KEY ADVANTAGES OF CONCENTRATING PHOTOVOLTAICS (CPV) FOR LOWERING LEVELIZED COST OF ELECTRICITY (LCOE)

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ABSTRACT: The argument is made that the best cost metric for decision making in the solar field is the Levelized Cost of Energy (LCOE), as adopted by the US Department of Energy and the US National Renewable Energy Laboratory. It is expressed as ¢/kWh, at net present value, and takes into account the complexities associated with the entire lifetime of a solar plant, from financing through to end of life. By comparison, the most common metric, Cost per Watt peak ($/W$_p$), refers to the installed capital equipment price only. Concentrating Photovoltaic Systems, a relatively recent form of solar power are then presented in the light of LCOE, and are shown to be very competitive with other forms of solar plant under suitable conditions.
Keywords: Concentrators, Economic Analysis, Levelized Cost of Electricity, PV Costs, PV Market Trends

1 THE CASE FOR LCOE

The Photovoltaic industry is rapidly maturing, and in many markets has passed the point of early adoption. In these markets, cost, margin, lifetime and reliability dominate over technology when decisions are being made. Especially in Europe, a photovoltaic plant is considered a financial instrument, and the constituents of the value chain are solely engaged with maximizing margin and revenue, and minimizing cost.

The classic definition of cost or price has been Dollars per Watt peak ($/Wp). It is relatively easy to calculate and understand, and is the quantity most quoted in the industry. A schematic of the calculation is below, fig 1.

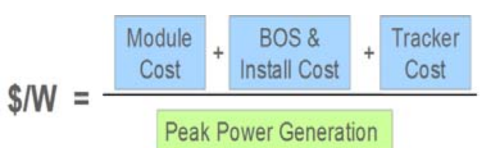

***Fig1**: Cost definition ($/W)*

While the above is a significant factor when marketing solar plant, as a financial metric it has significant limitations, especially when attempting to evaluate return on investment or when making cross-technology decisions. It does not take into account all major parameters involved with installing and operating photovoltaic plant, and it is a "fixed time" calculation – under normal circumstances it does not account for inflation or the cost of financing over the project lifetime.

A more accurate assessment of financial performance, the Levelized Cost of Energy (LCOE) was adopted several years ago by the National Renewable Energy (NREL) and the United States Department of Energy (DOE). Significantly, it was used as one of the metrics for evaluating and driving the goals for the Solar America Initiative, a novel and efficient grant program begun by DOE in 2005. In coordination with mounting the initiative, NREL produced the Solar Advisor Model (SAM)[1], which models the cost of any phovoltaic power station in terms of LCOE.

The LCOE takes into account installation and commissioning costs, operations and maintenance, degradation and lifetime, and the output. It calculates the average value of the total energy produced, revalued at the time of calculation based on forward assessments of inflation and costs of financing.

SolFocus has adopted LCOE as its dominant metric, and has been refining a model to help drive decisions both with customers, and internally.

1.1 The Definition of LCOE

The formal definition of LCOE[2] is given as:

$$LCOE = TLCC / \left\{ \sum_{n=1}^{N} \left[Qn / (1+d)^n \right] \right\}$$

Where:
- LCOE = levelized cost of energy
- TLCC = total life-cycle cost
- Q_n = Energy output in year n
- N = Analysis period
- d = Discount rate

In simplified terms, it can be thought of as:

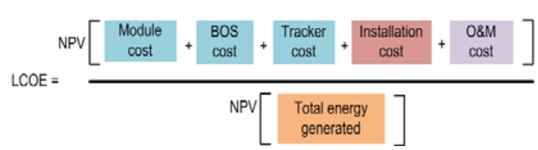

***Fig 2:** Cost definition, LCOE (c/kWh)*

It is, in effect, the average cost of every unit of energy produced by a generator across its entire lifetime, brought back to the value of that unit of energy determined at the time of the analysis.

1.2 The advantages of using LCOE

LCOE takes into account the *energy* generated by the plant over its entire lifetime and not the peak power. So technologies that have a larger kWh/kW$_p$ ratio will have their actual costs better presented. For example, tracked photovoltaic systems will harvest a greater number of kWh during the day because their active surface is presented to the sun at the optimum angle the entire time

– they don't suffer from "cosine loss". (see figure 3). Trackers cost more than the fixed tilt structures though, so despite harvesting approximately 40% more energy, the tracked system LCOE will reflect only a portion of that improvement. If a project manager is considering a tracked system, the LCOE calculation will put an upper bound on the tracker cost.

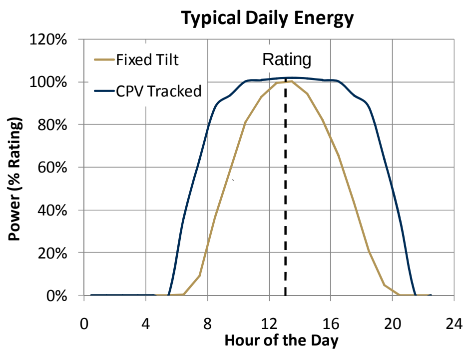

Fig 3: *Fixed tilt VS tracked PV, energy harvest*

Presenting the energy costs at net present value accounts for financing, depreciation, inflation and other economic realities when considering an investment, and will allow a comparison to be made between different technologies, for example wind or photovoltaics. Significantly, it also allows a comparison to be made between different funding scenarios, which can have a sizeable impact on average costs.

Finally, given that the operator of a plant is paid based on the energy produced, LCOE will give the best available estimate at the decision time, of the return on the investment for any particular product or design.

2 CPV AND LCOE

2.1 Key advantages of CPV

Concentrators or CPV systems use optics to efficiently harness a large area of light onto a small photovoltaic cell. One of their key ratings is the *concentration ratio*, usually expressed in "suns". The SolFocus 1000S concentrator uses a high concentration ratio of 500 Suns: the light energy of 500 square centimeters is entrained onto a 1 square centimeter cell.

There are a number of advantages of concentrator systems over non-concentrating or one sun systems, and a several added costs as well. Only a good LCOE calculation will allow the complexities to be seen in an overall sense, and allow decisions to be made as to their use. The LCOE model SolFocus maintains takes into account all of these tradeoffs, the major ones being described below.

CPV systems, because of their optics, must be tracked. SolFocus' 1000S has a field of view or *acceptance angle* of approximately +/- 1^{O} which, while very lenient for our concentration ratio, demands a high performance tracker. So the ratio between higher harvesting capabilities and higher tracker costs described above apply. SolFocus' model takes this into account, and includes the cost and time associated with ground preparation, installation and commissioning the trackers.

The high performance triple junction cells used by SolFocus have a lower coefficient of temperature degradation than Silicon, and so can be operated at higher ambient temperatures. Many sites appropriate to CPV have daytime temperatures in excess of 45C, which will significantly degrade the output of Silicon systems. Figure 4 presents experimental data on the degradation rate of the 1000S. The power coefficient for the system is approximately -0.17%/^{O}C, while a typical Silicon panel exhibits -0.48%/^{O}C. SolFocus' LCOE model takes this characteristic into account, and the model is run on every installation proposal using local weather data.

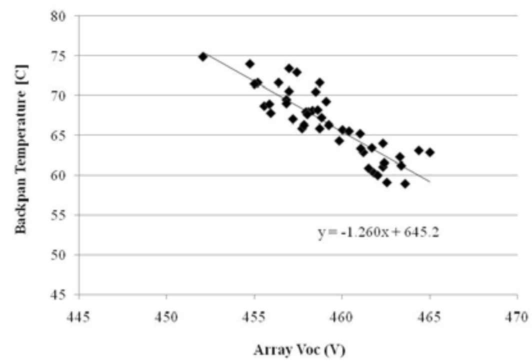

Fig 4: *Interpolation of power temperature coefficient for the SF-1000 CPV system*

The development of high efficiency cells, typified by the triple junction design first described by NREL[3], has recently dramatically accelerated. In addition to refinements to the multijunction design, new and interesting physics are being investigated by several new companies. Alongside this increase in technical activity, interest has been shown by the high volume manufacturing community, and as a result, it is expected that over the next few years the absolute cost of these cells will decrease. The LCOE calculation and associated model enables SolFocus to assess the potential impact these developments have on the competitiveness of our product, and allows us to plot a cost reduction roadmap to drive marketing, engineering and manufacturing activities.

3 CPV COST REDUCTION ROADMAP

With the key advantages of kWh/kWp and improved temperature performance, the true value of CPV systems is best represented by the LCOE in cents/kWh. Shown in Figure 5, a CPV industry cost reduction roadmap has been created based on improvements in panel efficiency (translating to increased energy generation) and system costs. The LCOE of CPV systems is plotted along with PV industry price and cost data for fixed tilted systems. The common factors such as cost of capital, inverter replacement costs, and solar resource and others are normalized to the same assumptions. The high DNI region of Phoenix, AZ, USA, was chosen because of the vast potential of CPV in the US southwest and is used by the DOE for the assessment of technologies being developed under the Solar America Initiative (SAI).

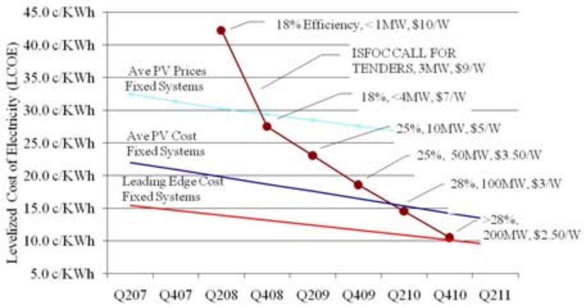

Figure 5. *CPV cost reduction roadmap*

Based on panel efficiency and manufacturing volume improvements, CPV has the ability to rapidly decrease the cents/kWh beyond that of conventional and leading edge PV systems. With targets defined for panel efficiency and installed system cost, CPV has a pathway to break through average PV costs of electricity in 2009 and lead the PV industry toward grid parity by the end of 2010.

4 CONCLUSION

Based on panel efficiency and manufacturing volume improvements, CPV has the ability to rapidly decrease the cents/kWh beyond that of conventional and leading edge PV systems. With targets defined for panel efficiency and installed system cost, CPV has a pathway to break through average PV costs of electricity in 2009 and lead the PV industry toward grid parity by the end of 2010.

4.1 References

[1] https://www.nrel.gov/analysis/sam/

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[3] S.R. Kurtz, D. Myers and J.M. Olson, "Projected Performance of Three- and Four-Junction Device Using GaAs and GaInP," Presented at the 26th Photovoltaic Specialists Conference, Anaheim, CA, Sep. 30-Oct. 3, 1997.