BNL-98017-2012-AB

Direct Te Mining: Resource Availability and Impact on CdTe PV Life-Cycle Assessments

Vasilis Fthenakis and Annick Anctil

Submitted to the 38th IEEE Photovoltaic Specialists Conference
June 3-8, 2012

May 2012

Sustainable Energy Technologies Department/Renewable Energy Group

Brookhaven National Laboratory

U.S. Department of Energy
Office of Energy, Efficiency and Renewable Energy

Managed by
Brookhaven Science Associates, LLC
for the United States Department of Energy under
Contract No. DE-AC02-98CH10886

Work is supported in part by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 under the U.S. Department of Energy.

DISCLAIMER

Direct Te mining: Resource availability and impact on CdTe PV life-cycle assessments

Vasilis Fthenakis[1,2] and Annick Anctil[2]
[1]Columbia University, New York, NY, USA
[2]Brookhaven National Laboratory, Upton, NY, USA

ABSTRACT

The availability of Te is constrained by the production rate of its main parent compound (copper) and a debate is going on related to the potential supply of Te for very large scale CdTe PV deployment. However, recent investigations point to the existence of Te-rich ores in several places of the world that are likely to allow economic recovery of Te, independently of the production of copper. Consequently, direct mining of Te from such ores may potentially increase the environmental burden of mining and smelting operations in the life cycle of CdTe PV systems. In conventional CdTe life-cycle assessments (LCA), one allocates the environmental impacts of mining and smelting to all the co-products on the basis of products' volumes or economic values.

Since Te in typical copper sulfide ores is in concentrations of about 1.5 ppm (global average) whereas the concentration of Cu in the same is about 6,000 ppm (0.6%), very little of the environmental impacts of mining and smelting are allocated to the production of Te. If economic value is used in the allocation, then ~0.7% of the emissions are assigned to the production of Te. In the case of direct Te mining the allocation of environmental impacts to Te assumes a larger share or the total impacts because the concentration of tellurium and the economic value are comparable to that of the co-products. An assessment of 5 project cases devoted to direct-mined tellurium is used to show how the, energy and chemical inventories in direct Te mining compares to those of the Te recovery from Cu production circuits. Other factors that influence the impacts of direct Te mining include the presence of co-products (e.g., gold), the relative contribution of Te to the life cycle cumulative energy demand of CdTe PV, the proportion of directly mined Te content relative to Cu bi-product content in the Te supply chain, and end-of-life CdTe PV recycling to mitigate the need for Te from mining.

INTRODUCTION

The availability of materials for very large growth of photovoltaics is of some concern. A recent European Commission report [1] and a U.S. DOE report [2] list gallium, indium and tellurium as critical in terms of supply risk and economic importance to European, U.S. and global markets. These materials are of constrained supply because they are minor byproducts of aluminum, zinc, and copper production; since their concentrations in the base metal ores are typically very low, mining for them (i.e., direct mining) is not cost effective, and, so far have only been produced as co-products in base metal production.
The availability of Te is constrained by the production rate of its main parent compound (copper), and a debate is going on related to the potential supply of Te for very large scales of CdTe PV deployment [3-6]. However, recent investigations point to the existence of Te-rich ores in several places of the world that are likely to allow economic recovery of Te, independently of the production of base metals. Consequently, direct mining of Te from such ores may potentially increase the environmental burden of mining and smelting operations in the life cycle of CdTe PV systems.

In conventional CdTe life-cycle assessments (LCA), one allocates the environmental impacts of mining and smelting to all the co-products on the basis of products' volumes or economic values. Since Te in typical copper sulfide ores is in concentrations of about 1.5 ppm (global average) whereas the concentration of Cu in the same is about 6,000 ppm (0.6%), very little (i.e., 0.02%) of the environmental impacts of mining and smelting are allocated to the production of Te. If economic value is used in the allocation, assuming a Te price of $230/kg, then 0.7% of the emissions are assigned to the production of Te. In the case of direct Te mining, the allocation to Te increases considerably.

Factors that influence the impacts of direct Te mining include the presence of co-products (e.g., gold), the small (<1%) relative contribution of Te to the life cycle cumulative energy demand of CdTe PV, the proportion of directly mined Te content relative to Cu bi-product content in the Te supply chain, and end-of-life CdTe PV recycling to mitigate the need for Te from mining.

In our study we consider five scenarios of direct Te mining and assess the corresponding impacts on the life-cycle of CdTe PV. These scenarios are:

a) Case 1 : Te rich ores containing Ag and Au - Example: Moctezuma, Mexico
b) Case 2: Te-Ag ores containing Au –Example: Deer Horn, Canada;
c) Case 3: Multi-element (Cu, Mo, Te, Bi, Ag, Ag) ores –Example: Sinivit, New Guinea
d) Case 4: Te-Au ores –Example: Boliden, Kankberg, Sweden

e) Case 5: Te-Bi ores –Example: Dashuigou and Majiagou, China

The environmental impacts of these cases are compared with a reference case of Te produced as minor metal in Cu production from the copper anode slimes.

f) Ref Case: Te as a by-product of Cu mines–
Example: Kennecott Utah

The concentrations of the recovered metals in the ores and the corresponding mass and price based allocations are shown in the Table below.

TABLE 1: CONCENTRATIONS OF RECOVERD METALS IN THE ORES AND CORRESPONDING MASS AND PRICE BASED ALLOCATIONS

Metals	Te	Au	Ag	Bi	Mo	Cu	Se
Prices ($/kg)	230	28,000	470	21	45	6.7	150
Case 1: Te rich ores							
Reserves (t)							
g/tonne ore	2100.0	4.0	5.0				
mass allocation (%)	99.6	0.2	0.2				
cost allocation (%)	80.9	18.7	0.4				
Case 2: Te-Ag-Au ores							
Reserves (t)							
g/tonne ore	220.0	6.7	249.0				
mass allocation (%)	46.2	1.4	52.3				
cost allocation (%)	14.2	52.8	32.9				
Case 3: Multi-element (Cu, Mo, Te, Bi, Ag, Au) ores							
Reserves (t)							
g/tonne	203.0	5.8	24.0	94.0	376.0	939.0	
mass allocation (%)	12.4	0.4	1.5	5.7	22.9	57.2	
cost allocation (%)	19.0	66.1	4.6	0.8	6.9	2.6	
Case 4: Te-Au ores							
Reserves (t)							
exp. prod. (t/yr)	41.0	1.15					
g/tonne	186.0	4.1					
mass allocation (%)	97.8	2.2					
cost allocation (%)	27.1	72.9					
Case 5: Te-Bi ores							
Reserves (t)	508			765			
g/tonne	1170			1760			
mass allocation (%)							
cost allocation (%)							
Global Ref. Case: Cu ores							
Reserves (t)							
g/tonne	1.5	4.1				6,000	4
mass allocation (%)	0.02	0.07				99.84	0.07
cost allocation (%)	0.2	73.6				25.8	0.4

The flows of the various metals in the corresponding productions circuits are followed and energy contributions and associated emissions are estimated. A flow chart corresponding to the case of Te-rich ores (Case1) is shown in Figure 2.

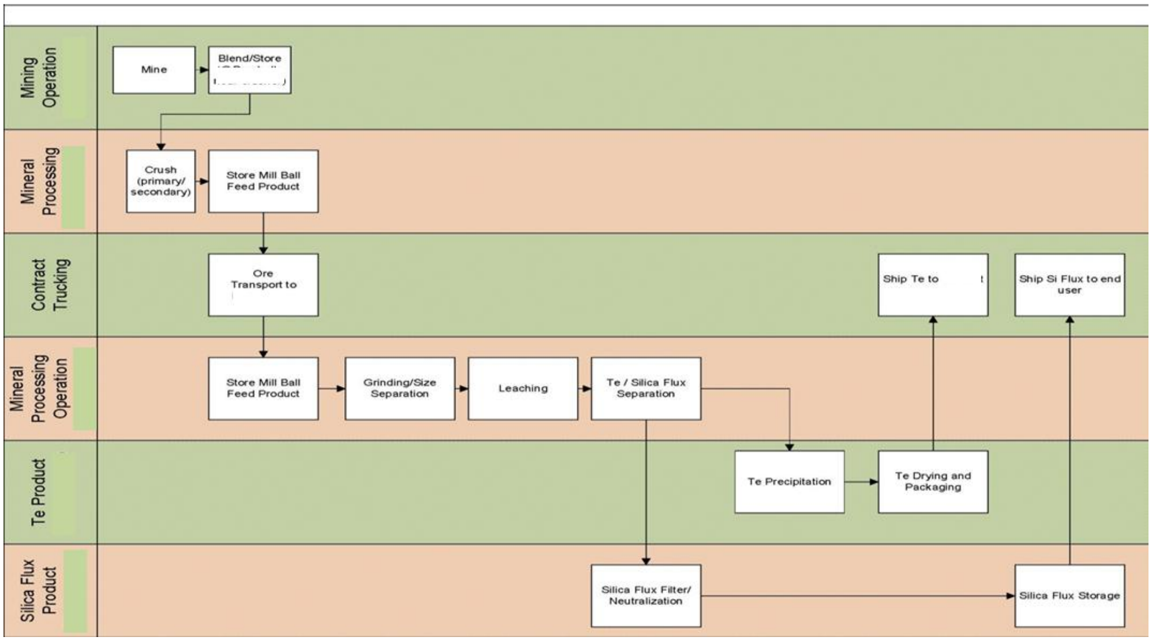

FIGURE 1: FLOW CHART FOR TE-RICH ORES (CASE 1)

Based on a preliminary assessment of inventory data shared by the industry, Te mining in Case 1 (Te-rich ores), is much less energy and chemical intensive than Cu mining. In Cases 2, 3 and 4 a cost allocation is heavily weighted towards Au; gathering and investigation of inventory data for these cases is in progress. Mining for Te in Case 5 (Te-Bi ores) may multiply the contribution of the metal production in the CdTe PV LCA, unless gold is a co-product there as well. However, since Te is a small proportion (<1%) of the life cycle cumulative energy demand of CdTe PV, the incremental impact of direct Te mining may not be significant. The proportion of directly mined Te- content relative to Cu bi-product Te-content in the Te supply chain will also influence the impact, and end-of-life CdTe PV recycling will mitigate the need for mined Te content [2]. Investigations are in progress to assess the environmental impact on the full life-cycle of CdTe PV of each of these scenarios.

REFERENCES

[1] R.L.Moss, E.Tzimas, H.Kara, P.Willis and J.Kooroshy. 2011. Critical Metals in Strategic Energy Technologies. European Commission JRC-IET. EUR24884 EN-2011.

[2] U.S. Department of Energy, Critical Materials Strategy, December 2010

[3] Green, M.A., *Progress in Photovoltaics: Research and Applications*,. **14**, 743 (2006).

[4] Ojebuoboh F. Selenium and tellurium from copper refinery slimes and their changing applications, World of Metallurgy – ERZMETALL – Heft 1/2008, vol. 61(1), 1, 2008.

[5] Fthenakis V., Sustainability of thin film photovoltaics, *Renewable and Sustainable Energy Reviews* 13, 2746-2750, 2009

[6] Zweibel K., *Science*, 328, 699 (2010)

[7] California Gold, “AuroTellurio.”: http://www.californiagoldcorp.com/operations-projects/aurotellurio.

[8] B. Lane, “Technical Report on the Deer Horn Gold-Silver-Tellurium Property”. 2010.

[9] New Guinea Gold: http://www.newguineagold.ca.