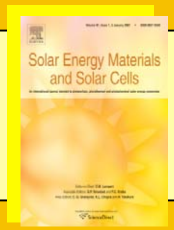
The Basic Economics of PV

A Case Study for Ag Nanowire Contacts



Greg P. Smestad, Ph.D. (Associate Editor)

Solar Energy Materials and Solar Cells, P.O. Box 5729, San Jose, CA 95150

Introduction

Annual production of Photovoltaic (PV) panels was estimated to be 3,073-3,800 Megawatts (MWp) in 2007 [1, 2, and Navigant Consulting]. Cumulative global production stands at approximately 12,400 MW. Annual growth in PV production continues to be 40-50%. According to the Earth Policy Institute, the industry has grown by an average of 48 percent each year since 2002. PV production has been doubling every two years, making it the world's fastest-growing energy source.

Module price is currently $2.5-3.8 per peak watt ($/Wp), which leads to a Levelized Cost of Electricity (LCOE) of approximately 21 U.S. cents per kilowatt-hour ($/kWh). When the LCOE for PV is half of this value, widespread economic deployment of PV power will likely be a reality. It is therefore useful for researchers in the field of solar energy to have at least some basic knowledge of the economic principles that govern PV modules and systems.

Several simplified and illustrative equations are presented and applied to the specific case of the use of silver (Ag) nanowire mesh transparent electrode that has recently been reported [J.-Y. Lee, S.T. Connor, Y. Cui, P. Peumans, "Solution Processed Metal Nanowire Mesh Transparent Electrodes," Nano Letters **8**, 689-692 (2008)] as a possible replacement to Transparent Conductive Oxides (TCOs) that are essential for thin film PV [4].

Goals

Using published and current data for silver (Ag), an attempt was made to determine whether silver nanowire meshes can economically replace currently used transparent conductive oxide materials for use in thin-film photovoltaic (PV) cells and modules based on the following:

- Cost - The cost per square meter for the Ag is compared to other costs for the PV module.
- Availability - The production capacity for Ag from mining is compared to the amounts necessary for Gigawatt (GW) and Terawatt (TW) level PV deployment.
- Resources - The resource utilization is considered with a view towards environmental considerations.
- Utility to Students - The economic framework and analysis is simplified so that it can be easily understood applied to PV materials such as Ag, Te, Ga, Ge, and In.

Method

The basic economic equations for PV are as follows:

$$\$/\mathrm{W_p} = \frac{\$/\mathrm{m}^2}{\eta \bullet 1000\ \mathrm{W_p/m^2}}$$

$$\frac{\mathrm{Cost}}{\mathrm{kWh}} = \frac{\left(\text{Cost of system } \$/\mathrm{m}^2\right) \bullet \text{amortization}}{\text{kWh produced each year}} + \mathrm{O\&M}$$

Where:

$/Wp = Cost per peak watt of the module

η = solar conversion efficiency

kWh = kilowatt hour

O&M = Operating cost and maintenance

$\$/m^2$ estimates take from literature [5, 7]

$$\mathrm{P(t)} = \mathrm{P(0)} \bullet \left[\mathrm{q(t)/q(0)}\right]^{-b}$$

Where:

P(t) is the average price of a product at time t

q(t) is the cumulative production at time t

b is the learning coefficient

Relevant Parameters (Ag) [6, 7]

Specific gravity = 10.4 g/cm^3

Layer thickness 0.3 microns (tube diameter 100 nm)

Material utilization 0.75 (i.e. 75%)

Amount used per unit area = 4.16 g/m^2

Price per gram = 0.2 - 0.4 $/g ($5 - $10 per troy oz.)

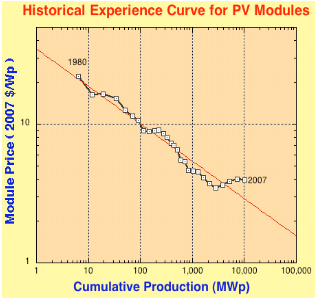
Conversion factor = 31.03 g/troy oz.

Current amount mined worldwide = 18,300 metric tons/year (U.S. Geological Survey & Silver Institute World Ag Survey)

Silver has recently experienced price volatility.

Results

- If Balance of Systems (BOS) costs are considered, the cost of power produced with PV could be 0.08-0.13 $/kWh, assuming a module of 15% efficiency that lasts at least 15 years under the irradiance levels found in the sunnier regions of the western United States [3,5,7].
- Although solar cells of 15% efficiency that last for 15 years can be competitive with fossil fuels, solar cells of less than 8% efficiency with lifetimes of less than 15 years will likely not lead to economically competitive products at MW scales [5, 7].
- The use of a Ag nanowire mesh would result in an addition of approx. $1/$m^2$ to the overall cost of materials, given the assumptions of this study and if increased Ag demand would not adversely alter prices or volatility.
- Considering that the near-term PV materials costs are between $300 - $400/$m^2$ and that long-term targets are under a $100/$m^2$, this may be an acceptable cost.
- It compares favorably with the cost of Pilkington TEC10 SnO_2:F float zone conductive glass ($20 - $30/$m^2$ at tens of megawatt equivalent production volumes).
- The limit set by current Ag production and availability would be approximately 290 GW/year at a cell efficiency of approx. 7%.
- For the past 2 years, PV modules prices have deviated from the historical 80% progress ratio exhibited since 1980 [R. Margolis]. This is believed to be due to strong demand and a Si supply shortage that is expected to end within the next two years.



*Learning curve for the photovoltaics industry updated to 2007 using data from **Navigant Consulting** in Palo Alto. Module costs have been adjusted using GDP deflator data from the Bureau of Economic Analysis (www.bea.gov).*

Conclusions

Economic analysis of solar energy materials and solar cells is often neglected at early stages of research. Such analysis can yield valuable insight into those research pathways that are most likely to lead to viable commercial photovoltaic panels at production volumes that are expected for the industry in the future.

Thin film PV modules are believed by some to allow for a rapid return to prior PV price reduction trends. Transparent front contacts are an essential part of this technology. From the technical standpoint, the utilization of Ag nanowire meshes have recently demonstrated that they can be an alternative to ITO and SnO_2:F TCOs. Adding to this, we can also say that their material costs are reasonable. Further work should be conducted to determine economic viability of this approach given suitable processing methods at large scales.

References

[1] P. D. Maycock, PV News, **26**/4, 8-9 (April 2007).

[2] "REN21, Renewables 2007, Global Status Report: A Pre-Publication Summary for the UNFCCC COP13" (Paris, December 2007), http://www.ren21.net/globalstatusreport/.

[3] R. M. Swanson, "A Vision for Crystalline Silicon Photovoltaics," Progress in Photovoltaics: Research and Applications, **14**, 443-453 (2006).

[4] T. Markvart and L. Castaner, *Solar Cells: Materials, Manufacture and Operation* (Elsevier, 2005).

[5] G. P. Smestad, *Optoelectronics of Solar Cells* (SPIE, 2002), Chap. 7; http://www.solideas.com/SolarCellBook.html

[6] A. Feltrin, A. Freundlich, "Material Considerations for Terawatt Level Deployment of Photovoltaics," Renewable Energy, **33**, 180-185 (2008).

[7] M.S. Keshner, R. Arya, "Study of Potential Cost Reductions Resulting from Super-Large-Scale Manufacturing of PV Modules," NREL/SR-520-36846 Final Subcontract Report (October 2004).

Acknowledgements

The author would like to thank Robert Margolis of NREL for providing the data for the PV learning curve. Additional Information on Solar Energy Materials and Solar Cells is found at:

http://ees.elsevier.com/solmat/