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The solar energy industry (PV) and it's future

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ABSTRACT

In this article, we reviw to provide a measure of suitable discussions on the current situation and future potential of the economy of the photovoltaic system. In specially, we brifly review a wide and latest range of academic and industry literature in order to highlight the main factors and uncertainties of the future costs of PV. Our main results are that the LCOE in the photovoltaic industry metrics can be misgiving and therefore be applied with wariness, as we require careful declaration and clarity.

***Keywords*:** Photovoltaics; Energy economics

1. INTRODUCTION

The generation of electric energy by the photovoltaic system is regarded as a clean technology, which has been used in a special sense for 50 years and in grids for 20 years is in need of large investments, but because of specific reasons this enterprise faces certain problems [1-5]. Issues such as:

- The uncertainty of the industry's future.
- The increasingly high prices of it's manufacturing and distribution.
- The complexity of the making of it's components.
- The harmonizing of it with both the distribution and transmission system as it is used today.
- The comparison of the recent methods for the generation of electric energy and PV which marks PV as very complex and expensive.

- The difference of the local markets over the PV distribution rate.
- Technical issues such as shortage of parts BOS (battery, installation, structures, restorers), low production scale, shortage of primary resources.

The above issues and legislation for the development and advance of this situation have thrown potential investors and policy makers into doubt. On the other hand cases such as should credit extra attention to this technology and situation:

- The result of academic research on the output and efficiency of this technology
- The potential of PV for generation of future energy.
- The cleanness of this technology (which serves as an important case in light of changing temperatures and global warming).
- The beneficence of this industry in the event of it's success for investors.

Even in view of these problems with sight of the above mentions a bright future can be predicted for this industry. In the first place for the elimination of some economic problems and confusion, we can create an analytical method and a give a clear definition of PV prices. For this purpose we introduce four standards for pricing [5-10]:

1- The price of each watt
2- 2- The capital cost of PV modules \$/W
3- 3- The level cost of electricity (LCOE) \$/kwh
4- 4- The concept of grid parity

Each of these standards has it's own special function for example the price of each watt has it's own simplicity but it doesn't express complete PV cost's such as installation and maintenance. For government investors LCOE and grid parity, which are dependent on many issues and measure all the cases are of vital importance. Now we state how these standards will bring us out of economic confusions [11-16].

2. THE CHANGES IN PV COST ON THE BASIS OF \$/W

From 2004 to 2008 the cost of PV modules has been from 3.5 to 4 \$/W [16-20]. Despite the efforts of manufacturers because of poly silicone shortage and German and Spanish tariffs in the markets, this cost stayed the same throughout this period. But after 2008 and the end of the tariffs, poly silicone production companies expanded and poly silicone production increased by 32%. Also by reducing their shares thin-film production companies reached 2 \$/W in 2009. With the arrival of chines crystalized silicone PV in the markets, the costs dropped lower until this PV reached 1 \$/W in late 2011. Yet the policy makers, legislator and consumer still believed this price too high and solar PV incapable of rivalry with other methods of technology improvement of processes and changes in the structure and industry hint at lower prices in the future [5].

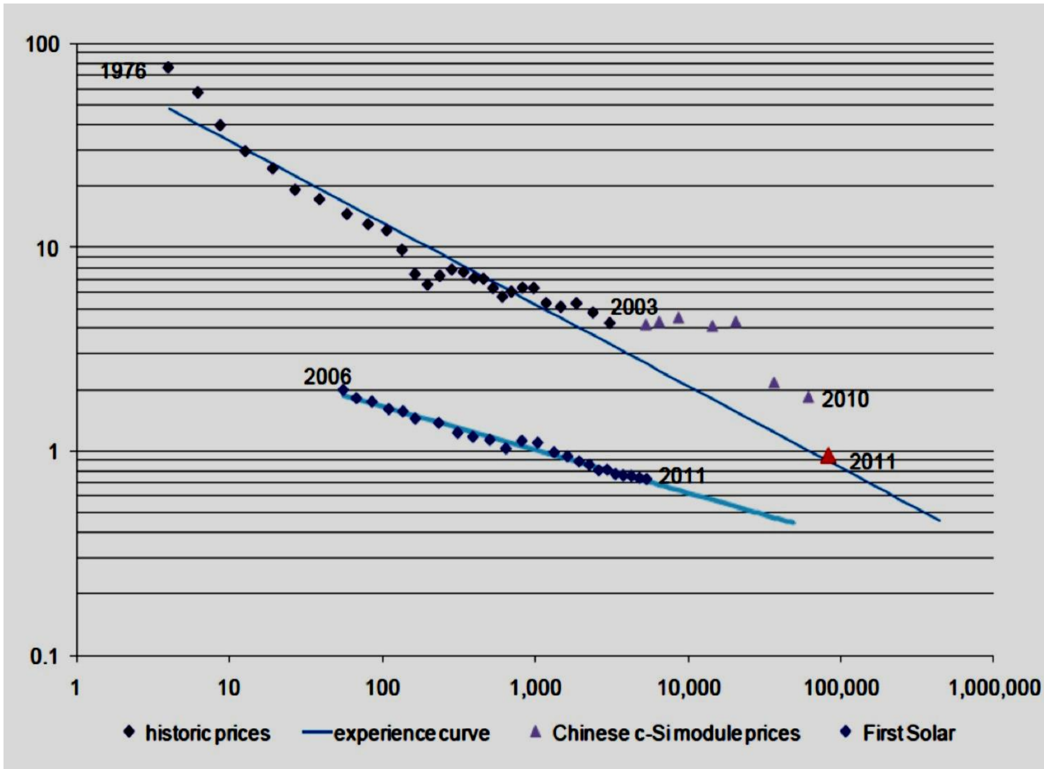

Figure 1. PV module experience curve 1976-2011 (BNEF, 2012a).

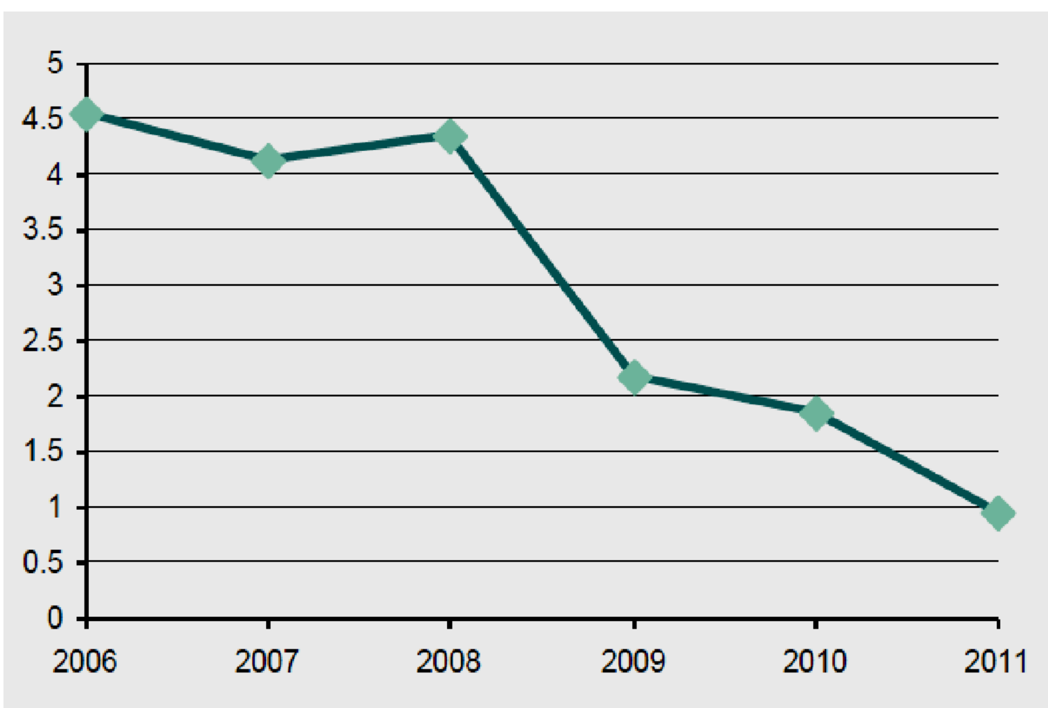

Figure 2. Chinese c-Si PV module prices ($/W): Note the change in the slope of the curve since 2008.

The most fundamental standard for the evaluation of PV module cost , price per-watt. In April 2012 module sale prices for chines crystalized silicone was 0.85 $/W and for other thin-film modules 1.1 $/W. Before modules made up %60 of PV system costs but now with reduction of module prices most of PV costs is related to BOS components [6].

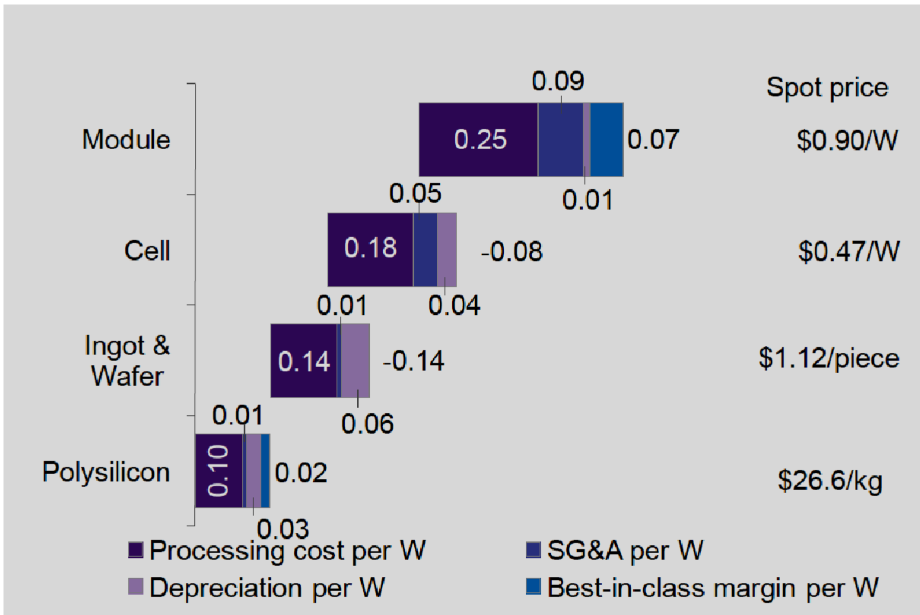

Figure 3. Chinese multicrystalline silicon module cost build-up (assuming 6.0g of silicon per watt of wafer), April 2012 (BNEF, 2012a).

Diagram 3 shows the analysis of chines multi-crystalline silicone modules in April 2012.

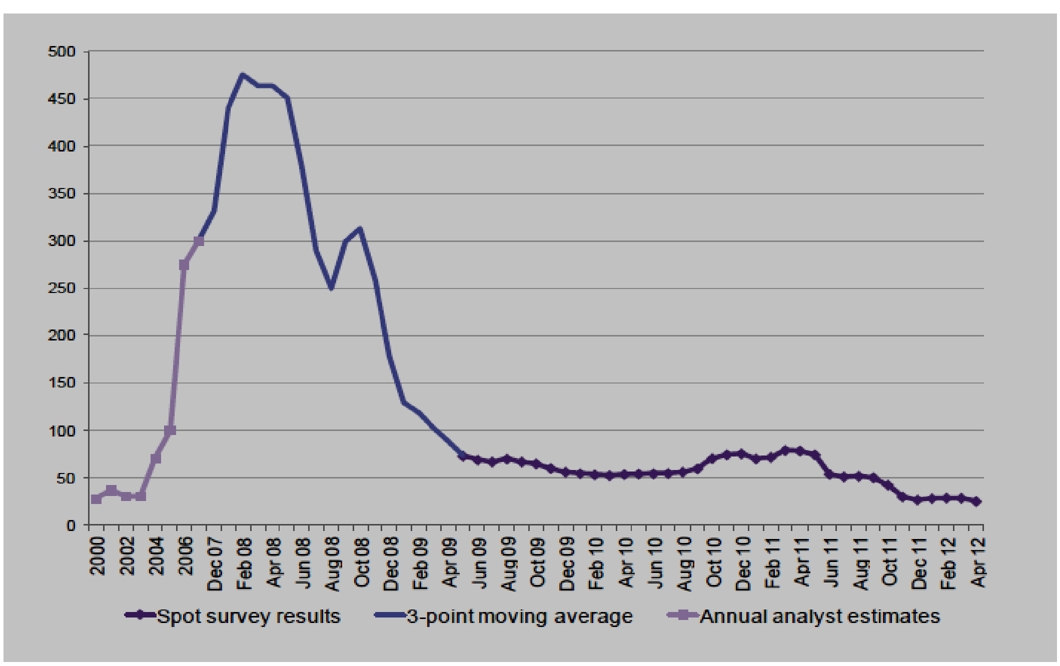

Figure 4. Spot price of solar-grade silicon ($/kg) (BNEF, 2012a).

Also in diagram 4 we see that silicone costs have decreased from 450 $/kg to 27 $/kg in 2012. This makes up 20% of present silicone cost. In all film costs have come from 1 $/w in 2009 to 0.35 $/W in 2012 and cell costs from 1.3 $/W in 2009 to 0.55 $/W in 2012 of course, these numbers represent crystalline and multi crystalline films and the thin film industry has in creased it's own share in the market from 6% in 2005 to 20% in 2009. Later this share reached 11% in 2011 so that in 2012 thin-film module costs were between 0.79 $/W for CDTE and 0.92 $/W for ASI module. But with the price reduction of crystallized silicone in 2012 this industry has come under pressure.

3. THE ECONOMIC ANALYSIS OF PV BY LCOE STANDARDS

LCOE is used as the long-time guide to measure the competitiveness of technologies. the analysis of LCOE considers the distributed costs in the project and collects a more accurate economic estimate, then needs a longer time period for system component analysis; such as the solar insulation of the corresponding location, technologies, component, specifications, design, installation, and maintenance.

For example the LCOE for c-si PV has decreased 50% and reached from 0.32 $/kWh in 2009 to 0.17 $/kWh in 2012, also thin film prices from 0.23 $/kWh to 0.11 $/kWh.

Since the price reductions, there has been much research done for estimating LCOE for PV , for example the US DOE organization has estimated LCOE PV of about 0.1 $/kWh to 0.18 $/kWh for general industries, 0.16 $/kWh to 0.31 $/kWh for advertising systems and 0.16 $/kWh to 0.25 $/kWh for domestic systems. And according to some articles the cost of electricity generation is 0.1 $/kWh to 0.15 $/kWh for Canada, and LCOE prices for Africa are estimated at 0.2 $/kWh to 0.5 $/kWh. But overall on average the cost of LCOE is estimated at 0.1 $/kWh to 0.3 $/kWh. Still with all these price reductions some believe that PV systems should be cheaper, because in comparison with other systems (fossils - nuclear) PV is still seen as expensive. Although a set standard from the LCOE price producers doesn't exist and the presented numbers from various organizations differ.

A lot of standard definitions like IEA or NREL have been proposed for LCOE, also different methods such as using parametric explanations in place of numbers for estimating different factors and performances in estimating LCOE costs; factors such as the effective life-time of PV systems, climate changes, technology rate, number and rate of manufacturing, discount rate, debt payment (see diagram 5).

The concept of grid parity is more important than the two past standards for PV systems . this concept addresses the replacement of solar PV in place of other methods of electricity production. Although this concept is a little complex and difficult, and it cannot be used easily, because it is in need of exact LCOE-PV amount. In return, the electricity usage cost for consumers and other generation costs (for policy and decision markers) is evident. As the cost of PV is still too expensive from the viewpoint of policy and decision makers and also as they do not possess in-depth information on PV-LCOE they still haven't been convinced of solar PV's grid parity with other methods; but for domestic users this concept can open a window into energy that is economically advantageous for families.

So the concept of parity is usable in small scale.

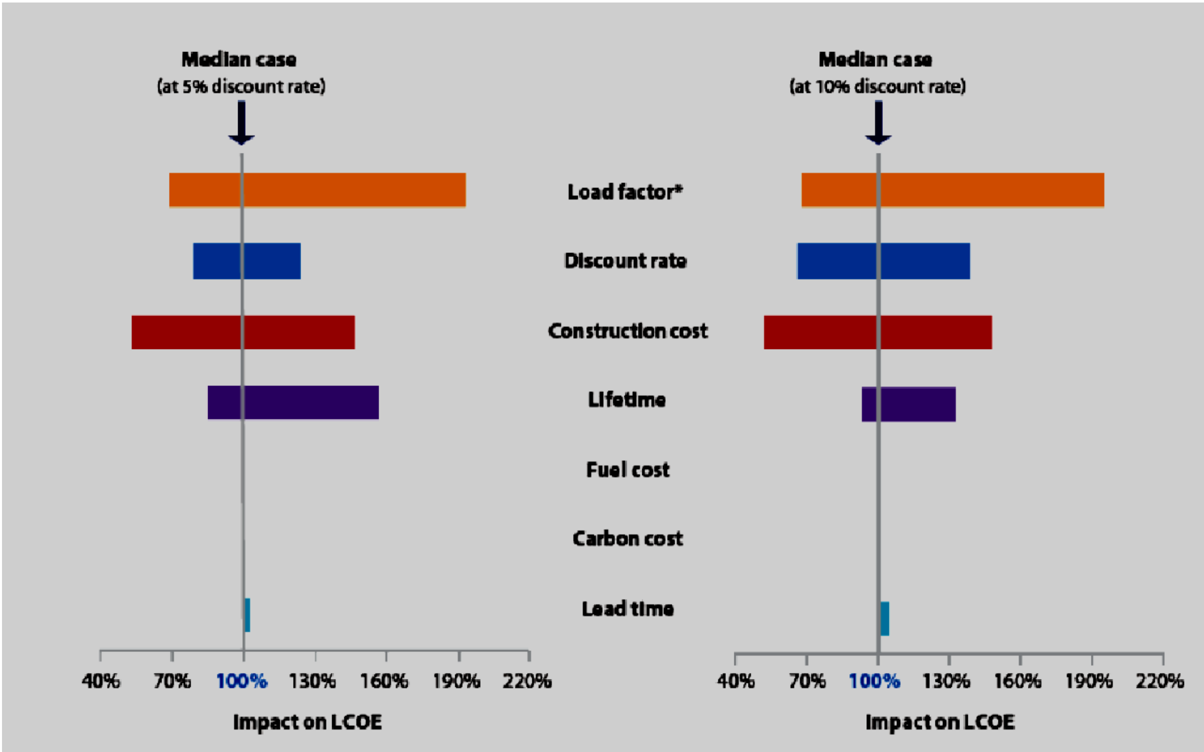

Figure 5. Tornado graph PV LCOE (IEA et al., 2010).

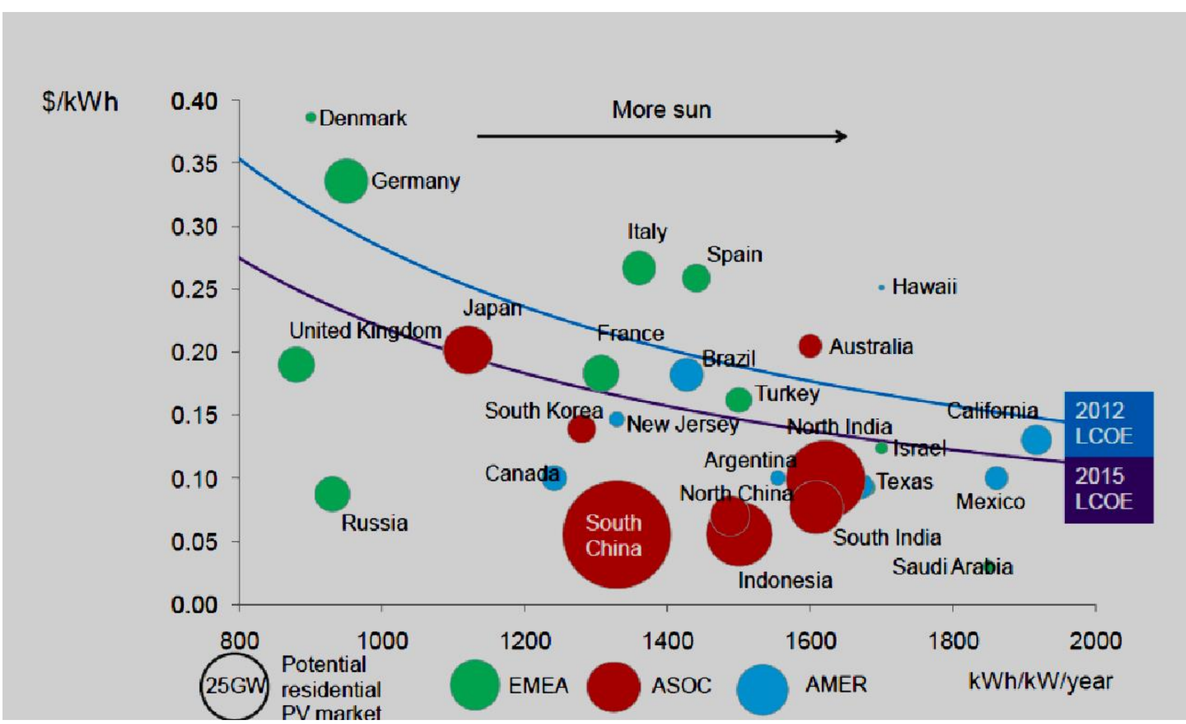

Figure 6. Residential PV price parity (size of bubbles refers to market size) (BNEF, 2012a).

But unlike the stand point of many decision markers a lot of research shows that large scale grid parity could happen in the never future; for example, according to statistics Germany will reach grid parity in 2014 and it already exists in Canada, also from 2011 to 2013 the industry will start in other parts of the world .diagram 6 show us which countries will reach grid parity at which time.

4. ENVIRONMENTAL IMPACTS OF PHOTOVOLTAIC TECHNOLOGIES

Types of impacts

While solar photovoltaic (PV) cells are promising for clean energy production, their deployment is hindered by production costs, material availability, and toxicity. Life cycle assessment (LCA) is one method of determining environmental impacts from PV [20-25]. Many studies have been done on the various types of PV including first generation, second generation, and third generation. Usually these PV LCA studies select a cradle to gate system boundary because often at the time the studies are conducted, it is a new technology not commercially available yet and their required balance of system components and disposal methods are unknown.

A traditional LCA can look at many different impact categories ranging from global warming potential, eco-toxicity, human toxicity, water depletion, and many others. Most LCAs of PV have focused on two categories: carbon dioxide equivalents per kWh and energy pay-back time (EPBT). The EPBT is defined as "the time needed to compensate for the total renewable - and non-renewable- primary energy required during the life cycle of a PV system". A 2015 review of EPBT from first and second generation PV suggested that there was greater variation in embedded energy than in efficiency of the cells implying that it was mainly the embedded energy that needs to reduce to have a greater reduction in EPBT. One difficulty in determining impacts due to PV is to determine if the wastes are released to the air, water, or soil during the manufacturing phase. Research is underway to try to understand emissions and releases during the lifetime of PV systems.

Impacts from first-generation PV

Crystalline silicon modules are the most extensively studied PV type in terms of LCA since they are the most commonly used. Mono-crystalline silicon photovoltaic systems (mono-si) have an average efficiency of 14.0%. The cells tend to follow a structure of front electrode, anti-reflection film, n-layer, p-layer, and back electrode, with the sun hitting the front electrode. EPBT ranges from 1.7 to 2.7 years. The cradle to gate of CO2-eq/kWh ranges from 37.3 to 72.2 grams.

Techniques to produce multi-crystalline silicon (multi-si) photovoltaic cells are simpler and cheaper than mono-si, however tend to make less efficient cells, an average of 13.2%. EPBT ranges from 1.5 to 2.6 years. The cradle to gate of CO_2-eq/kWh ranges from 28.5 to 69 grams. Some studies have looked beyond EPBT and GWP to other environmental impacts. In one such study, conventional energy mix in Greece was compared to multi-si PV and found a 95% overall reduction in impacts including carcinogens, eco-toxicity, acidification, eutrophication, and eleven others.

Impacts from second generation

Cadmium telluride (CdTe) is one of the fastest-growing thin film based solar cells which are collectively known as second generation devices. This new thin film device also shares similar performance restrictions (Shockley-Queisser efficiency limit) as conventional Si devices but promises to lower the cost of each device by both reducing material and energy consumption during manufacturing. Today the global market share of CdTe is 5.4%, up from 4.7% in 2008. This technology's highest power conversion efficiency is 21%. The cell structure includes glass substrate (around 2 mm), transparent conductor layer, CdS buffer layer (50-150 nm), CdTe absorber and a metal contact layer.

CdTe PV systems require less energy input in their production than other commercial PV systems per unit electricity production. The average CO2-eq/kWh is around 18 grams (cradle to gate). CdTe has the fastest EPBT of all commercial PV technologies, which varies between 0.3 and 1.2 years.

Copper Indium Gallium Diselenide (CIGS) is a thin film solar cell based on the copper indium diselenide (CIS) family of chalcopyrite semiconductors. CIS and CIGS are often used interchangeably within the CIS/CIGS community. The cell structure includes soda lime glass as the substrate, Mo layer as the back contact, CIS/CIGS as the absorber layer, cadmium sulfide (CdS) or Zn (S,OH)x as the buffer layer, and ZnO:Al as the front contact. CIGS is approximately 1/100th the thickness of conventional silicon solar cell technologies. Materials necessary for assembly are readily available, and are less costly per watt of solar cell. CIGS based solar devices resist performance degradation over time and are highly stable in the field. Reported global warming potential impacts of CIGS range from 20.5-58.8 grams CO_2-eq/kWh of electricity generated for different solar irradiation (1,700 to 2,200 kWh/m2/y) and power conversion efficiency (7.8-9.12%). EPBT ranges from 0.2 to 1.4 years, while harmonized value of EPBT was found 1.393 years. Toxicity is an issue within the buffer layer of CIGS modules because it contains cadmium and gallium. CIS modules do not contain any heavy metals.

Impacts from third generation

Third-generation PVs are designed to combine the advantages of both the first and second generation devices and they do not have Shockley-Queisser efficiency limit, a theoretical limit for first and second generation PV cells. The thickness of a third generation device is less than 1 μm.

One emerging alternative and promising technology is based on an organic-inorganic hybrid solar cell made of methylammonium lead halide perovskites. Perovskite PV cells have progressed rapidly over the past few years and have become one of the most attractive areas for PV research. The cell structure includes a metal back contact (which can be made of Al, Au or Ag), a hole transfer layer (spiro-MeOTAD, P_3HT, PTAA, CuSCN, CuI, or NiO), and absorber layer ($CH_3NH_3PbIxBr_3$-x, $CH_3NH_3PbI_xCl_3$-x or $CH_3NH_3PbI_3$), an electron transport layer (TiO, ZnO, Al_2O_3 or SnO_2) and a top contact layer (fluorine doped tin oxide or tin doped indium oxide).

There are a limited number of published studies to address the environmental impacts of perovskite solar cells. The major environmental concern is the lead used in the absorber layer. Due to the instability of perovskite cells lead may eventually be exposed to fresh water during the use phase. Two published LCA studies looked at human and ecotoxicity of perovskite solar cells and found they were surprisingly low and may not be an environmental issue.

Gong et al. found direct processing energy as 30 MJ/m^2, while Espinosa didn't report this value (but estimated around 1000 MJ/m^2). Global warming potential was found to be in the range of 24-1500 grams CO_2-eq/kWh electricity production. Similarly, reported EPBT of the published paper range from 0.2 to 15 years. The large range of reported values highlight the uncertainties associated with these studies.

Two new promising thin film technologies are copper zinc tin sulfide (Cu_2ZnSnS_4 or CZTS) and zinc phosphide (Zn_3P_2). Both of these thin films are currently only produced in the lab but may be commercialized in the future. Their manufacturing processes are expected to be similar to those of current thin film technologies of CIGS and CdTe, respectively. Yet, contrary to CIGS and CdTe, CZTS and Zn_3P_2 are made from earth abundant, nontoxic materials and have the potential to produce more electricity annually than the current worldwide consumption. While CZTS and Zn_3P_2 offer good promise for these reasons, the specific environmental implications of their commercial production are not yet known. Global warming potential of CZTS and Zn_3P_2 were found 38 and 30 grams CO_2-eq/kWh while their corresponding EPBT were found 1.85 and 0.78 years, respectively. Overall, CdTe and Zn3P2 have similar environmental impacts but can slightly outperform CIGS and CZTS.

Organic and polymer photovoltaic (OPV) are a relatively new area of research. The tradition OPV cell structure layers consist of a semi-transparent electrode, electron blocking layer, tunnel junction, holes blocking layer, electrode, with the sun hitting the transparent electrode. OPV replaces silver with carbon as an electrode material lowering manufacturing cost and making them more environmentally friendly. OPV are flexible, low weight, and work well with roll-to roll manufacturing for mass production. OPV uses "only abundant elements coupled to an extremely low embodied energy through very low processing temperatures using only ambient processing conditions on simple printing equipment enabling energy pay-back times". Current efficiencies range from 1-6.5%, however theoretical analyses show promise beyond 10% efficiency.

Many different configurations of OPV exist using different materials for each layer. OPV technology rivals existing PV technologies in terms of EPBT even if they currently present a shorter operational lifetime. A 2013 study analyzed 12 different configurations all with 2% efficiency, the EPBT ranged from 0.29-0.52 years for 1 m² of PV. The average CO_2-eq/kWh for OPV is 54.922 grams [26-34].

5. CONCLUSION

After 2008, when PV systems prices started to decrease the idea that in future PV systems will replace other methods of electricity generation took root. Even now that electricity costs are high in certain countries, PV systems have a tight competition with other methods, but the need for more specific PV LCOE estimates is still felt for persuading policy and decision makers in PV's effectiveness. In addition we have to wait for the development of PV production technologies to generate PV on a large scale with lower costs. For example the new Nano solar Company in California claims that it can produce solar PV films with a new method by the name of print technology with different and cheap raw materials like copper, indium, gallium and silicone and wants to establish a power house with a potency of 430 MW. However this is a big number (most companies produce a maximum of 50 MW) but with the success of this company new doors will open to this industry, and make it into an unrivaled industry in electricity generation.

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