is to make a significant contribution to the Kyoto Protocol target. For instance the use of sulphur hexafluoride for filling car tyres will be prohibited.

Fluorinated gases may be used in PV production for reactor cleaning and etching silicon wafers. As pointed out by Agostinelli [31] alternative routes to high global-warming-potential gases and/or a viable route to their abatement/recycling is needed.

6 EuP: ENERGY USING PRODUCTS

EuP is a proposal for a directive on establishing a framework for the setting of **eco-design** requirements for energy-using or energy-generating products [32]. It will be effective from 1 July 2006.

A photovoltaic system would *in principle* fall under the EuP definition. Although a final selection of the products to be covered by the EuP legislation has not been made yet. However, we think it is not likely that PV modules will be covered by the implementing measures, because PV modules produce energy during their complete life cycle and thereby contribute to the reduction in greenhouse gas emissions, which is a key environmental priority as set in the 6th Environment Action Programme. Nevertheless, the application of eco-design is of course a good approach to enhance the environmental profile of photovoltaics to save natural resources, avoid waste and avoid damage to the environment.

7 CONCLUSIONS

An overview has been prepared of new European environmental regulations (like WEEE and RoHS) and their potential impacts on the PV industry. It was found that there would have been significant impacts, were it not that presently PV modules are being exempted from most regulations. The lead content of traditional solders and metallisation pastes would have been in violation of the RoHS directive were it not that PV panels are exempted from RoHS at this moment.

A closed production cycle would probably prevent the commission as well as member states to impose legislative measures. Therefore we strongly recommend that PV industry takes a pro-active approach to avoid any substances that are considered hazardous, publish typical data on the module compositions and that it develops take-back and recycling schemes.

To encourage high value recycling approaches, the recovery of valuable materials like silicon wafers, broken wafers for feedstock and silver should be promoted by near-term legislation.

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