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"Emissions from Photovoltaic Life Cycles"

by Vasilis M. Fthenakis, Hyung Chul Kim, and Erik Alsema.
Environmental Science & Technology, 2008, Vol. 42, No. 6, pg. 2168-2174.

In this study, researchers present the life cycle emissions of greenhouse gases (GHGs), criteria pollutants, and heavy metals from four types of solar photovoltaic (PV) systems that are commercially available: multicrystalline silicon (13.2% efficient), monocrystalline silicon (14% efficient), ribbon silicon (11.5% efficient), and thin film cadmium telluride (CdTe; 9% efficient).

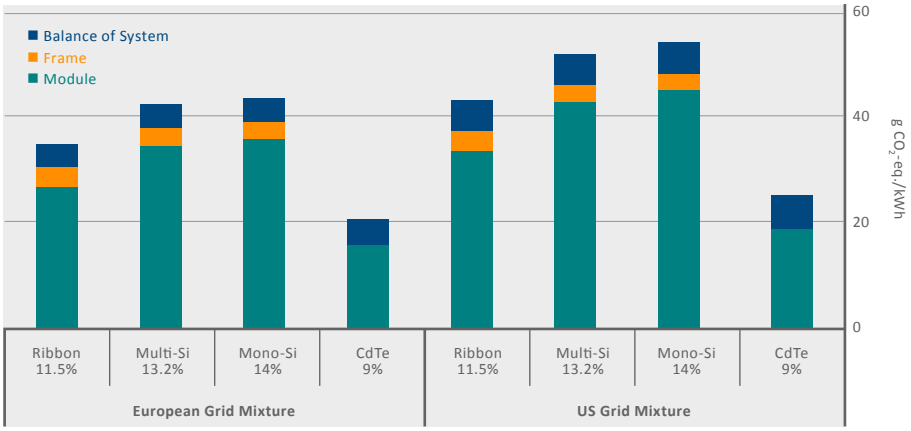
Life cycle assessment (LCA) is a cradle-to-grave quantitative assessment of the environmental impacts associated with a product, process, or service. In the case of a product, life cycle refers to the major activities undertaken in the course of its lifespan from raw material sourcing, manufacturing, and use, to its final disposal or reuse. LCA allows comparisons of the environmental attributes of competing alternatives in accordance with a systematic, data-based methodology. LCA is a comprehensive approach; it takes into account any transfer of environmental impacts from one medium to another.

In this study, life cycle emissions were determined by employing average electricity mixtures in Europe and the United States during the materials and module production for each PV system. The results show that:

- Among the current vintage of PV technologies, thin film emits the least amount of harmful air emissions on a life cycle basis as it requires the least amount of energy during module production.
- CdTe PV systems have the lowest carbon footprint of analyzed PV technologies on a life cycle basis (see Figure 1).
- On a life cycle basis, CdTe PV systems have the lowest emissions of heavy metals, including cadmium, of analyzed PV technologies (see Figures 2 and 3).
- Replacing grid electricity with central CdTe PV systems results in significant environmental benefits, including a reduction of 89-98% of GHG emissions, criteria pollutants, and heavy metals.
- Emissions of cadmium (including in cadmium-containing compounds) from CdTe PV systems are over 100 times lower than those from coal-fired generation, over 130 times lower than grid-based electricity in Europe, and over 1440 times lower than oil-fired generation on a life cycle basis (see Figure 2).

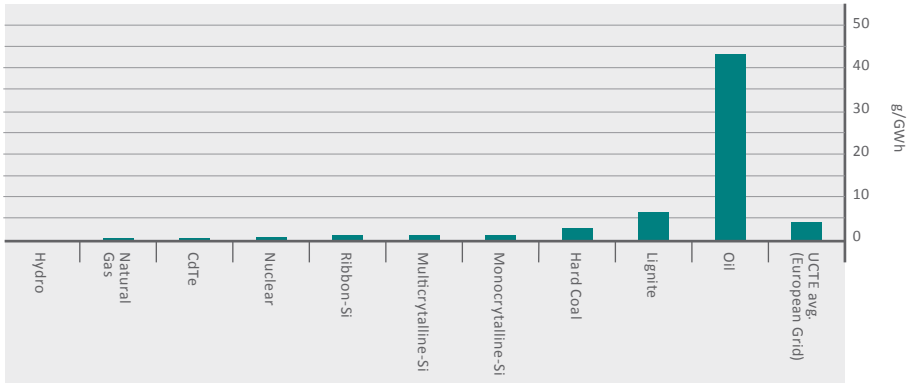



Figure 1: Life cycle GHG emissions from silicon and CdTe PV modules



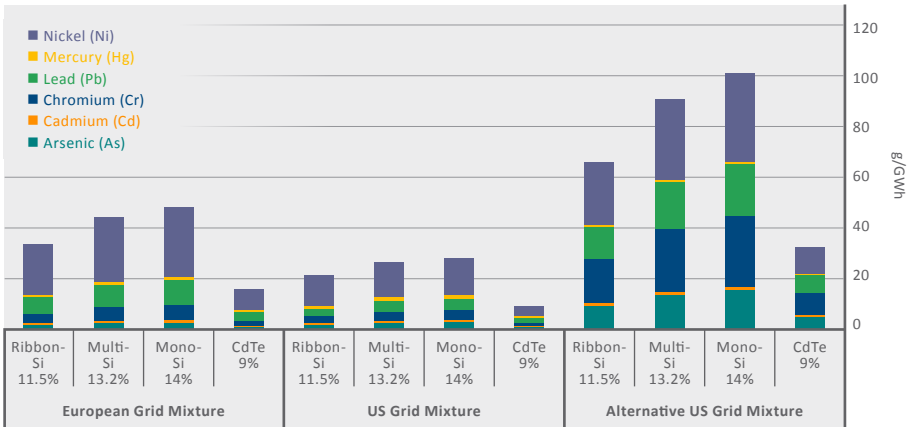
Source: "Emissions from Photovoltaic Life Cycles" by Vasilis M. Fthenakis, Hyung Chul Kim, and Erik Alsema. *Environmental Science & Technology*, 2008, Vol. 42, No. 6, pg. 2168-2174, Fig. 2). Balance of system (BOS) includes module supports, cabling, and power conditioning. Conditions: ground-mounted PV systems, Southern European insolation of 1700 kWh/m^2/yr, performance ratio of 0.8, and lifetime of 30 years. European grid mixture: Ecoinvent database for medium-voltage electricity of the UCTE grid (Ecoinvent Centre. Ecoinvent data v1.1. Final reports ecoinvent 2000 No. 1–15; Swiss Centre for Life Cycle Inventories: Dübendorf, 2004). U.S. grid mixture: Franklin database for the U.S. average grid mixture (USA LCI Database Documentation; Franklin Associates: Prairie Village, KS, 1998).

Figure 2: Life cycle atmospheric Cd emissions from PV and other electricity generation options



Source: "Emissions from Photovoltaic Life Cycles" by Vasilis M. Fthenakis, Hyung Chul Kim, and Erik Alsema. *Environmental Science & Technology*, 2008, Vol. 42, No. 6, pg. 2168-2174, Fig. 3). Life cycle atmospheric Cd emissions for PV systems from electricity and fuel consumption, normalized for a Southern Europe average insolation of 1700 kWh/m^2/yr, performance ratio of 0.8, and lifetime of 30 years. Ground-mounted BOS is assumed for all PV systems.

Figure 3: Life cycle atmospheric heavy-metal emissions for PV systems



Source: "Emissions from Photovoltaic Life Cycles" by Vasilis M. Fthenakis, Hyung Chul Kim, and Erik Alsema. *Environmental Science & Technology*, 2008, Vol. 42, No. 6, pg. 2168-2174, Fig 4. Life cycle atmospheric heavy-metal emissions for PV systems (normalized for Southern European average insolation of 1700 kWh/m^2/yr, performance ratio of 0.8, and lifetime of 30 years). Each PV system is assumed to include ground-mounted balance of systems. European grid mixture: Ecoinvent database for medium-voltage electricity of the UCTE grid (Ecoinvent Centre. Ecoinvent data v1.1. Final reports ecoinvent 2000 No. 1–15; Swiss Centre for Life Cycle Inventories: Dübendorf, 2004). U.S. grid mixture: Franklin database for the U.S. average grid mixture (USA LCI Database Documentation; Franklin Associates: Prairie Village, KS, 1998). Alternative grid mixture: Emission factors of a recent study by Kim and Dale for the U.S. grid mixture (Kim, S.; Dale, B. E. Life Cycle Inventory Information of the United States Electricity System Int. J. LCA 2005 10 294 310).

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