UNDERSTANDING THE POSSIBILITIES AND CONCERNS OF THIN-FILM CADMIUM TELLURIDE (CdTe) SOLAR PHOTOVOLTAIC TECHNOLOGY

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Cadmium Telluride (CdTe) photovoltaic (PV) solar cells have exciting investment potential in solar energy markets. This analysis will discuss CdTe's history, technological advantages, along with its challenges. Finally, I will discuss improvements in CdTe development which are currently happening.

What is CdTe?

A smelting and mining by-product of cadmium and telluride, CdTe offers possibilities in advancing thin-film technologies, despite some environmental concerns over toxicity (Lynn, 2010). CdTe's bandgap on the solar spectrum of 1.45 eV, is also great fit within the solar spectrum (Ullal, 2010).

CdTe PV panels make up 7% of the 2014 solar panel market in 2014 (US Department of Energy, 2016), and estimates have the CdTe market at 30% or greater by 2030 (Lynn, 2010). CdTe along with amorphous silicon (a-Si), and copper indium gallium (di) selenide (CIGS), make up the thin-film PV technologies (Ullal, 2008).

Germans D. Bonnet and H. Rabinherse in 1972, reported a polycrystalline thin-film CdTe, which spurred interest between the 1970's through the 1980's (Zweibel, 2013). Interest waned in the 1980's, until later that decade, with corporations becoming more curious about CdTe (Zweibel, 2013).

The process of the p-n heterojunction thanks to doping CdTe layer mixed with the n cadmium (cds layer). A pretend window layer is created, while CdTe's structure is the same as CIGS. Field assisted collection, and drift helps to accomplish carrier collection for CdTe. (US Department of Energy, 2016).

Advantages CdTe

Future solar PV markets can leverage many benefits of CdTe technology.

One gain with CdTe thin-film PV, along with a-Si, and CIGS is decreased capital costs compared to standard home solar systems (IRENA, 2012). CdTe Leveled Cost of Electricity (LCOE) offers $0.07-$0.15 kWh depending on individual factors including solar radiance, development costs, and interest rates, according to First Solar (2016a), which specializes in CdTe thin-film PV technology.

CdTe provides better cell efficiency rates, and lower production costs compared to other thin-film technologies, outside of decreased capital costs (IRENA, 2012). The upper limit rate for thin-film is around 20%, according to the Shockley Queisser limit (Solar Cell Central.com, 2016).

Research from various groups globally in improving the absorption layer and its processes has helped to improve efficiencies to 10% or higher (Ullal, 2008). First Solar recorded a record for thin-film PV cell efficiency with 22.1% in February, 2016 (Wesoff, 2016).

As CdTe production offer low-cost manufacturing potential, (Zweibel, 2013), improving cell efficiencies and lowering CdTe costs make it more attractive for higher demand and increased utilization, compared to standard silicon PV technology. One potential example is Building Integrated Photovoltaics (BIPV), which allows for mixing building interiors with solar PV systems (including façades or roofs) (WBDG, 2016).

As urban planners look to integrate thin-film technologies, CdTe PV technologies offer environmental benefits. CdTe thin-film currently has lower lifecycle carbon emissions than standard PV technology based on Life Cycle Inventory (LCI) data (Frischknecht et al., 2015).

Thin-film modules create electricity, offer partial shade, wrapping it all together as a complete sustainability package (Lynn, 2010). Integrating PV into buildings can provide cost savings in construction materials, along with electricity prices, cutting carbon emissions (WBDG, 2016).

Challenges facing CdTe

Addressing CdTe solar challenges now as the technology advances is critical.

Increasing module efficiency is essential for improving prices, and make it even more attractive to customers. CdTe module laboratory efficiency rates were around 8.3% (Karagiorgis, 2014).

Thin-film solar cells need bigger surface area due to lower module efficiency than standard crystalline PV modules (IEA, 2011). More CdTe materials would increase costs making it less economical. According to the NREL (2015), a large section of CdTe modules costs come from Tellurium prices. Tying future CdTe PV success with keeping costs in line is necessary. Deployment of CdTe PV would be limited by future Te supplies, even if there were technological improvements in reducing Te intensity (MT Te/GW) (NREL, 2015). When using copper mining as the only source for Te in CdTe PV technology, by 2020, yearly production of CdTe PV technology would be limited to 10GW, while 40-70 GW yearly by 2030 (NREL, 2015).

With improving efficiencies, declining CdTe module prices would follow, (Woodhouse et al., 2013), with production costs as low as $0.47/w, and sold at $0.57/w. A $0.10/w profit is created, based on an 18% module efficiency rate (Woodhouse et. al., 2013).

Woodhouse et al. (2013) said there is much potential in future advancements in module efficiency ranges, as CdTe bandgap is 1.45eV, within the Shockley-Queisser bandgap for CdTe cells, while much work is required to improve efficiencies in today's modules.

Cell reliability plagues CdTe technology. Power loss from cell degradation is due from environmental exposure (Strevel, Trippel, Kotarba, & Khan, 2014), as solar panels last 25-30 years (NREL, 2016). Understanding how to improve the lifespan of CdTe cells, cell reliability is necessary for both hot and cold extremes, as solar capacity is expected to increase globally.

Acknowledging CdTe electronic waste (E-waste) is in preventing potential environmental damage. CdTe has the highest levels of toxicity of the three thin-film technologies, according to McEvoy, Markvart, Castañer, Markvart, T., & Castaner (Eds.) (2003). Cadmium is used in Ni-cd batteries, while Te is used to make catalysts and photosensitive materials (Ethenakis, 2004). Preliminary research (Okkennhaug, 2010) suggests uncontrolled dumping of CdTe modules could create future environmental concerns, including local contamination of soil, groundwater, and water.

Moving CdTe Forward

Understanding CdTe's advantages (lower capital costs, better cell efficiency, lower carbon emissions compared to other PV Technologies, diversity in PV) and disadvantages (lower module efficiency, cell reliability and high toxicity from CdTe cells) is vital in providing solutions for weaknesses to make CdTe a secure investment.

Analysts call CdTe solar cells a "dark horse" because of its future potential in high efficiency, and cheap manufacturing costs (Zweibel, 2013). US-based First Solar, a thin-film solar PV company specializing in CdTe technology, has reached module efficiency beyond industry standards with 18% module efficiency (First Solar, 2015).

First Solar reduced module shading to increase efficiency. Techniques to limit shaded cells affecting other module cells helped increased energy yields and utilized more loads per square footage than others (First Solar, 2015).

Meanwhile, First Solar accomplished cutting their long-term degradation rate guidance through advancing module steadiness versus bias driven power and thermal degradation, with new ZnTe back contact integrated with its new S3 Black Plus Module (Strevel, et al., 2014). Module and cell efficiencies are boosted through this process, according to Strevel et al. (2014).

CdTe companies can reduce toxicity by following e-waste recycling and regulations. First Solar has an end of life management (EOL) pay as you go recycling programs for their CdTe PV solar modules (First Solar, 2016b). First Solar said (2016b) 90% of both semiconductor and glass materials from its thin-film modules is recycled and reused again.

In 2003, European Union passed Waste Electrical and Electronic Equipment Directive (WEEE) legislation to reduce e-waste through extended producer responsibility. The policy was updated in 2012 to include solar PV technology as solar energy was gaining ground (WEEE, 2016). As cadmium is a byproduct of zinc smelting and mining, taking it out and using it for solar cells may help environmentally, as long as there is recycling in place (Lynn, 2010).

Both First Solar and the European Union have taken leads in e-waste recycling mechanisms & policies needed to address decommissioning of the upcoming influx of future solar e-waste within the next 10-15 years, given solar panels last 25-30 years.

Conclusion

CdTe has shown a lot of promise for investors. CdTe Technology has fewer capital costs than standard home systems, while better efficiency rates, and produces less carbon dioxide than other PV modules.

However, addressing concerns over CdTe module efficiency, cell reliability, and toxicity concerns is important moving forward. Currently numerous companies, who are working to address module efficiency and cell reliance. First Solar has gotten module conversion efficiency rates to 18% with shading reduction. They are also working on modules to improve cell reliability, and module efficiency.

Both First Solar and the European Union have taken steps to reduce e-waste of PV solar equipment through recycling and policy programs, to cut toxicity from CdTe PV e-waste.

Based on this analysis given the world faces climate change concerns, improving the lives of developing nations, and improving sustainable urban planning, CdTe thin-film PV solar is an energy technology worth investing.

References

First Solar (2015). First Solar: Our Technology Advantage. *First Solar.* Retrieved July 3, 2016 from http://www.firstsolar.com/-/media/Images/Our-Advantage/TechnologyAdvantage_BR_19AUG15.ashx?la=en.

First solar (2016a) Energy Capacity Assessment Tool. *First Solar.* Retrieved June 28, 2016 from http://www.firstsolar.com/en/Solutions/Utility-Scale-Generation.

First Solar (2016b). The Recycling Advantage: Committed to Responsible Life Cycle Management. *First Solar*. Retrieved July 2, 2016 from http://www.firstsolar.com/en/Technologies-and-Capabilities/Recycling-Services.

Frischknecht, R., Itten, R., Sinha, P., de Wild-Scholten, M., Zhang, J., Fthenakis, V., ... & Stucki, M. (2015). Life cycle inventories and life cycle assessment of photovoltaic systems. *International Energy Agency (IEA) PVPS Task*, *12*.

International Energy Agency (IEA) (2011). *Solar Energy Perspectives*. IEA.

IRENA (2012). RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES: Volume 1: Power Sector Issue 4/5: Solar Photovoltaics. *IRENA*. Retrieved July 3, 2016 from https*://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-SOLAR_PV.pdf*.

Karagiorgis, G. (2014). Photovoltaics Technology Overview (2014, May 29-30). International Renewable Energy Agency. IRENA. Retrieved July 3, 2016 from http://www.irena.org/DocumentDownloads/events/2014/June/15_Karagiorgis.pdf.

Lynn, P. A. (2010) Front Matter, in Electricity from Sunlight: An Introduction to Photovoltaics, John Wiley & Sons, Ltd, Chichester, UK

McEvoy, A., Markvart, T., Castañer, L., Markvart, T., & Castaner, L. (Eds.). (2003). *Practical handbook of photovoltaics: fundamentals and applications*. Elsevier.. Retrieved June 24, 2016 from https://books.google.ca/books?id=7HAYuePR0JsC&pg=PA1089&lpg=PA1089&dq=CdTe+toxicity+concerns&source=bl&ots=zGttp69usr&sig=LA1FyV8bTJHwoMr4mh0sR6KyzWg&hl=en&sa=X&ved=0ahUKEwiH7ODVnszNAhXp5IMKHZbkD2M4ChDoAQg3MAQ#v=onepage&q=CdTe%20toxicity%20concerns&f=false.

National Renewable Energy Laboratory (NREL). (2015, April 28). Energy Analysis: Supply Constraint Analysis. *NREL.* Retrieved July 3, 2016 from http://www.nrel.gov/analysis/key_activities_jobs_sup_cstr.html.

National Renewable Energy Laboratory (NREL). (2016). Photovoltaics Research. *NREL.* Retrieved July 3, 2016 from http://www.nrel.gov/pv/thinfilm.html.

Okkenhaug, G. (2010). Environmental risks regarding the use and end-of-life disposal of CdTe modules *NDI.* Retrieved June 28, 2016 from https://www.dtsc.ca.gov/LawsRegsPolicies/upload/Norwegian-Geotechnical-Institute-Study.pdf.

SolarCellCentral.com (2016). Solar Efficiency Limits. *SolarcellCentral.com*. Retrieved June 27, 2016 from http://solarcellcentral.com/limits_page.html.

Strevel, N., Trippel, L., Kotarba, C., & Khan, I. (2014). Improvements in CdTe module reliability and long-term degradation through advances in construction and device innovation. *Photovoltaic international*. Retrieved July 2, 2016 from https://www.cips.org/Documents/Knowledge/Categories-Commodities/Buying-Energy/PVI_22_First_Solar_Reliability_WhitePaper_lowres.pdf.

Ullal, H. S. (2008). *Overview and challenges of thin film solar electric technologies*. National Renewable Energy Laboratory. Retrieved June 23, 2016 from http://www.nrel.gov/pv/pdfs/43355.pdf.

US Department of Energy (2016). Cadmium Telluride. *US Department of Energy*. Retrieved June 23, 2016 from http://energy.gov/eere/sunshot/cadmium-telluride.

WEEE (2016). Solar Waste: European WEEE Directive. *WEEE*. Retrieved July 2, 2016 from http://www.solarwaste.eu/pv-waste-legislation/.

Wesoff, (2016, February 23). First Solar Hits Record 22.1% Conversion Efficiency for CdTe Solar Cell. *GreenTech Media.* Retrieved July 3, 2016 from http://www.greentechmedia.com/articles/read/First-Solar-Hits-Record-22.1-Conversion-Efficiency-For-CdTe-Solar-Cell.

Whole Building Design Guide (WBDG) (2016). Building Integrated Photovoltaics *WBDG.* Retrieved June 28, 2016 from https://www.wbdg.org/resources/bipv.php.

Woodhouse, M., Goodrich, A., Margolis, R., James, T., Dhere, R., Gessert, T., ... & Albin, D. (2013). Perspectives on the pathways for cadmium telluride photovoltaic module manufacturers to address expected increases in the price for tellurium. *Solar Energy Materials and Solar Cells*, *115*, 199-212.

Zweibel, K. (2013). *Harnessing solar power: The photovoltaics challenge*. Springer. Retrieved June 24, 2016 from https://books.google.ca/books?id=bB8GCAAAQBAJ&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q=CdTe&f=false.