Accident Risk Evaluation of Photovoltaics (PV) in a Comparative Context

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Summary

The photovoltaic (PV) industry experienced strong annual growth rates in the past decade, and it is generally viewed as a clean and low-risk technology. Recent studies have mainly addressed the areas of Life Cycle Assessment (LCA) of PV electricity generation, health and environmental hazards of PV production, and various risk assessment aspects in the fabrication of PV modules. However, there is still a need to further improve the methodological framework for PV risk estimation to enable a consistent comparison between PV and other energy sectors.

Therefore, the aim of this master thesis work is to perform a detailed analysis of accident risks associated with the PV industry. For this purpose, the following tasks are carried out: (1) identification of hazardous materials used in PV production, (2) survey and analysis of historical experience as available from different accident databases, and (3) application of simulation tools to calculate site-specific release scenarios both for PV production facilities and the transportation of hazardous substances that are needed in the fabrication processes.

The first part of the study analyzes different steps involved in the manufacture of different PV technologies such as monocrystalline silicon, polycrystalline silicon, a-Si, CdTe (Cadmium Telluride) and CIGS (Copper Indium Gallium Selenide) cells. A variety of hazardous materials used during the different production processes of the selected PV technologies are identified.

In the second part of the study, a large compilation of data about accidents is examined. The data are collected from six different databases: Emergency Response Notification System (ERNS), Major Hazard Incident Data Service (MHIDAS), Major Accidents Reporting System (MARS), Analysis Research and Information on Accidents (ARIA), OSH update and Risk Management Plan (RMP). These databases provide information about incidents that occurred around the world. The RMP database is used extensively throughout this study since it is a mandatory program and the data reported to it covers not only accidents but also information about the facilities using the chemicals.

The collected data are employed to calculate general risk measures such as accident frequency and severity for all databases, as well as frequency per amount of chemical and per number of facilities exclusively for the RMP database. The estimated figures are used in order to compare the hazardousness among the different materials assessed. Through this study, chlorine and hydrogen selenide are identified to be the most dangerous materials. For these two substances Frequency-Consequence (F-N) curves were calculated.

The third part of the study deals with scenario analysis to calculate site-specific consequences for the release of selected hazardous materials, which are based on the worst case scenario as defined by RMP. First, the consequences of the worst case scenario are estimated for several facilities reporting the use of the studied chemicals. The calculations are done using the software RMP comp, which is especially developed for this purpose by the United States Environmental Protection Agency (US EPA).

Second, several scenarios are simulated to analyze potential off-site consequences of an accidental release from selected RMP facilities involving the most hazardous materials, namely hydrogen selenide, diborane and trichlorosilane. The simulations are performed utilizing ALOHA (Areal Locations of Hazardous Atmospheres), which is a software designed to be used as a guide during a chemical emergency. It is able to model three kinds of hazards, namely toxic gas dispersion, fire and explosions. The scenarios simulated in ALOHA give a dispersion plume that can be located in the release source employing a mapping program such as Marplot or Google Maps.

This simulation method is used in order to study the consequences of an accidental release for the surrounding inhabitants of a PV/semiconductor plant. It is shown that the release of hydrogen selenide could affect the population located further than 10 kilometers from the release source, whereas the release of diborane affects a smaller area since the dispersion plume of this chemical is thinner than the one of hydrogen selenide. Therefore the potential consequences for the population are generally less severe in the case of diborane. On the other hand, it is demonstrated that a trichlorosilane explosion is only a local event, i.e. the consequences are limited to the facility.

Third, ALOHA is also applied to compare numerous site-specific transportation scenarios that were calculated for a release of chlorine and hydrochloric acid (HCl), respectively. The results indicate that chlorine could affect higher amounts of population. Additionally, several real-world accidents were compared to worst case scenarios.

The chlorine and hydrochloric accident transportation scenarios are calculated without an assumption of the industry in which the specific chemical is used. However, data on the demand of the different chemicals allow allocating the consequences of the accidents to the different industrial sectors. This approach is utilized in order to evaluate the responsibility of the PV industry for an accidental release of chlorine or hydrochloric acid during railway transportation.

As mentioned before, chlorine and hydrogen selenide are identified as the most hazardous materials among the different chemicals studied. Nevertheless it is important to remark that the use of hydrogen selenide in the PV industry is limited to the manufacture of CIS solar cells, whose share in the global PV market is only 1%. On the other hand chlorine is used in the production of silicon PV cells, which represent around 86% of the PV market. Thereby it is important to mention new processes for the production of silicon PV cells avoiding the use of chlorine have been developed and adopted by leading manufacturers.

Additionally, the market shares are likely to change in the future. By 2020 it is expected that the participation of the CIGS will rise to around 15 %, thus increasing the risk due to the use of hydrogen selenide. Moreover, by that time new concepts that make use of nanotechnology will be available on the market. With them, new risks could appear which cannot be assessed at the moment.

Nonetheless the use of chlorine for PV represents currently less than 0.04 % of total chlorine consumption in the US according to the American chemistry industry. This number is marginal compared with the use of chlorine in other economic sectors such as the production of vinyl and phosgene, which represent 36 % and 9 % of the total chlorine consumption, respectively. Therefore only a small part of the consequences of disastrous chlorine accidents can be attributed to the PV industry today. However, this may change depending on the future expansion of PV. Furthermore, within a comparative assessment of energy technologies they are not negligible because both empirical evidence and scenario simulations indicate that accidents occur and that there is a potential for larger consequences than have been observed up to now.

The chlorine transportation scenarios prove to be one of the most hazardous situations with the potential to affect high amounts of population. Chlorine is usually transported in tankers of 90 tons. However, no information could be obtained on the amounts of chlorine typically stored in a PV facility and on the frequency and amounts of deliveries. Nevertheless it is important to recognize that the industry is consciously working to reduce chlorine transport.

To solve these questions, a further step on this research should try to establish cooperation with the PV industry. In this way specific data from this industry could be used to refine current estimates. This kind of study would also increase the public credibility of the PV industry in terms of accident risks.