CdTe PV: Facts and Handy Comparisons

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1. Amount of Cd compounds encapsulated in CdTe modules.

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. There is about 2.9 g of Cd in a square meter area of CdTe one micron thick. There is about 3.7 g of Cd in the same amount of CdS. Most CdTe layers are about 1-3 microns thick, and most CdS layers are about 0.2 microns thick. This means that 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.

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Anderson, B. A., Materials availability for large-scale thin film photovoltaics, *Progress in Photovoltaics*, 8, 61-76, 2000.

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

Zweibel K., Reducing ES&H impacts from thin film PV, in *Environmental Aspects of PV Power Systems*, Utrecht University. The Netherlands, 1997.

Answer: about 7 g/m^2 mainly in the form of CdTe (range 3 to 10 g/m^2)

2. Is CdTe as dangerous as Cd?

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. However, CdTe is a more stable and less soluble compound than Cd and, therefore, is possibly less toxic than Cd. However, OSHA makes no such distinction, 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 US 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 continuously monitored by medical tests, thus preventing health risks.

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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.

Answer: Although CdTe is possibly less dangerous than Cd, the PV industry applies to CdTe the same precautions that apply to Cd.

3. Amount of Cd in Ni/Cd batteries and comparisons with PV

Size AA - 3.2 g in the form of metal Cd and $Cd(OH)_2$
Size C - 10.5 g
Size D- 21 g

REFERENCES
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.
Horn G. Recycling of NiCd Batteries, Some Practical Aspects, Nickel-Cadmium Battery Update Seminar, pp. 56-58, Paris, April 1988, Published by the Cadmium Association, London, UK
http://www.steatite.co.uk/batt/nicd.html

Answer: CdTe modules occupying 1 m^2 (10.7 ft^2) contain less Cd than one C –size flashlight battery.

4. Amount of Cd per kW of power produced by CdTe modules

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.

Answer:
Cd per kW - 70 g/kW
Cd per MW – 70 kg/MW
Cd per GW – 70 Metric Tons (MT)/GW

5. Amount of Cd in a CdTe module per kWh of electricity produced by CdTe modules (in an average US solar location)

In an average solar location in the US like Kansas, a one-square meter, 10%-efficient CdTe module with 7 g of Cd in it, produces 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 NOT an emission. It can be completely recycled.)

Answer:
Cd in a module per kWh – 0.001 g/kW
Cd per MWh – 1 g/MWh
Cd per GWh – 1 kg/GWh

6. How Much Cd in CdTe modules versus Cd in batteries on a per kWh basis?

The NiCd battery industry estimates that an AA or C size NiCd battery can be re-charged 700 to 1200 times over its life. Under this assumption, a battery 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 2500 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.

REFERENCES:
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.
http://www.steatite.co.uk/batt/nicd.html
http://www.greatcell.com/english/reseau/products/accus/accus.htm

Answer: Over the life of a CdTe module (without recycling) versus the life of a Ni/Cd battery, the PV module uses Cd about 2500 times more efficiently in producing electricity. (If either or both were recycled, this would improve the efficiency of using the Cd/kWh of output.)

7. Where does Cd come from?

Cadmium is a by-product of smelting of zinc, lead, and copper. Its major feedstock, sphalerite (ZnS), contains only 0.25% of Cd. Because Zn is produced in very large quantities (8 million metric tons in 1999, per USGS), substantial cadmium is generated as a by-product, <u>no matter how much Cd is used in PV,</u> 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, this is cemented and buried, stored for future use, or disposed of to landfills as hazardous waste.

REFERENCE:
http://wrgis.wr.usgs.gov/open-file/of02-29/tables/6_Zn_statistics.xls
Plachy J., U.S. Geological Survey Minerals Yearbook- 2001, Cadmium-Chapter 17
Morrow H., The International Cadmium Association, personal communication, 1/17/03.

Answer: Cadmium is a by-product of zinc, lead, and copper mining, and as such will be either used in products or be disposed of.

7. How much cadmium is needed for very large-scale CdTe PV?

Cadmium is used primarily (~65%) in nickel-cadmium rechargeable batteries, paint pigments (~17%), plastic stabilizers (~10%), for metal plating (~5%) and metal solders (~2%) (Figure 1). The total Cd use in the US was 2600 tons in 1997; globally the total use is 19,000 to 20,000 tons.

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.

Why? Using only 3% of the US consumption of cadmium in the manufacture of CdTe solar cells (i.e., 78 tons), would generate over 1 GW of new PV per year. Note that the total current PV capacity in the US is only 0.3 GW and is projected to grow (under optimistic assumptions) to about 3.2 GW/yr by the year 2020. Even if we envision an order of magnitude higher PV production, this would require only about a third of the current US Cd consumption. And the result? New solar energy of 10 GW/year, which would quickly accumulate and significantly change the mix of electricity sources in the US and abroad, preventing carbon dioxide and other emissions. Isn't this more valuable than current uses of Cd, mostly for toy batteries?

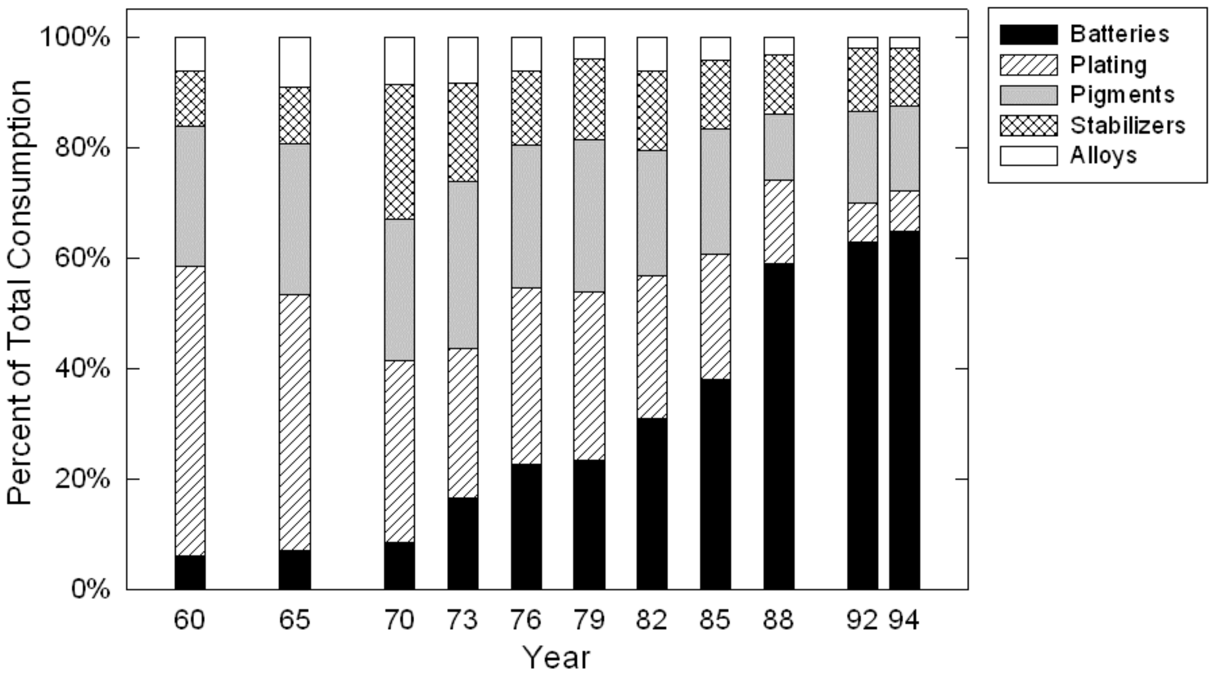

Figure 1. This figure shows world cadmium consumption by end use. Source: Cadmium Market Update Analysis and Outlook, Roskill Information Services Ltd., 1995.

REFERENCES
Anderson, B. A., Materials availability for large-scale thin film photovoltaics, Progress in Photovoltaics, 8, 61-76, 2000.
Cadmium Market Update Analysis and Outlook, Roskill Information Services Ltd., London, UK, 1995

Answer:
Cadmium is generated anyway as a byproduct of zinc smelting and needs to be put in beneficial use or be disposed of to the environment.
Less than 3% of the *current* US Cd consumption is needed for large (i.e., GW/year) production of CdTe PV; using less than a third of the current Cd consumption in PV, would change our electricity infrastructure in just a few years.

9. Sources of Cd exposure to humans

Most human cadmium exposure comes from ingestion of food, and most of that arises from the uptake of cadmium by plants from fertilizers, sewage sludge, manure and atmospheric deposition. Van Assche (1998) has developed a model for cadmium exposure for human beings and allocated this exposure to these sources. The assumptions and the data inputs for the model have been based on actual data from Belgium and the European Community (ERL, 1990; OECD, 1994). The model estimates of the relative importance of various cadmium sources to human exposure are shown in Table 2.

Table 2. Sources and Relative Contributions of Cd Exposure to Humans (in Europe)	
Phosphate Fertilizers	41.3 %
Fossil Fuel Combustion	22.0 %
Iron & Steel Production	16.7 %
Natural Sources	8.0 %
Non-ferrous Metals	6.3 %
Cement Production	2.5 %
Cadmium Products	**2.5 %**
Incineration	1.0 %

As shown form the data above, phosphate fertilizers, fossil fuel combustion, and other industrial activities contribute far more to human cadmium exposure than production, use, and disposal of cadmium products. ‘Solving the Cd problem’ in PV by eliminating CdTe makes very little sense from a broader perspective, since Cd-products bear so little relation to actual human exposure; CdTe PV itself can contribute to reducing other, larger forms of exposure such as fossil fuel combustion (see below for more on this).

REFERENCES

ERL, 1990. Environmental Resources Limited, Evaluation of the Sources of Human and Environmental Contamination by Cadmium. Prepared for the Commission of the European Community, Directorate General for Environment, Consumer Protection and Nuclear Safety, London, February 1990.

OECD, 1994. Organization for Economic Co-operation and Development, Risk Reduction Monograph No. 5: Cadmium OECD Environment Directorate, Paris, France.

Van Assche, F. J., and Ciarletta, P., (1993). "Environmental exposure to cadmium in Belgium: Decreasing trends during the 1980s." Heavy Metals in the Environment Volume 1, pages 34-37. Toronto-September 1993.

Van Assche, F. J., (1998) "A Stepwise Model to Quantify the Relative Contribution of Different Environmental Sources to Human Cadmium Exposure," NiCad '98, Prague, Czech Republic, September 21-22, 1998.

Answer: Cadmium is released into the environment from phosphate fertilizers, burning fuels, mining and metal processing operations, natural sources, cement production, and disposing of metal products. Releases from disposed cadmium products including NiCd batteries are minor contributors to human exposures, because Cd is encapsulated in their structure.

10. Can CdTe from PV module 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.

See the next question for a discussion of fires as a potential source of exposure.

The only issue of some concern is the disposal of the well-encapsulated, relatively immobile CdTe at the end of the modules' useful life. Today's CdTe PV end-of-life or broken modules pass Federal (TCLP-RCRA) leaching criteria for non-hazardous waste. 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 towards large and cost-effective production. 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

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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.

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.

Fthenakis V., Eberspacher C. and Moskowitz P., Recycling strategies to enhance the commercial viability of photovoltaics, *Progress in Photovoltaics*, 4, 447-456, 1996

Fthenakis V. and Gonsiorawski R., Lead-free solder technology from ASE Americas, Workshop Report BNL-67536, Oct. 19, 1999, Brookhaven National Laboratory, Upton, NY 11973.

Fthenakis V. Could CdTe PV Modules Pollute the Environment? Aug. 2002, Brookhaven National Laboratory, Upton, NY 11973. www.pv.bnl.gov

Answer: No emissions of any kind can be generated when using PV modules. The only issue is what to do with the modules about 30 years later, if they are not useful any longer. 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.

11. Do CdTe modules present additional health risks during a fire?

The flame temperatures in typical US residential fires are not high enough to vaporize CdTe; flame temperatures in roof fires are in the 800-900 ^{o}C range, and, in basement rooms, in the 900-1000 ^{o}C range[1]. The melting point of CdTe is 1041 ^{o}C, and evaporation starts at 1050 ^{o}C. Sublimation occurs at lower temperatures, but the vapor pressure of CdTe at 800 ^{o}C is only 2.5 torr (0.003 atm). The melting point of CdS is 1750 ^{o}C and its vapor pressure due to sublimation is only 0.1 torr at 800 ^{o}C. Preliminary studies at Brookhaven[2] and at the GSF Institute of Chemical Ecology in Germany[3], showed that CdTe releases are unlikely to occur during residential fires or during accidental breakage[4]. The thin layers of CdTe and CdS are sandwiched between the glass plates and 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. Additional experimental studies are planned at Brookhaven to test this assumption and quantify the thermal behavior of modules during fires. In any case, the fire itself and other sources of emissions within the burning structure are expected to pose incomparably greater hazard than any potential Cd emissions from PV systems.[5]

REFERENCES:

1. Drysdale D., An Introduction to Fire Dynamics, pp. 329-330, Wiley, NY, 1985.
2. Moskowitz P. and Fthenakis V., Toxic materials released from photovoltaic modules during fires; health risks, *Solar Cells*, 29, 63-71, 1990.
3. Thumm W. Finke A., Nuemeier B., Beck B., Kettrup A., Steinberger H. and Moskowitz P., Environmental and health aspects of CIS-module production, use and disposal," presented at the First World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii 5-9 December 1994.
4. 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.
5. Patterson M., Turner A., Sadeghi M., Marshall R., HSE aspects of the production and use of CdTe thin film modules, Presented at the 12th European PV Solar Energy Conference, Amsterdam, 1994.

Answer: 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.

12. CdTe PV will prevent Cd emissions in the environment!

Coal burning routinely generates Cd, since Cd is contained in the coal. A typical US 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 (ESP) or bag-houses operating at 98.6% efficiency, and median concentration of Cd in US coal of 0.5 ppm). Power plants with less efficient pollution controls will produce more Cd in gaseous form. Furthermore, a typical US coal-power plant emits about 1000 tons of CO_2, 8 tons of SO_2, 3 tons of NOx, and 0.4 tons particulates per GWh of electricity produced. All these emissions will be avoided when PV replaces coal-burning for some fraction of electricity generation.

REFERENCES

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

Answer: PV, when it replaces coal-burning for electricity generation, will prevent a minimum of 2 g of Cd in gaseous emissions and about 140 g of Cd in ash form for each GWh of electricity produced. In addition, PV would prevent the emissions of about 1000 tons of CO_2, 8 tons of SO_2, 3 tons of NOx, and 0.4 tons particulates per GWh produced.

13. But Why Bother with CdTe PV If Other, Presumably Less Toxic PV Alternatives Exist?

1. The threat from CdTe PV is so minimal as to be entirely open to question. The use and

sequestration of Cd to a safe product like a PV module (as opposed to its disposal or its use in other products) is actually a net environmental advantage. Every energy source or product may present some environmental health and safety (EHS) hazards. Even crystalline-Si PV modules, which are thought to be completely benign, present some EHS issues (e.g., lead solder and higher manufacturing energy-input translating to lower reduction of CO_2 emissions), so it is an open question whether avoiding CdTe PV versus other PV technologies is actually environmentally advantageous.

2. CdTe is a thin film technology. As such, it has potential cost-per-square-meter advantages over existing crystalline silicon PV options. In addition, CdTe modules with over 10% efficiency have been produced by several deposition techniques. The combination of reasonable efficiencies and very low costs would make CdTe PV modules quite inexpensive – perhaps a fraction of existing crystalline silicon alternatives. Direct competition would come from other thin film technologies, such as amorphous silicon or copper indium diselenide. Unfortunately, amorphous silicon has not demonstrated adequate efficiencies (closer to 6%-8% in modules, with little recent progress); and copper indium diselenide has been difficult to scale-up to volume production. At this point in the still early development of thin films, CdTe and copper indium diselenide lead in the critical performance and cost parameters needed to make PV cost-effective for energy-significant uses. Both face technical hurdles, and neither could be called a sure thing. Thus there is no clearly identifiable substitute for CdTe thin film PV for potentially low-cost PV modules. We don't know yet, which if any, of the thin film options will end up meeting all the ambitious technical goals needed to make PV electricity inexpensive.