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CdTe PV: Real and Perceived EHS Risks

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CdTe PV: Real and Perceived EHS Risks

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ABSTRACT

As CdTe photovoltaics reached commercialization, questions were raised about potential cadmium emissions from CdTe PV modules. Some have attacked the CdTe PV technology as unavoidably polluting the environment, and made comparisons of hypothetical emissions from PV modules to cadmium emissions from coal-fired power plants. This paper gives an overview of the technical issues pertinent to these questions and further explores the potential of environmental, health, and safety (EHS) risks during production, use, and decommissioning of CdTe PV modules. The following issues are discussed: (a) the physical and toxicological properties of CdTe, (b) comparisons of Cd use in CdTe PV with its use in other technologies and products, and (c) the possibility of CdTe releases from PV modules.

1. Toxicology of CdTe

Elemental cadmium, which forms CdTe when reacted with tellurium (Te), is a lung carcinogen, and long-term exposures can cause detrimental effects on kidney and bone. Very limited data exist on CdTe toxicology, and no comparisons with the element Cd have been made [1]. However, CdTe is a more stable and less soluble compound than Cd and, therefore, is probably less toxic than Cd. However, OSHA groups all Cd compounds together, and as a general guidance, all facilities working with any such compounds should control the indoor concentrations of CdTe dust or fumes to below the Permissible Exposure Level-Time Weighted Average (PEL-TWA) Cd concentration of 0.005 mg/m^3.

The U.S. CdTe PV industry is vigilant in preventing health risks and has established proactive programs in industrial hygiene and environmental control. Workers' exposure to cadmium compounds in PV manufacturing facilities is controlled by rigorous industrial hygiene practices and is monitored by frequent medical tests. Results of years of biomonitoring have shown that there are no significant observed increases in levels of worker exposure [2].

2. Amount of Cd Compounds Encapsulated in CdTe Modules and NiCd Batteries

The amount of Cd compounds in PV modules is proportional to the area of the module and the thickness of the CdTe and CdS layers. Most CdTe layers are about 1-3 microns thick, and most CdS layers are about 0.2 microns thick. Therefore, about 3–9 g/m^2 Cd is contained in CdTe, and less than 1 g/m^2 is contained in CdS. A reasonable average amount would be about 7 g/m^2 Cd in CdTe modules. Layer thickness is expected to be reduced as research and development efforts continue, further reducing the amount of Cd compounds in the cells [3].

A CdTe module of 10% sunlight-to-electricity conversion efficiency produces about 100 W of output under standard sunlight conditions. So, there is an average of 7 g/100 W = 70 g per kW of electric power produced. In an average solar location in the United States, such as Kansas, a one-square-meter, 10%-efficient CdTe module containing 7 g of Cd would produce about 5400 kWh over its expected service life of 30 years. That is about 770 kWh per gram of Cd, or 0.001 g/kWh. (Note, this amount is in the module and is <u>not</u> an emission. It can be completely recycled.)

Table 1 shows a comparison of the Cd content in CdTe PV and in NiCd batteries. CdTe modules occupying 1 m^2 contain less Cd than one C–size flashlight battery. A 1-kW system would contain as much Cd as seven C-size batteries. On a per kWh basis, assuming that a NiCd battery can be recharged 700 to 1200 times over its life [4], it would produce an average of 0.046 kWh per g of its weight, which corresponds to 0.306 kWh per g of Cd contained in the battery. This is 2,500 times less than a CdTe PV module. Thus the value of using Cd in PV is much greater than its value elsewhere in the marketplace.

Table 1. Cd Content in CdTe PV and NiCd Batteries

	g/unit	g/kW (ton/GW)	mg/kWh (kg/GWh)
PV CdTe	7 g/m2	70	1.3
NiCd battery -C size	10		3265.

3. EHS Risks during Cadmium Mining

CdTe is manufactured from pure Cd and Te, both of which are by-products of smelting prime metals (e.g., Cu, Zn, Pb, and Au). About 80% of the world's production of cadmium is generated as a by-product of smelting zinc ores. Its major feedstock, sphalerite (ZnS), contains about 0.25% Cd. Secondary cadmium is produced from recycling spent NiCd batteries and other scrap. The demand of zinc has been steadily increasing for decades as driven by economic growth. Therefore, cadmium (in impure form) is produced regardless of its use. Cadmium is used primarily (~65%) in nickel-cadmium rechargeable batteries, paint pigments (~17%), plastic stabilizers (~10%), metal plating (~5%), and metal solders (~2%). When there is no cost-effective market for the metal, raw Cd is disposed of [5].

The total Cd use in the United States was 2,600 tons in 1997; globally, the total use is 19,000 to 20,000 tons. Using only 3% of the U.S. consumption of cadmium (i.e., 78 tons) in the manufacture of CdTe solar cells would generate over 1 GW of new PV per year. Note that the total current PV capacity in the United States is only 0.3 GW and is projected to grow (under optimistic assumptions) to about 3.2 GW/yr by 2020. Even if we envision PV production that is an order of magnitude higher, it would require only about a third of the current U.S. Cd consumption. Yet to change the world's energy infrastructure with CdTe PV, much less Cd would be needed, and it would not impact the overall smelting of Cd at all. In fact, it would provide a beneficial use of Cd that could otherwise be cemented or end up in a waste dump.

4. EHS Risks in CdTe PV Manufacture

In production facilities, workers may be exposed to Cd compounds through the air if contaminated, and by ingestion from hand-to-mouth contact. Inhalation is probably the most important pathway, because of the larger potential for exposure and higher absorption efficiency of Cd compounds through the lung than through the gastrointestinal tract. Processes in which Cd compounds are used or produced in the form of fine particulates or vapor present larger hazards to health. Hazards to workers may arise from feedstock preparation, fume/vapor leaks, etching of excess materials from panels, maintenance operations (e.g., scraping and cleaning), and during waste handling. Caution must be exercised when working with this material, and several layers of control must be implemented to prevent exposure of the employees. In general, the hierarchy of controls includes engineering controls, personal protective equipment, and work practices. The U.S. industry is vigilant in preventing health risks, and has established proactive programs in industrial hygiene and environmental control. Workers' exposure to cadmium in PV manufacturing facilities is controlled by rigorous industrial hygiene practices and is continuously monitored by medical tests, thus preventing health risks [2].

5. Can CdTe from PV Modules Harm Our Health or the Environment?

Toxic compounds cannot cause any adverse health effects unless they enter the human body in harmful doses. The only pathways by which people might be exposed to PV compounds from a finished module are by accidentally ingesting flakes or dust particles, or inhaling dust and fumes. The thin CdTe/CdS layers are stable and solid and are encapsulated between thick layers of glass. Unless the module is purposely ground to a fine dust, dust particles cannot be generated. The vapor pressure of CdTe at ambient conditions is zero. Therefore, it is impossible for any vapors or dust to be generated when using PV modules.

The only issue of some concern is the disposal of the well-encapsulated, relatively immobile CdTe at the end of the modules' useful life. Thin CdTe PV end-of-life or broken modules pass Federal (TCLP-RCRA) leaching criteria for non-hazardous waste [6]. Therefore, according to current laws, such modules could be disposed of in landfills. However, recycling PV modules offers an important marketing advantage, and the industry is considering it as they move toward large and cost-effective production [7,8]. This issue of recycling is not unique to CdTe. The disposal of current x-Si modules, most of which incorporate Pb-based solder, presents similar concerns. Recycling the modules at the end of their useful life completely resolves any environmental concerns.

6. Do CdTe Modules Present Additional Health Risks during a Fire?

The flame temperatures in typical U.S. residential fires are not high enough to vaporize CdTe; flame temperatures in roof fires are in the 800°–900°C range, and, in basement rooms, in the 900°–1000°C range [9]. The melting point of CdTe is 1041°C, and evaporation starts at 1050 °C. Sublimation occurs at lower temperatures, but the vapor pressure of CdTe at 800 °C is only 2.5 torr (0.003 atm). The melting point of CdS is 1750°C, and its vapor pressure due to sublimation is only 0.1 torr at 800°C. Preliminary studies at Brookhaven [10] and at the GSF Institute of Chemical Ecology in Germany [11] showed that CdTe releases are unlikely to occur during residential fires or during accidental breakage. The thin layers of CdTe and CdS are sandwiched between glass plates; at typical flame temperatures (800°–1000°C), these compounds would be encapsulated inside the molten glass so that any Cd vapor emissions would be unlikely. In any case, the fire itself and other sources of emissions within the burning structure are expected to pose an incomparably greater hazard than any potential Cd emissions from PV systems.

7. CdTe PV Can Prevent Cd Emissions from Coal-Burning Power Plants

Coal-burning routinely generates Cd, because Cd is contained in the coal. A typical U.S. coal-power plant will generate waste in the form of fine dust or cake, containing about 140 g of Cd, for every GWh of electricity produced. In addition, a minimum of 2 g of Cd will be emitted from the stack (for plants with perfectly maintained electrostatic precipitators or bag-houses operating at 98.6% efficiency, and median concentration of Cd in U.S. coal of 0.5 ppm) [12]. Power plants with less efficient pollution controls will produce more Cd in gaseous form. Furthermore, a typical U.S. coal-power plant emits about 1000 tons of CO_2, 8 tons of SO_2, 3 tons of NOx, and 0.4 tons of particulates per GWh of electricity produced. All these emissions will be avoided when PV replaces coal-burning for some fraction of electricity generation.

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8. Conclusion

The potential EHS risks related to the cadmium content of CdTe PV modules were highlighted for all the different phases of a large-scale implementation of the technology. The basic conclusions are:

Cd Mining: Cadmium is produced primarily as a by-product of zinc production. Because Zn is produced in large quantities, substantial quantities of cadmium is generated as a by-product, no matter how much Cd is used in PV, and can either be put to *beneficial* uses or *discharged* into the environment. When the market does not absorb the Cd generated by metal smelters/refiners, it is cemented and buried, stored for future use, or disposed of to landfills as hazardous waste. Arguably, encapsulating cadmium as CdTe in PV modules presents a safer use than its current uses and is much preferred to disposing it off.

CdTe PV Manufacture: In CdTe PV production facilities, workers may be exposed to Cd compounds through the air they breathe and by ingestion from hand-to-mouth contact. These are real risks and continuing vigilance is required. However, current industrial practice suggests that these risks can be managed and controlled successfully.

CdTe PV Use: No emissions of any kind can be generated when using PV modules under normal conditions. Any comparisons made with cadmium emissions from coal fired power plants are erroneous, because they compare potential accidental emissions from PV systems to routine (unavoidable) emissions from modern coal-fired plants. In reality, PV, when it replaces coal-burning for electricity generation, will prevent Cd emissions in addition to preventing large quantities of CO_2, SO_2, NOx, and particulate emissions.

Related to NiCd batteries, a CdTe PV module uses Cd about 2500 times more efficiently in producing electricity. A 1-kW CdTe PV system contains as little cadmium as seven size-C NiCd batteries. Thus the incremental risk to the house occupants or firefighters from roof fires is negligible. In addition, it is unlikely that CdTe will vaporize during residential fires because the flames are not hot enough. In any case, the fire itself would pose a much greater hazard than any potential Cd emissions from PV systems.

CdTe PV Decommissioning: The only environmental issue is what to do with the modules about 30 years later, if they are no longer useful. Although cadmium telluride is encapsulated between sheets of glass and is unlikely to leach out, the PV industry is considering recycling of these modules at the end of their useful life. Recycling will completely resolve any environmental concerns.

In conclusion, the environmental risks from CdTe PV are minimal. Every energy source or product may present some environmental, health, and safety hazards, and those of CdTe are by no means barriers to scaling-up the technology.

REFERENCES

[1] Fthenakis V., Morris S., Moskowitz P., and Morgan D., "Toxicity of cadmium telluride, copper indium diselenide, and copper gallium diselenide," *Progress in Photovoltaics*, 7, 489-497, 1999.

[2] Bohland J. and Smigielski K., "First Solar's CdTe module manufacturing experience; environmental, health and safety results," *Proceedings of the 28th IEEE Photovoltaic Specialists Conference, Anchorage, AK, September 2000.*

[3] Zweibel K., "Issues in thin film PV manufacturing cost reduction," *Solar Energy Materials and Solar Cells*, 59, 1-18, 1999.

[4] Morrow H., "The Importance of recycling to life cycle analysis of nickel cadmium batteries," *Proceedings of the 8th International Nickel Cadmium Battery Conference, Prague, Czech Republic, September 21-22, 1998.*

[5] Plachy J., *U.S. Geological Survey Minerals Yearbook*, Cadmium-Chapter 17, 2001.

[6] Cunningham D., Discussion about TCLP protocols, *Photovoltaics and the Environment Workshop, July 23-24, 1998,* Brookhaven National Laboratory, BNL-52557.

[7] Bohland J., Dapkus T., Kamm K., and Smigielski K., "Photovoltaics as hazardous materials: the recycling solution," *Proceedings of the 2nd IEEE World Photovoltaic Specialists Conference, pp. 716-719, 1998.*

[8] Fthenakis V., "End-of-life management and recycling of PV modules," *Energy Policy Journal*, 28, 1051-1059, 2000.

[9] Drysdale D., *An Introduction to Fire Dynamics*, pp. 329-330, Wiley, NY, 1985.

[10] Moskowitz P. and Fthenakis V., "Toxic materials released from photovoltaic modules during fires; health risks," *Solar Cells*, 29, 63-71, 1990.

[11] Steinberger H., HSE for CdTe and CIS thin film module operation, IEA expert workshop, *Environmental aspects of PV power systems, May 23, 1997,* Report No. 97072, Niewlaar E. and Alsema E. (ed.), Utrecht University, The Netherlands.

[12] Electric Power Research Institute (EPRI), PISCES data base for US power plants and US coal, copyright EPRI 2002.

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