

Thin-Film Cadmium Telluride Photovoltaics: ES&H Issues, Solutions, and Perspectives

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Photovoltaics (PV) is a growing business worldwide, with new technologies evolving towards potentially large-volume production. PV use produces no emissions, thus offsetting many potential environmental problems. However, the new PV technologies also bring unfamiliar environment, safety, and health (ES&H) challenges that require innovative solutions. This is a summary of the issues, solutions, and perspectives associated with the use of cadmium in one of the new and important PV technologies: thin-film, cadmium telluride (CdTe) PV, which is being developed and commercialized by several companies including Solar Cells Inc. (Toledo, Ohio), BP Solar (Fairfield, California), and Matsushita (Japan).

The principal ES&H issue for thin-film cadmium telluride PV is the potential introduction of cadmium—a toxic heavy metal—into the air or water. The amount of cadmium in thin-film PV, however, is quite small—one nickel cadmium flashlight battery has about as much cadmium (7 g) as a square meter of PV module using current technology (see discussion below)—and a typical cordless power tool will have 5-10 batteries. CdTe modules are also very well sealed, limiting the chance of release. Nonetheless, minimizing the amount of cadmium in cadmium telluride modules and preventing the introduction of that cadmium into the environment is a top priority for National Renewable Energy Laboratory researchers and cadmium telluride PV manufacturers.

The Amount and Nature of Cadmium in CdTe PV

A thin CdTe semiconductor layer is essential to the performance of the CdTe PV technology. As such, it cannot be eliminated. However, the amount of CdTe can be quite minimal. Today, about 2-5 microns of CdTe—already a very small amount—are used in CdTe products. However, only about 0.5 microns are needed to effectively absorb sunlight for the solar device to perform. Indeed, known engineering approaches associated with trapping light within semiconductors suggest that the ultimate thickness of CdTe layers could be as little as 0.2 microns. Table 1 summarizes the amount of Cd in CdTe products based on these different layer thicknesses:

Table 1. The Amount of Cadmium in CdTe Layers of Various Thicknesses

	5 microns	2 microns	1 micron	0.5 micron	0.2 micron
g/m ²	14 g	5.5 g	2.75 g	1.4 g	0.55 g

There is a very thin CdS layer in CdTe products. Its thickness is small (under 0.1 micron) and getting smaller. It is not an essential part of the device and is likely to either disappear or be minimized to under 0.03 micron when the technology is mature. At that thickness, it would contribute another 0.1 g/m² to a CdTe product. In addition, film fabrication processes are not 100% efficient. They cannot deposit 100% of the Cd on a PV device; some small percentage is wasted during processing, and some further amounts are wasted because production yields are also imperfect. Thus, about 25%-50% more Cd feedstock than shown in Table 1 will be needed for each square meter of module. We estimate that between 1-2 g/m² would be needed for a mature technology.

Is 1-2 g/m² a lot of cadmium? Consider the following:

- There are 20,000 MT of Cd used worldwide each year, about half for Ni/Cd batteries [1,2]. If used for PV, 20,000 MT/yr (@2 g/m²) would supply about 10¹⁰ m² of new PV annually, which at 10% sunlight-to-electricity conversion efficiency would produce 1000 GW_p of new PV capacity per year, and approximately 1.6 million GWh of new PV electricity each year. The U.S. utility grid produces about 3 million GWh of electricity each year, so 2 years of using the world's Cd would displace the entire U.S. electricity grid! And PV modules are designed to last 30 years.
- Using a more practical example of how large-scale PV might develop, at 1000 MT/year Cd (5% of world Cd use), 500 million m²/year of CdTe PV could be manufactured (at 10% efficiency), producing 50 GW_p/year of new PV (80,000 GWh/yr of added electricity). In only four years, this would result in the equivalent of 10% of U.S. electricity being produced with PV (about the same as hydropower and half as much as nuclear power). Compare this with the current use of most Cd, which is to provide battery power for home electronics and toys.

In summary, using cadmium for PV has tremendous potential value to change the world's energy infrastructure and ameliorate existing environmental problems resulting from the use of conventional energy sources.

In-Plant Energy Use, Safety, and Recycling

Some cadmium ends up on the walls of reactors; some remains as partially used feedstock; and more can be found in partial layers on rejected, incomplete modules. These feedstock losses must be dealt with via disposal or recycling. Because of the success of two U.S. Department of Energy (DOE) Small Business Innovation Research (SBIR) grants to U.S. small businesses (Solar Cells, Inc. and Drinkard Metalox), technology has been developed for recycling both in-plant wastes and "spent" CdTe modules [3]. This new process separates the various metal, glass, and pottant layers so that they can be individually recycled. In addition, cadmium suppliers are willing to take back cadmium wastes for re-smelting and recovery. Finally, glass manufacturers are also willing to recycle broken glass [4]. For each type of process, techniques are being developed for cleaning and waste minimization or recycling. In all cases, the best possible procedures are being developed to minimize exposure during manufacture or cleaning. Current approaches to CdTe manufacture can easily meet today's Occupational Safety and Health Administration and state and local in-plant ES&H regulations.

Product Distribution and Use

PV modules are sealed to prevent the ingress of water vapor or any other potentially harmful influences. This is done to protect the metal contacts from corrosion, which would cause the modules to lose power or fail. Because modules can be effectively sealed, they carry warranties for as much as 20 years or more. This highly effective sealing also keeps PV modules from leaching material to the environment [10] unless artificially ground into very small pieces. In fact, semiconductors such as CdTe are among the most stable and impervious materials known: CdTe is nonflammable and melts at over 1000 °C. Fires are considered a potential hazard, but studies [9] indicate that CdTe modules have so little material and are basically so inert that they add almost negligibly to residential fire hazards. It is likely, for example, that there would be nearly as much cadmium inside a burning home (in chemical form, within batteries) as in solid, inert form on a rooftop covered with CdTe modules. A rooftop installation about 50 m² of PV modules—enough to meet an average household's total electrical needs—would contain about 500 grams of cadmium, about the amount in 10 cordless power tools. It is also likely that severe dangers from fires—e.g., smoke from burning furniture—could be far deadlier than any source of cadmium fumes.

Product Disposal and Recycling

What happens to PV modules at the end of their use? First, because modules are expected to last about 30 years, wastes are minimized. Technology already exists for recycling CdTe modules, and costs associated with recycling appear to be acceptable (approximately 5 cents/W) [4,5]. The feasibility of PV module collection and recycling has been extensively studied by Brookhaven National Laboratory and Unisun [11,12]. Patterns of collection and recycling from other industries, such as electronics, can be paradigms for future PV collection and recycling. Also, large-scale collection and recycling can be done with reverse-logistics companies (collection, moving, and delivery companies that need freight for underutilized return trips) and metal smelters. In addition, manufacturing plants can implement small-scale recycling for their PV scrap, using technologies currently being developed by the DOE SBIR Program.

How big is the cadmium disposal problem? Today's utility coal plants not only produce more familiar pollutants; they also produce heavy-metal pollution. Among these pollutants are cadmium, which goes up the stack in quantities of about 4 g/MWh [6]. This material enters the environment in vapor form. What about CdTe PV? One square meter of module at 10% efficiency produces 180 kWh in an average U.S. location each year. In 30 years, it would produce about 5000 kWh. If there are 2 g of Cd used to make the module, PV would use 0.4 g/MWh, one-tenth the amount sent up the stack by coal burning. Meanwhile, the module would be using an inert form of cadmium that can be recycled. The U.S. Environmental Protection Agency (U.S. EPA) reports that coal burning is by far the largest source of atmospheric cadmium [7], providing more than two-thirds of identifiable air emissions (240 short tons/yr in 1990). By offsetting conventional sources of electricity, PV clearly reduces the impact of cadmium on the environment.

In addition, at 1000 MT/yr of cadmium use, PV would barely change the world's use of this material, which is 20,000 MT/yr. Thus, the issues of Cd disposal would hardly be changed by a technology that has the potential to change the entire world's energy infrastructure.

Conclusions: Overall Perspectives

Cadmium telluride PV is an important, potentially cost-competitive PV electricity option. Like any innovative technology, it poses some new ES&H challenges. However, PV modules contain only a very small amount of inert CdTe. The use of cadmium for PV is actually small compared to its current use in Ni/Cd batteries. In PV, none of the cadmium material is likely to enter the environment during use, and cost-effective methods for recycling exist. Consumers face no significant risks, even under such unusual circumstances as a house fire. The use of CdTe PV modules to offset electricity that would otherwise come from conventional sources such as coal plants is clearly beneficial to the environment.

However, challenges remain. Manufacturers must demonstrate their willingness to adopt best-possible safety practices [8]. Engineering and in-plant administrative controls are needed to prevent occupational hazards [13,14] (for example, dust inhalation). Technological and logistic development of product recycling must continue, especially during the early period when disposal/recycling will be minimal. And, finally, researchers must fully develop the use of very thin layers to minimize cadmium use.

If economically successful, CdTe PV technology should provide substantial relief from existing environmental stresses. The issues associated with the use of cadmium should be manageable and small compared to the positive offsets of using PV to produce our electricity.

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