Competitive Cost Position of Novel Thin Film Photovoltaic Module Technologies in High Temperature and Low Light Conditions

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ABSTRACT

Few Industries more strictly obey competitive costs in technology strategy decisions than does the electricity generation market. Although governments often specify the amount of energy generated by renewable sources, technology selection is left up to the energy provider. Climate, more than any other variable plays the greatest role in these decisions – vastly influencing the economics of candidate technologies, such as wind and solar. Solar technologies are particularly sensitive to the available solar resources in a location, as well as that location's latitude, and climate.

Over the past three decades, the cost of manufacturing solar photovoltaic products has continued to improve at a consistent and impressive rate, providing this family of renewable energy technologies the opportunity for broader consideration[1]. No longer is solar electricity only being considered in locations, which have an obvious abundance of solar resources and preferable climate. Today, moderate climates in temperate regions, such as Germany are among the strongest markets for solar photovoltaics.

Solar modules based on crystalline silicon (X-Si) materials make up the majority of the world's installed Photovoltaic (PV) energy generation capacity. Under Standard Test Conditions (STC's), commercially available PV-products often demonstrate higher efficiencies than those based on thin film process technologies. However, due to a global shortage of available feedstock materials the cost of manufacturing solar cells based on bulk (poly) crystalline materials has recently increased.

Customers have traditionally perceived thin film photovoltaic products as a low cost, albeit low performance product alternative; useful in novel applications, such as building integrated product forms and remote, off grid device power generation (e.g. boat batteries). Perception is not necessarily reality, however.

Just as photovoltaics based on bulk silicon materials have enjoyed manufacturing cost reductions based on the Industry's collective manufacturing experience, thin film technologies have also matured. The cost of manufacturing thin film products on ever larger substrates and in ever increasing quality has driven the costs, and subsequently prices for these products down, all while improving the cell efficiencies. Thin films may be tailored to provide absorption performance across a broader spectrum of solar conditions than bulk silicon products.

In this article, the author utilizes models developed by the United States' National Renewable Energy Laboratory (NREL) to contrast the performance associated with six (6) photovoltaic products installed in low light (Portland, Oregon) and high temperature (Phoenix, Arizona) locations. For each technology, functionally equivalent one megawatt field installations are described in detail. The systems are compared based on the Levelized Cost of Electricity (LCOE) they provide. The impact of improved low light performance and thermal derate on system performance and economics is quantified.

Keywords: solar, photovoltaics, amorphous silicon, cost analysis, thin film

1 INTRODUCTION

The Levelized Cost of Electricity (LCOE) is the principle metric by which electricity generation technologies are compared. This established basis for evaluating the cost of a generation method takes into account those aspects of a technologies performance that directly impact power generation efficiency, system cost, and reliability. LCOE is a measure of the total lifecycle costs associated with a PV system divided by the expected lifetime-energy output, while accounting for the appropriate adjustments such as time value of money, etc.

Five (5) key competing PV products have been chosen as the scope of this analysis; representing a diverse range of available and leading field-installation PV products.

- a-Si triple junction
- mc-Si
- CIGs
- CdTe
- X-Si
- A-Si tandem junction (XsunX)

The technologies were chosen based on their prominence in the market and contrasting performance characteristics in low light and high temperature conditions.

The scope of the analysis was further constrained to two (2) US locations that provide bases for evaluating the products in extreme temperature and diffuse light conditions.

- Phoenix, AZ
- Portland, OR

2 SYSTEM DESCRIPTIONS

Levelized Cost of Electricity (LCOE) analyses are calculated based on simulations of products and systems designs in specific locations. The module technologies under consideration may be configured in a wide range of stationary, tracking, rooftop or field installations. The choice of system design drives the Balance of System (BoS) requirements, land usage, maintenance and installation costs and performance (tracking).

Cell performance characteristics were collected from commercially available product specification sheets, academic literature, and academically reviewed publications. In the case of the novel (non-commercial) product, performance characteristics were provided by the manufacturer (XsunX) and verified, wherever possible by comparison to analogous technologies.

XsunX, Inc. has developed a novel thin film solar Photovoltaic (PV) cell technology which is comprised of tandem junction amorphous silicon layers (a-Si tandem junction).

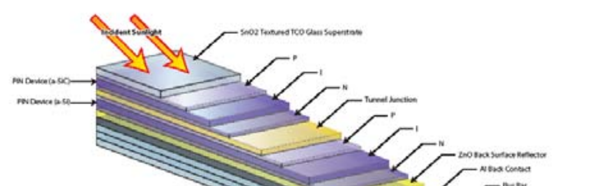

Figure 1: Scehmatic representation of tandem junction a-Si solar cell

Due to its novel material structure, the technology has several key performance attributes that make it cost competitive in low light and high temperature conditions. Early morning and late afternoon solar irradiance generally provides light consists of a shorter wavelength. Based on the photo-absorbent material components in each cell, performance during early and late day time periods will vary. It has been found that the improved low light performance of amorphous silicon, which is contained in both the "triple junction" as well as the "tandem junction" amorphous silicon XsunX cells improve overall cell output by approximately 20%[1].

Although amorphous silicon solar cells suffer from lower conversion efficiency under Standard Test Conditions (STC), it has been found that the performance of this type of solar photovoltaic cell technology is outstanding in low light (diffuse) conditions. As a result, under non-ideal conditions amorphous silicon solar cells can outperform crystalline cell products.

Non-ideal conditions, for which amorphous silicon cells are particularly well suited, include non-ideal orientations and low light conditions. The Pacific Northwest, Portland, Oregon for instance is typically not thought to be an area where solar photovoltaics are viable. The amount of cloud cover (diffuse light) is on average, quite high. However, every location, no matter how well suited they appear for solar electricity generation, suffers some losses early in the morning and late in the afternoon.

Cell technology	Temperature coefficient % / ˚ C
CIGs	-0.60
X-Si	-0.47
mc-Si	-0.47
a-Si (triple junction)	-0.31
CdTe	-0.20
a-Si (tandem junction)	-0.00

Table 1: Solar cell performance characteristics

The power density (DC peak) of the product is approximately 78.75 WDC peak / m^2 (fourth highest among the six products investigated in this analysis).

Cell Technology	Power Density $W_{DC\ peak} / m^2$
X-Si	133.0
mc-Si	123.6
CIGs	81.46
a-Si (tandem junction)	75.84
CdTe	72.39
a-Si (triple junction)	60.09

Table 2: Suitability for rooftop installations

The relatively low power density makes amorphous silicon products most suitable for installations where space is not limited (i.e. non-rooftop or field installation applications). Rooftop applications are a key market that XsunX, Inc. and other amorphous silicon cell manufacturers are targeting, especially in niche markets, such as low light and high heat climates, and BIPV applications.

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2.1 Cell Performance Characteristics

The performance characteristics of the competing cell and module technologies was collected from first hand (i.e. manufacturers, solar integrators), as well as through public literature.

In the case of system degradation, reliable data was not readily available for all products. As a result, a constant was chosen for all module technologies. This represents an area where greater resolution is likely to become available as longitudinal data becomes available from aging installations (experience).

2.2 System Size

The baseline system size considered was chosen to represent a “large” (e.g. power purchase or utility) installation; 1MW $_{\text{AC peak power}}$ per year.

In addition to directly impacting the investment requirements for items such as BoS components, racks, and installation labor, system size also directly impacts module price. Discounts to retail module prices are often offered to customers making large purchases.

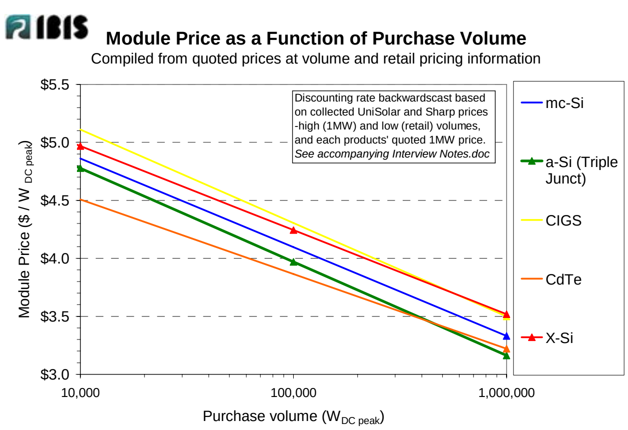

Figure 2: Module prices as a function of purchase volume

High volume module prices were collected for each technology of interest. In case of two of the five products multiple data points were collected describing the volume price discount available. These relationships were used to back-cast the lower volume purchase price for the remaining three products, based on the discount rate and known high volume (1MW$_{\text{DC peak}}$) purchase price for each.

Whether the non-rooftop field installation is being installed for a utility or commercial Power Purchase Agreement (PPA), the end user is most likely to determine the system ‘size’ based on power generation (AC Watts). Differences exist among the technologies of interest, in terms of the power density (W $_{\text{DC peak}}$ / m2) they provide. In addition, the performance of each module also varies.

General system derate factors were held constant for the purposes of this analysis. Soiling, AC and DC wiring, module mismatch, and diode losses have been held constant. Inverter conversion efficiency was also held constant for each module.

Derate Factor	Assumption
PV module nameplate DC rating	95%
Total DC/AC inverter efficiency	94.50%
Mismatch	98%
Diodes and connections	96.0%
DC wiring	97.5%
AC wiring	97.5%
Soiling	100%
System availabilty	100%
Shading	100%
Sun-tracking	100%
Age	100%

Table 4: System derate assumptions

Additionally, the temperature coefficients (see Table 2 in the above section) and climate variables (hours and intensity of solar irradiance) contribute to the amount of power provided by each module technology. The number of modules required to achieve the minimum AC power output given each system’s derate and conversion performance factors was calculated for each module technology.

The baseline analysis was conducted around a 1 MW fixed field installation. The tilt was calculated to be equivalent with that of the location’s latitude, in order to maximize the performance during the entire year. Land usage is calculated based on the number of modules required to provide the minimum power requirement, footprint of each module, and minimum spacing to accommodate the maximum shadowing affect between each row, given the tilt angle.

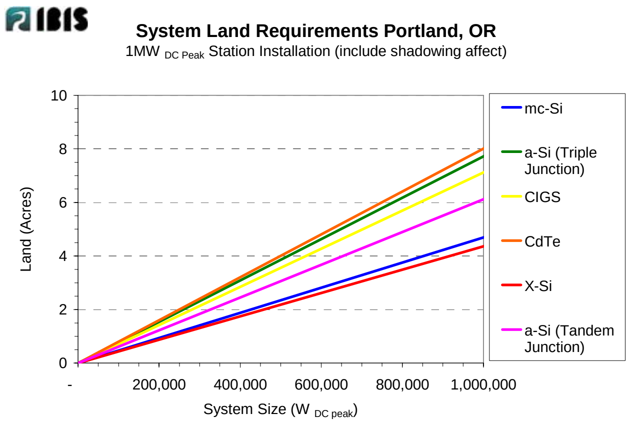

Figure 3: System land requirements – 1MW$_{AC}$ Portland, Oregon installations

The difference in available solar resources between the locations of interest; Portland, Oregon and Phoenix, Arizona, as well as the module performance differences in these conditions, and latitude (tilt) of the cells account for the difference in land requirements between the regional installations.

3 BALANCE OF SYSTEM COSTS

The Balance of System costs associated with each module's installation design is directly related to the size of the installation; number of modules and module size (land requirements, and weight).

Relative System Size - Phoenix, AZ (1MW AC)

	mc-Si	a-Si (Triple Junction)	CIGS	CdTe	X-Si	a-Si (Tandem Junction)
Area	1.00	1.65	1.52	1.71	0.93	1.30
# modules	1.0	1.85	2.50	5.75	1.38	1.98

Table 5: Relative system sizes (1MW$_{AC}$ field installations) – Phoenix, Arizona

Relative System Size - Portland, OR (1MW AC)

	mc-Si	a-Si (Triple Junction)	CIGS	CdTe	X-Si	a-Si (Tandem Junction)
Area	1.00	1.65	1.52	1.71	0.93	1.30
# modules	1.0	1.85	2.50	5.75	1.38	1.98

Table 6: Table 5: Relative system sizes (1MW$_{AC}$ field installations) – Phoenix, Arizona

The cost of balance of system components was estimated by a number of solar integrators and module providers (see Appendix: Interview Notes). This data was supplemented with academic publications and information from the public domain .

The model has the capacity to predict the balance of system costs based on the installation size. The amount (cost) of "long wiring" and "conduit" scales as the land requirements scale. The cost of "cable housing, fuse boxes, connectors" and "connection wiring" (between modules) scales with the number of modules that are required to achieve the predetermined annual power output.

Inverter costs, lifetime, and size were chosen based on conversations with solar integrators who have experience installing 1MW field systems. The costs parameters and product performance was held constant across all module technologies. Advanced Energy Industries' 333kW inverter (94.5% efficiency) with monitoring and data acquisition capabilities was selected.

4 RESULTS AND ANALYSES

Phoenix, Arizona and Portland, Oregon were selected as the locations of the analyses because of the contrasting climatic conditions found in those areas. While Phoenix has a plenty of direct solar resources, as a result the cell temperatures are elevated. In Portland there are far less solar resources available (i.e. diffuse light as a result of significant cloud cover), but the cell temperatures are much more moderate.

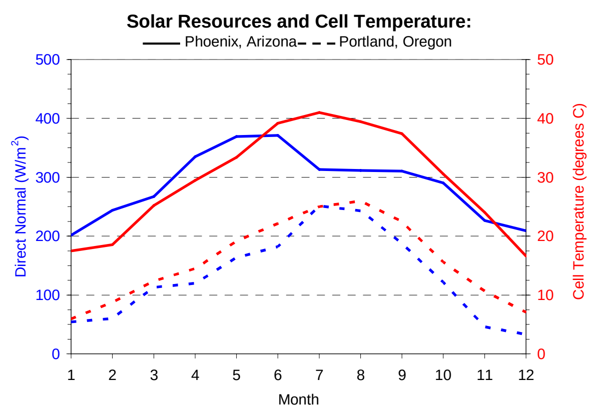

Figure 4: Solar Resources and cell temperature characteristics – Portland, OR and Phoenix, AZ

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It was found that a 1-axis tracking system provides a performance benefit of approximately 33%.

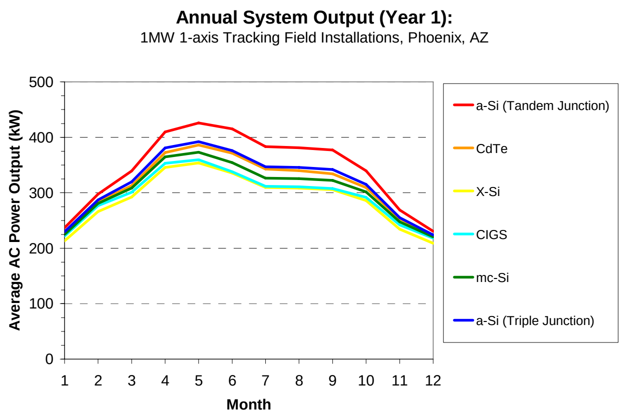

Figure 5: Annual system output – competing 1-axis tracking systems in Phoenix, AZ

The model developed by IBIS utilizes a bottoms-up approach to quantifying the Levelized Cost of Electricity (LCOE). For each cell technology, $1MW_{AC}$ power field installations were designed, including all supporting components and balance of system infrastructure. IBIS interviewed system integrators and public utilities who have experience designing, installing, and operating this type of solar electricity generation system, and at this scale.

The bottom's up approach to modeling system costs and cell performance enables a detailed analysis of the competitive costs for each technology to be considered.

In Arizona, the relatively high cell temperatures provided the most significant impact on power generated by the competing technologies, and had the greatest influence on equivalent system design and costs.

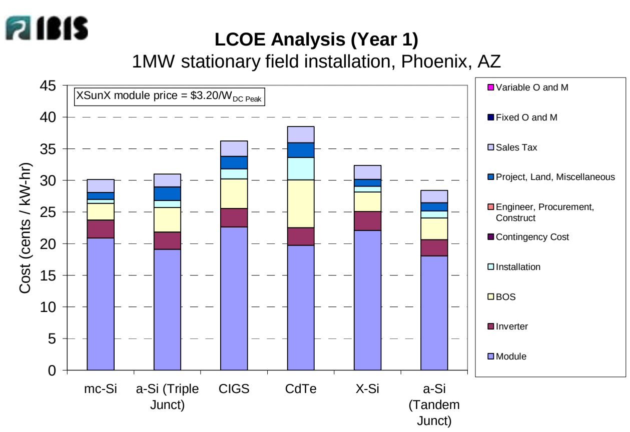

Figure 6: LCOE Cost results – competing PV technologies in Phoenix, AZ $1MW_{AC}$ field installations

Amongst the various systems, difference in balance of system requirements and installation costs were characterized largely based on the number of modules required to generate at least 1MW of AC power.

Cadmium telluride modules, for instance were found to have relatively low power densities and high module weights. In areas where racks are not designed to support snow loads, this difference in module weight contributed to the cost of the racks. The large module count indicates a high level of installation labor, and connection (e.g. connectors, short wiring, conduit) material costs.

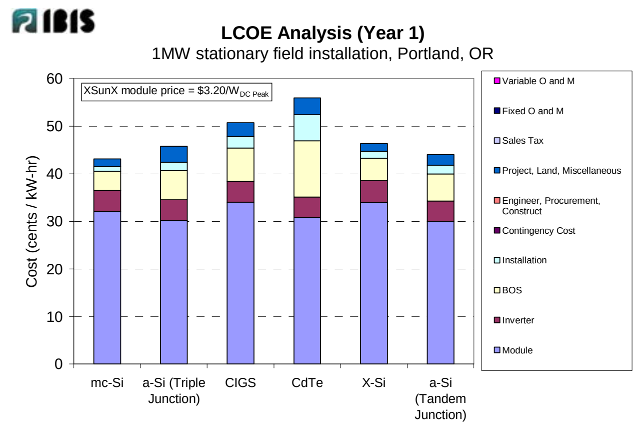

Figure 7: LCOE Cost results – competing PV technologies in Portland, OR $1MW_{AC}$ field installations

5 CONCLUSIONS

Module technologies which provide high power densities ($W_{DC\ peak}$ per module area) are most competitive in systems installed on roof tops. In field installations where the area available for the system is not typically limited, thin film technologies often provide a cost benefit.

While crystalline silicon technologies are among the highest performing under Standard Test Conditions, they often suffer from temperature degradation, and low light losses. Solar photovoltaics are rarely installed in laboratory conditions. A detailed assessment of any proposed site's solar resources, and climatic variables which may impact power generation is required to fully assess the competitive economics of alternative solar products.

REFERENCES

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