SUNPOWER®
Smarter Solar™

THE DRIVERS OF THE

Levelized Cost of Electricity

for Utility-Scale Photovoltaics

SUNPOWER CORPORATION
14 August 2008

EXECUTIVE SUMMARY

For more than three decades, utility-scale solar generated electricity has been dismissed as too costly. But the cost of solar generated electricity is consistently coming down, while the cost of conventional electricity is increasing. Advances in solar cell technology, conversion efficiency and system installation have allowed utility-scale photovoltaic (PV) to achieve cost structures that are competitive with other peaking power sources. The calculation of the levelized cost of electricity (LCOE) provides a common way to compare the cost of energy across technologies because it takes into account the installed system price and associated costs such as financing, land, insurance, transmission, operation and maintenance, and depreciation, among other expenses. Carbon emission costs and solar panel efficiency can also be taken into account. The LCOE is a true apples-to-apples comparison.

Around the globe, the solar industry has installed approximately 10 gigawatts of solar PV systems. Pacific Gas & Electric Co. has announced more than 2 gigawatts of agreements involving both solar thermal and PV technologies, including 800 megawatts of photovoltaic power – the largest utility-scale contracts for PV in the world. SunPower's 250 megawatt central station, high-efficiency, PV power plant in California Valley will be the first to deliver utility-scale PV power to PG&E. These solar power plants are vivid examples of how the electricity production landscape is changing rapidly to embrace a much broader portfolio of renewable resources. The LCOE equation sorts through the relative costs of such systems and pinpoints the increasingly positive economics for harvesting the world's most abundant energy resource – sunshine.

The economies of scale inherent in utility-scale solar systems are similar to those found with other power options, but PV has the benefit of being completely modular – PV works at a 2 kilowatt residential scale, at a 2 megawatt commercial scale or at a 250 megawatt utility scale. PV has the unique advantage among renewable resources of being able to produce power anywhere: deserts, cities or suburbs. Smaller scale PV costs more on an LCOE basis, but it can be selectively deployed on the grid wherever and whenever needed to reduce distribution capacity constraints and transmission congestion while producing pollution-free power. All PV can be constructed quickly and even utility-scale power plants can begin delivering power within a few quarters of contract signing – a major advantage when compared to conventional power plants. At SunPower, we serve customers across the spectrum, from small-scale to utility-scale solar, because each application has distinctive advantages and will contribute to driving solar power to become a major source of carbon-free power.

The LCOE Equation – a Key to Evaluating Emerging Energy Technologies

The LCOE equation is an evaluation of the life-cycle energy cost and life-cycle energy production. It allows alternative technologies to be compared when different scales of operation, investment or operating time periods exist. For example, the LCOE could be used to compare the cost of energy generated by a PV power plant with that of a fossil fuel-generating unit or another renewable technology.[1] It captures capital costs, ongoing system-related costs and fuel costs – along with the amount of electricity produced – and converts them into a common metric: $/kWh.

What drives LCOE reduction for PV?

Both capital costs and operating and maintenance costs are driven by the choice of technology and the area of the solar system. We outline in this paper how the following key factors drive the LCOE for solar PV power plants.

1) Panel Efficiency: SunPower's high-efficiency solar panels generate up to 50 percent more power than conventional technology and up to four times as much power as thin film technologies, thereby lowering area-related costs.
2) Capacity Factor: SunPower's tracker technology can increase energy production from solar panels by up to 30 percent, further reducing area-related costs and contributing more high-value energy during afternoon hours than fixed-tilt systems.
3) Reliable System Performance and Lifetime: SunPower's established crystalline silicon technology, with its history of consistent, predictable performance, reduces power plant financing costs lowering the LCOE.

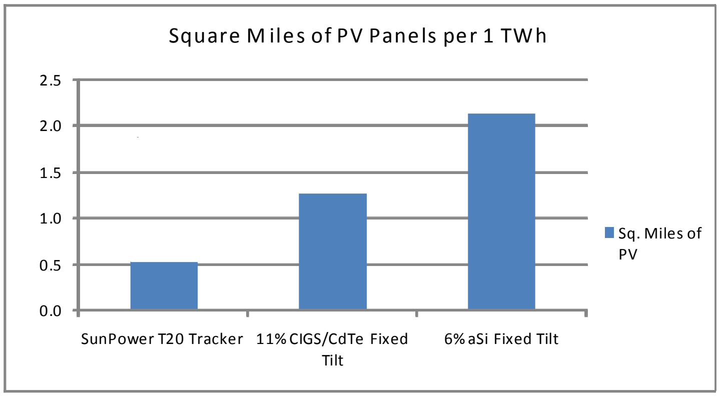

Figure 1 - PV Panel Area Required for 1 TWh Annual Production

Sunlight is a diffuse energy resource. Maximizing energy production per panel area is critical to achieve the best LCOE in a utility-scale PV power plant. As shown in Figure 1, if a PV power plant with 1 terawatt hour (TWh) of annual energy production is built with SunPower high-efficiency PV panels mounted on solar trackers, up to 75 percent less panel area is required when compared with thin film technology mounted in a fixed tilt configuration. This energy production density leverages almost all PV power plant fixed plant and operation and maintenance (O&M) costs, directly reducing the system LCOE.

Based on the LCOE, SunPower's high-efficiency power plants generate energy at a price competitive with other peak power resources. Given our technology roadmap and LCOE forward cost curve, we expect our high-efficiency silicon PV technology to maintain that competitive position.

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[1] W. Short, D. Packey, T. Holt, "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies", National Renewable Energy Laboratory – March 1995

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I. The LCOE Equation

The recent announcements of a wide variety of utility-scale solar photovoltaic (PV) power projects provide evidence that utility-scale PV is now reaching levels that are price competitive on a levelized cost of electricity (LCOE) basis with other peak power sources. Deriving a utility-scale PV LCOE requires a range of inputs which this paper discusses in detail. It also will review the LCOE benefits of high-efficiency silicon PV technology for utility-scale solar power plants.

A. Introduction

The LCOE equation is one analytical tool that can be used to compare alternative technologies when different scales of operation, investment or operating time periods exist. For example, the LCOE could be used to compare the cost of energy generated by a PV power plant with that of a fossil fuel generating unit or another renewable technology.[2]

The calculation for the LCOE is the net present value of total life cycle costs of the project divided by the quantity of energy produced over the system life.

$$\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

The above LCOE equation can be disaggregated for solar generation as follows:

$$= \frac{\text{Initial Investment} - \sum_{n=1}^{N} \frac{\text{Depreciation}^{n}}{(1+\text{Discount Rate})^{n}} \times (\text{Tax Rate}) + \sum_{n=1}^{N} \frac{\text{Annual Costs}^{n}}{(1+\text{Discount Rate})^{n}} \times (1-\text{Tax Rate}) - \frac{\text{Residual Value}}{(1+\text{Discount Rate})^{n}}}{\sum_{n=1}^{N} \frac{\text{Initial kWh/kWp} \times (1 - \text{System Degradation Rate})^{n}}{(1 + \text{Discount Rate})^{n}}}$$

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[2] W. Short, D. Packey, T. Holt, "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies", National Renewable Energy Laboratory – March 1995

When evaluating the LCOE and comparing other commonly known \$/kWh benchmarks it is important to remember that the LCOE is an evaluation of levelized life cycle energy costs. The price of energy established under Power Purchase Agreements (PPAs) or by feed-in-tariffs (FITs) may differ substantially from the LCOE of a given PV technology as they may represent different contract or incentive durations, inclusion of incentives such as tax benefits or accelerated depreciation, financing structures, and in some cases, the value of time of day production tariffs.

B. Major LCOE Inputs

1. INITIAL INVESTMENT

The initial investment in a PV system is the total cost of the project plus the cost of construction financing. The capital cost is driven by:

- **Area-related costs** which scale with the physical size of the system namely the panel, mounting system, land, site preparation, field wiring and system protection.
- **Grid interconnection costs** which scale with the peak power capacity of the system including electrical infrastructure such as inverters, switchgear, transformers, interconnection relays and transmission upgrades.
- **Project-related costs** such as general overhead, sales and marketing, and site design which are generally fixed for similarly sized projects.

2. DEPRECIATION TAX BENEFIT

$$\sum_{n=1}^{N} \frac{\text{Depreciation}^{n}}{(1+\text{Discount Rate})^{n}} \times (\text{Tax Rate})$$

The depreciation tax benefit is the present value of the depreciation tax benefit over the financed life of the project asset. Public policy which enables accelerated depreciation directly benefits the system LCOE because faster depreciation translates to faster recognition of the depreciation benefit.

3. ANNUAL COSTS

$$\sum_{n=1}^{N} \frac{\text{Annual Costs}^{n}}{(1+\text{Discount Rate})^{n}} \text{ X } (1-\text{Tax Rate})$$

In the LCOE calculation the present value of the annual system operating and maintenance costs is added to the total life cycle cost. These costs include inverter maintenance, panel cleaning, site monitoring, insurance, land leases, financial reporting, general overhead and field repairs, among other items.

4. SYSTEM RESIDUAL VALUE

$$\frac{\text{Residual Value}}{(1+\text{Discount Rate})^{n}}$$

The present value of the end of life asset value is deducted from the total life cycle cost in the LCOE calculation. Silicon solar panels carry performance warranties for 25 years and have a useful life that is significantly longer. Therefore if a project is financed for a 10- or 15-year term the project residual value can be significant.

5. SYSTEM ENERGY PRODUCTION

$$\sum_{n=1}^{N} \frac{\text{Initial kWh/kWp x } (1 - \text{System Degradation Rate})^{n}}{(1 + \text{Discount Rate})^{n}}$$

The value of the electricity produced over the total life cycle of the system is calculated by determining the annual production over the life of the production which is then discounted based on a derived discount rate. The first-year energy production of the system is expressed in kilowatt hours generated per rated kilowatt peak of capacity per year (kWh/kWp). The kWh/kWp is a function of:

- The amount of sunshine the project site receives in a year
- How the system is mounted and oriented (i.e. flat, fixed tilt, tracking, etc.)
- The spacing between PV panels as expressed in terms of system ground coverage ratio (GCR)

- The energy harvest of the PV panel (i.e. performance sensitivity to high temperatures, sensitivity to low or diffuse light, etc.)
- System losses from soiling, transformers, inverters and wiring inefficiencies
- System availability largely driven by inverter downtime

To calculate the quantity of energy produced in future years, a system degradation rate is applied to initial system performance to reflect the wear of system components. The system degradation (largely a function of PV panel type and manufacturing quality) and its predictability is an important factor in life cycle costs as it determines the probable level of future cash flows.
Finally, the system's financing term will determine the duration of cash flows and impact the assessment of the system residual value.

C. The LCOE Model Sensitivity

The LCOE is highly sensitive to small changes in input variables and underpinning assumptions. For this reason, it is important to carefully assess and validate the assumptions used for different technologies when comparing the LCOE.

Figure 2 illustrates the model's sensitivity to input assumptions. We provide three scenarios that all start with the same PV system price and predicted energy output using a tracker in a high insolation[3] location. We then modify 1) the annual degradation rate, 2) the forecasted economic life, 3) the annual O&M expense, and 4) the discount rate. The resulting LCOE for the three scenarios range from $0.09 / kWh to $0.23 / kWh, illustrating that for the same system capital cost and initial energy output the range of energy prices can vary by a factor of two or more. Comparing LCOE calculations and power plant energy pricing requires aligning assumptions across examples and calibrating against empirical data to generate a more accurate LCOE forecast.

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[3] Insolation is the level of solar radiation received at a given location

Figure 2
Solar PV LCOE Sensitivity to Variable Changes

	Case 1	Case 2	Case 3
System Price	100%	100%	100%
kWh/kWp	100%	100%	100%
Annual Degradation	1.0%	0.5%	0.3%
System Life	15	25	40
Annual O&M $/kWh	$0.030	$0.010	$0.005
Discount Rate	9%	7%	5%
LCOE $/kWh	$0.23	$0.13	$0.09

One use for LCOE calculations is to compare costs without incentives. If incentives such as the U.S. Investment Tax Credit (ITC) are assumed in an LCOE calculation they should be specifically referenced to make clear the basis for comparison between technologies.

Given the high sensitivity of the LCOE to input variables, it is important to understand the validity of performance output over a system's lifetime. Silicon PV systems have been operating outdoors for more than 20 years[4] and therefore the performance and degradation mechanisms are well understood. For silicon-based PV systems it is possible to accurately forecast future output allowing one to populate the LCOE equation variables with a high level of confidence.

II. LCOE Variables for Utility-Scale PV

To understand the LCOE outlook for utility-scale PV it is important to understand the lifetime system performance and cost. The following sections summarize key cost and performance drivers for a utility-scale PV power plant.

A. PV Power Plant Performance

The lifetime energy generated from a PV power plant is a product of the plant location, annual performance for a given capacity, component degradation and system lifetime.

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[4] E. Dunlop, D. Halton, H. Ossenbrink, "20 Years of Life and More: Where is the End of Life of a PV Module?" IEEE Proceedings 2005, p.1595

1. SYSTEM CAPACITY FACTOR

The capacity factor is a key driver of a solar project's economics. With the majority of the expense of a PV power plant being fixed, capital cost LCOE is strongly correlated to the power plant's utilization. The annual capacity factor for a PV power plant is calculated as:

$$\frac{\text{Annual kilowatt -hours generated for each kilowatt AC of peak capacity (kWh/kWp)}}{\text{8760 hours in a year}}$$

A PV power plant's capacity factor is a function of the insolation at the project location, the performance of the PV panel (primarily as it relates to high temperature performance), the orientation of the PV panel to the sun, system electrical efficiencies and the availability of the power plant to produce power.

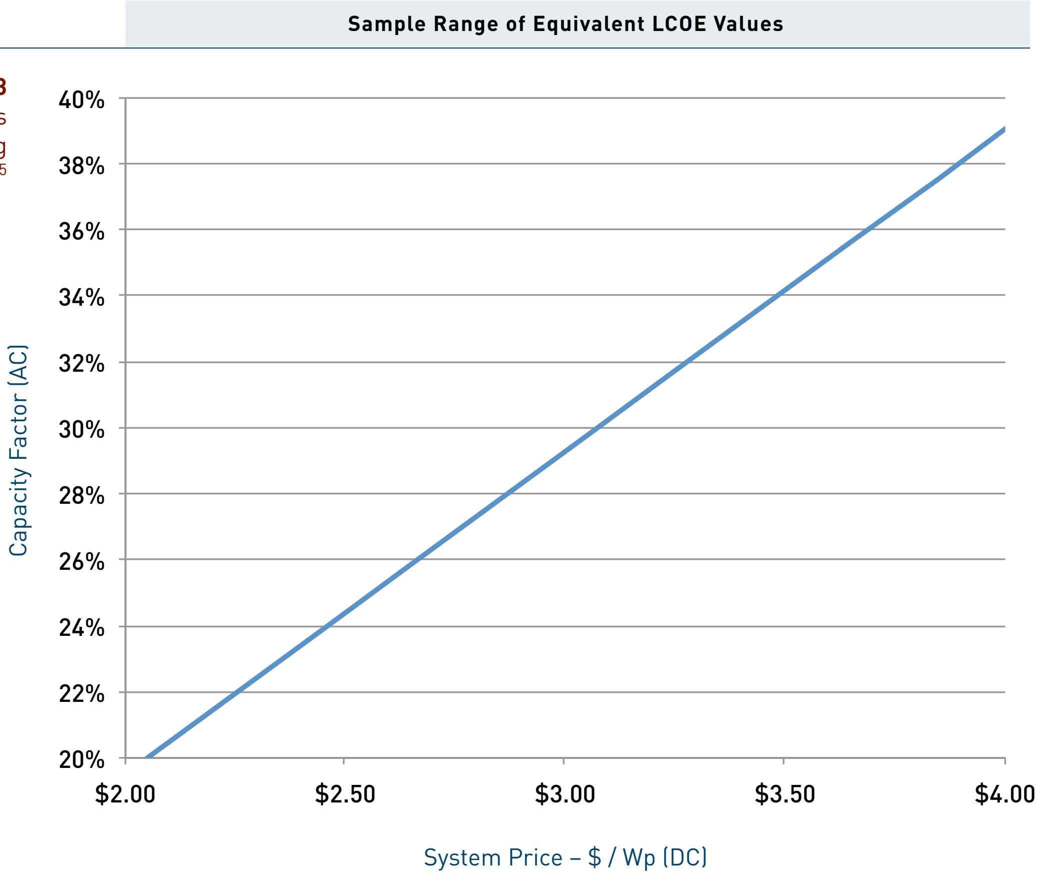
Sample Range of Equivalent LCOE Values

Figure 3
Associated Capacity Factors and System Prices Producing an Identical LCOE[5]

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[5] Capacity factor is generally expressed as a function of the AC rating of a plant so the above kWh/kWp calculation is based on the kWh per AC watt peak as opposed to the DC watt peak

Figure 4 - SunPower's T0 Tracker

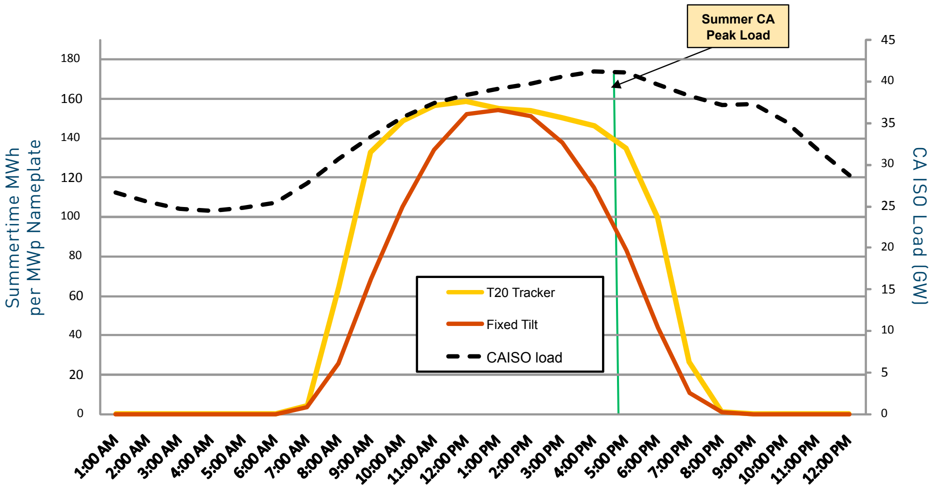
Figure 5 - SunPower's T20 Tracker

The economic impact of the capacity factor is substantial. Figure 3 illustrates a range of identical LCOE values, expressed in $/kWh, for a given PV power plant system price as expressed in $/Wp and the associated capacity factor. As the capacity factor declines, the required installed system price must also substantially decline to maintain system economics. For example, a $2.50/Wp system with a 24 percent capacity factor (such as with a fixed tilt configuration) delivers the same LCOE as a $3.50/Wp system with a 34 percent capacity factor (such as with a tracker). The highest capacity factors are generated with trackers which follow the sun throughout the day to keep the panel optimally oriented towards the sun. This tracking also has the benefit of generating more energy in the peak electricity demand periods of the afternoon. SunPower has developed two patented tracking systems to optimize the capacity factor of a PV power plant: the T0 Tracker – optimized for space-constrained sites – and the T20 Tracker – optimized for maximum energy production.

The LCOE model assigns an equal value to electricity generated throughout the year. However, electricity generated at peak periods is more valuable to the utility. The use of tracking with a solar system can increase the output of a plant after 4 p.m. in the summer by more than 40 percent, which is often a period of peak demand on the system when energy is highly valued. Figure 6 gives a comparison for the summer energy output of a fixed and tracking PV power plant as compared with the California ISO load. A tracker enables higher output during the peak afternoon period for a given plant capacity.

SunPower Production vs. Load Profile

Figure 6
Comparison of California Summer Load Requirements with Fixed and Tracking PV Systems



2. PV PANEL PERFORMANCE AND LIFETIME

Successful prediction of PV panel performance over time is critical to project investors. Furthermore, demonstrating the historical performance of a company's panel technology is critical to determine financing parameters which underpin the LCOE calculation.

Silicon PV has the longest operating history of any solar cell technology. The photograph in Figure 7 shows a monocrystalline silicon panel after 20 years of outdoor exposure with no major visual degradation. Studies on the performance of silicon PV panels show only four percent total degradation after 23 years of outdoor exposure.[6] This experience provides a high level of confidence in making future performance predictions. Note that most investors finance a solar system based on an assumed panel degradation rate of 0.5 to 1.0 percent per year, a faster rate than this historical data for silicon PV might indicate.

Figure 7
Monocrystalline Silicon PV Panel after 20 years of Outdoor Exposure

Research on silicon PV historical performance suggests that panel life may extend much further than the 25-year design life.[7] This demonstrates that long-term performance may enable longer financeable system lives in the future. Figure 8 illustrates the LCOE model sensitivity to financed system life based on a seven percent discount rate. As indicated in the figure, extending the financed term of the project beyond today's 20- to 25-year values could have a material impact to the LCOE.

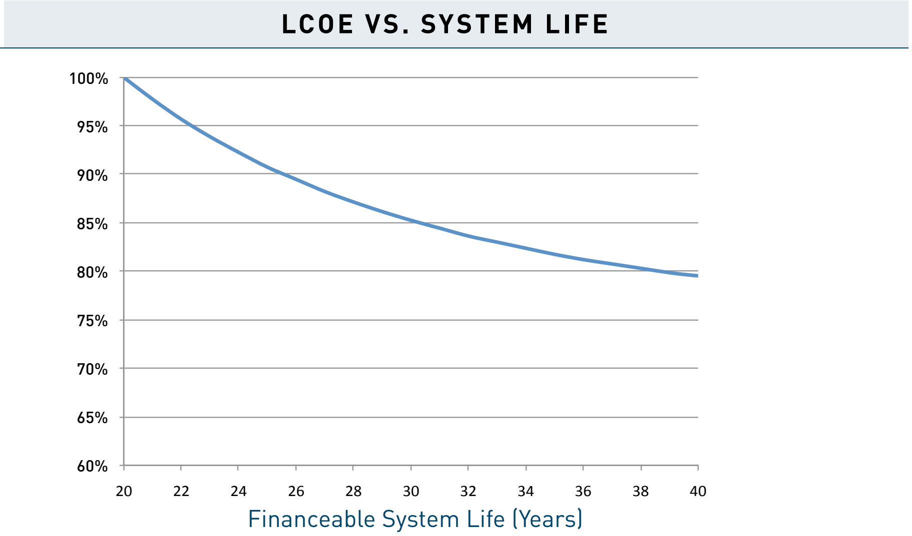


Figure 8
LCOE Sensitivity to Financeable System Life

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[6] F. De Lia, S. Castello, L. Abenante, "Efficiency Degradation of C-Silicon Photovoltaic Modules After 22-Year Continuous Field Exposure," Proc. 3rd World Conf. on PV Energy Conversion, May 2003, Osaka, Japan.

[7] E. Dunlop, D. Halton, H. Ossenbrink, "20 Years of Life and More: Where is the End of Life of a PV Module?" IEEE Proceedings 2005, p.1595

13. PREDICTING SYSTEM PERFORMANCE

In addition to calculating PV panel output, an estimate of the system's overall performance must be made to finance a project. The key variables in a PV power plant's performance are plant uptime, weather-based performance (insolation, ambient temperature, soiling, etc.), inverter and power system efficiency, and system component degradation (largely from the panel).

SunPower has developed an analytical model, PV Grid, which accounts for the above variables and makes future performance predictions based on SunPower's experience with more than 450 installed commercial rooftop and power plant systems. With this tool SunPower provides project investors with a well-demonstrated means of estimating project cash flows.

Bavaria Solarpark Performance

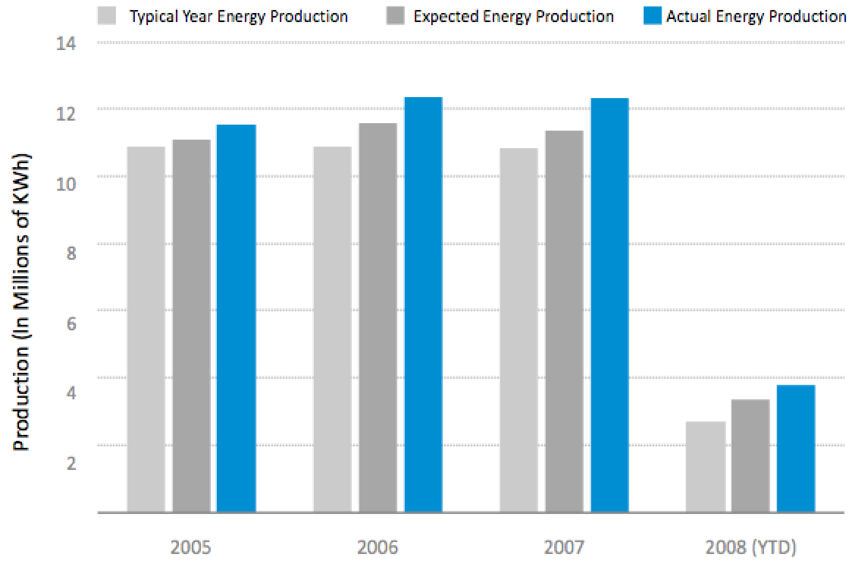

Figure 9
Expected and Actual Energy Production for 10MW Bavaria Solar[8]

Figure 9 illustrates the actual versus expected performance for a 10 megawatt SunPower tracking power plant system in Germany, Bavaria Solar I. During the first three years of operation, the system performance has exceeded the performance estimates under which the project was financed.

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[8] A. Kimber, "Long Term Performance of 60MW of Installed Systems in the US, Europe, and Asia", Proceedings of the 22nd Annual Photovoltaic Solar Energy Conference, September 2007

This correlation between empirical data and future predictions is critical in reducing investor risk and the related cost and terms of capital investments. An important path to utility-scale LCOE reduction is to demonstrate to investors the predictable output, degradation and system life which would support a lower cost of project capital. As more PV data is generated and investors become more familiar with the technology, this may become possible.

Figure 10
Representative Experience of SunPower PV Power Plant Technology

Isla Mayor Spain,
8.4 MW SunPower T0 Tracker

Muehlhausen, Bavaria, Germany,
6 MW SunPower T0 Tracker

Trujillo, Extremadura, Spain-Elecnor
23 MW SunPower T0 Tracker

Jumilla, Murcia, Spain-Elecnor
23 MW SunPower T0 Tracker

Serpa, Portugal
11 MW SunPower T0 Tracker

Las Vegas, US - Nellis AFB
14.2 MW SunPower T20 Tracker

B. Initial PV Power Plant Investment

1. PV Panel

When discussing the potential for photovoltaic solar cost reduction the focus is understandably placed on the panel. Over the past several years, solar panel prices have represented approximately $4/Wp of total PV system installed prices of $6-$9/Wp[9] depending on the market and application type.

Until 2004, PV cell and panel production costs were steadily declining following classic learning curve behavior as the solar

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[9] Within the PV industry system prices and sizes are often referred to in terms of the DC Wp of the system such as here. In other instances AC Wp prices and sizes are published. AC Wp prices are higher than DC values because of the losses in transforming power from DC to AC i.e. a 1 megawatt DC system at $7.00/Wp might be rated as 0.8 megawatts AC and $8.75/AC Wp.

industry grew. In 2004 and through 2008 however, the rapid growth in PV demand led to a global shortage of solar-grade polysilicon, the key raw material used in conventional silicon solar cells. The spot market price of polysilicon during this period rose from $25/kg to greater than $500/kg for some reported transactions. The cost of polysilicon became the driving cost of a conventional solar panel, increasing production costs to artificially high levels relative to the historic learning curve. As a secondary effect, solar cell manufacturing costs also suffered as the result of underutilized, silicon-constrained factories.

In 2007, some solar manufacturers entered into new intermediate and long-term contracts that will continue through the rest of the decade, lowering feedstock costs for those that have contracted for that silicon. The polysilicon industry should also benefit from an improved cost structure — as compared with pre-shortage levels — due to the scale economies of the new factories being built and new silicon purification process technology. In the first half of 2008, SunPower saw its first material silicon cost reductions as we benefited from the delivery of substantial volumes of polysilicon under supply contracts from new production facilities.

One benefit of the silicon shortage was that the cost and scarcity of silicon prompted a significant improvement in silicon utilization by solar cell manufacturers. In SunPower's case, the grams of polysilicon consumed to manufacture a watt at the solar cell level declined from 13 g/W in 2004 to 6.3 g/W in 2008 and is planned to decline to an estimated 5 g/W with SunPower's Gen 3 technology now under development. By 2011 this approximately 60 percent reduction in the use of silicon, coupled with an approximately 50 percent decline in the price of polysilicon, will independently drive large cost reductions for PV panels.

Cell and panel conversion costs are driven by yield, depreciation, labor, chemical consumption, electricity cost and materials. Conversion costs can be improved by shorter and more efficient processes, higher throughput production lines, larger plant sizes driving scale economies, and greater automation, among other factors. All of these costs are also leveraged by the efficiency of the solar cell. SunPower's cost structure and cell efficiency advantage demonstrate that higher efficiency cells can absorb the increased manufacturing costs to make each cell due to the higher watts per cell. Efficiency advantages continue downstream into panel assembly, sales, marketing and installation. For example, holding all other costs constant, an increase in cell efficiency of one percentage point will equate to approximately a five percent decrease in installed system costs. Figure 11 illustrates the solar conversion of efficiency of SunPower's solar cells relative to conventional silicon and thin film PV technologies.

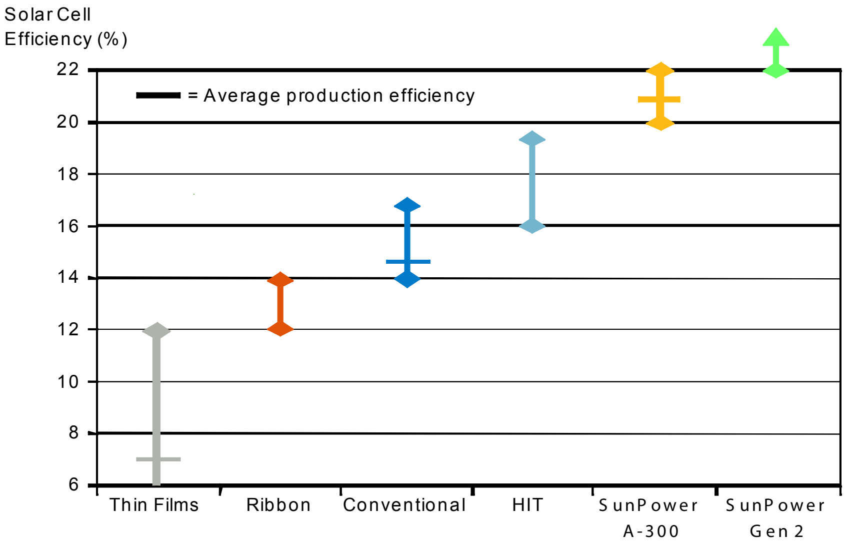
Relative Solar Cell Conversion Efficiencies

Figure 11
Relative Solar Cell Conversion Efficiencies

2. AREA-RELATED EXPENSES

PV power plant area-related expenses include system costs which directly scale with the area of PV panels used. These expenditures are the dominant non-panel costs in a PV system and include steel, foundations, mounting hardware, plant installation, shipping and warehousing, field wiring, and the electrical components used to connect the panels. Area-related costs are highly correlated with the prices of steel, copper and concrete as well as transportation expenses.

The structural materials necessary for panel installation are driven by the wind load requirements of the project. These are a function of the PV panel surface area that is exposed to the wind whether the system is tracking or fixed (similar to how the wind force on a sail is a function of the sail size). As a result, simplified tracking and fixed tilt configurations share similar cost structures with the exception of the drive and control components.

There is a common misconception that trackers significantly add to the cost of a system over fixed tilt configurations. SunPower has developed trackers which can move up to 300kWp of panels with a simple half-horsepower motor which requires little maintenance. SunPower has determined that the financial benefit of the increased energy production generated by tracking the sun significantly outweighs the incremental system costs. By the end of 2008, SunPower and its partners will have deployed more than 250 megawatts of tracking systems on three continents. With this experience, SunPower has determined that tracking systems have delivered superior LCOE economics for its customers than fixed configurations.

Area-related installation costs can vary substantially by site and by country. For example, a fence post-like support foundation might be easily driven into the ground in Bavaria whereas a South Korea typhoon zone may require a thick steel beam placed in a hole drilled into rock and secured with reinforced concrete at four times the cost. As a result the range of foundation costs for a fixed tilt system or single-access tracker could vary from $30 - $200 / m2 of PV depending on the site. Additionally, differences in government electrical codes can significantly impact costs; one jurisdiction may require expensive steel wire conduit while others allow the direct burial of cable into the ground.

Once the area-related costs for a system are calculated, a simple transformation to $/Wp can be accomplished by dividing $/m2 by the Wp/m2 of the panel. In the case of SunPower's high-efficiency panels, area-related $/Wp costs are approximately 50 percent lower than thin film PV panels. Figure 12 below demonstrates how area related costs are leveraged through efficiency for a sample central station PV solar power plant with 1 TWh of annual energy production. Note that although the material costs are higher for standard efficiency and thin film panels, they are largely similar to what they would be with a fixed tilt system so tracking still makes economic sense provided there is available land.

Area Related Costs for a 1 TWh T20 Tracker Project

PV Panel Used for Project	SunPower	Standard Efficiency	Thin Film
PV Panel Efficiency	20.0%	14.0%	11.0%
System Size (DC kWp)	423,191	439,754	430,108
Land Required (Sq Miles)	5.11	7.58	9.44
Truckloads of Concrete Required	12,718	18,218	22,678
Steel Required (Tons)	35,083	50,258	62,561
Cabling Required (Miles)	410	587	730
Trenching Required (Miles)	32	45	57
Modules to Wash (Sq Feet)	14,579,689	21,643,300	26,941,782
Tracker Installation Labor (hours)	365,450	523,516	651,678
Concrete Required (Tons)	254,353	364,367	453,568

Figure 12
Area Related Cost Components for a T20 Tracker Power Plant with 1 TWh of Annual Production

3. LAND USE AND EXPENSE

Land used for solar power plants has been readily available and inexpensive in the past, largely because the land had little economic value other than in some cases low-yielding agricultural activities. As solar power plant developers began acquiring land in South Korea, Southern Europe and the southwest U.S., prices for prime land conducive to a solar power plant rapidly increased in cost and general land availability became an issue. Korea and Southern Europe have seen solar-suitable land price increases of more than 300 percent and southwest desert land has sold for prices as high as a reported $23,000 per acre for flat land[10] with high insolation located near electrical transmission lines, a roughly 15,000 percent increase over historical values for the same parcels.

There are two fundamental drivers for the land consumed by a solar power plant: solar panel efficiency and system ground coverage ratio (GCR). System GCR is the ratio of solar panel area to land area.

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[10] T. Woody, "The Southwest Desert's Real Estate Boom," Fortune Magazine, July 11, 2008.

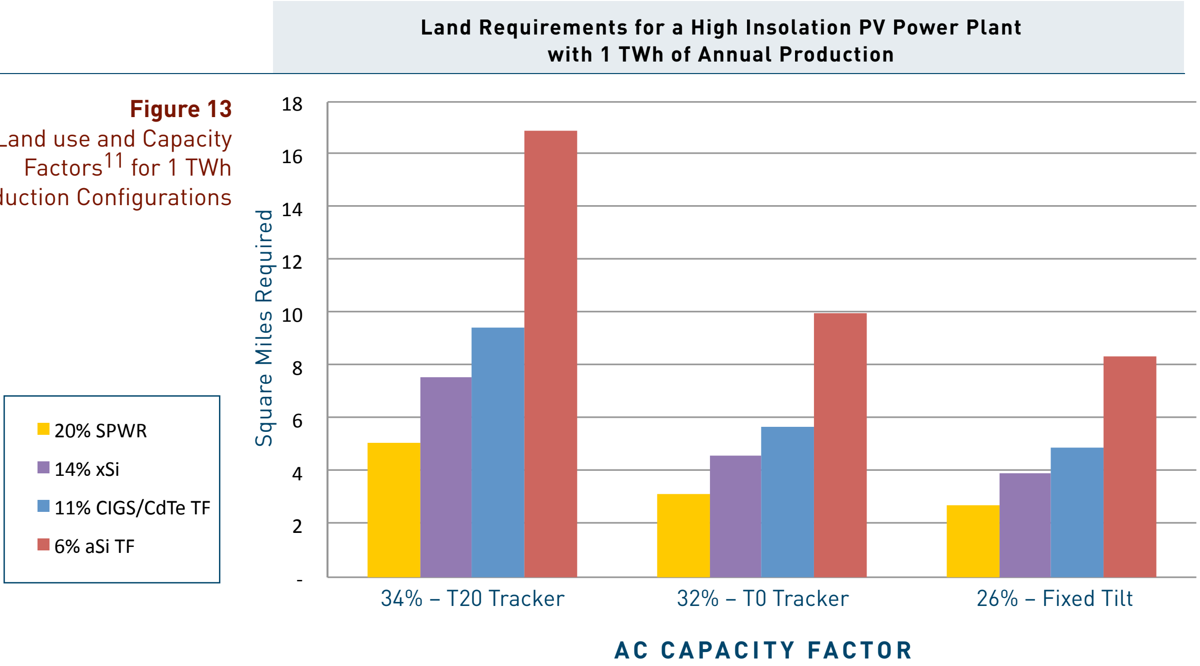
PV panels mounted flat use land the most efficiently and have the maximum GCR but have the lowest capacity factor, meaning lower utilization of fixed plant costs. Conversely a two-axis tracker has the maximum possible capacity factor but requires up to 10 times more land than flat configurations. To put it simply, the better the orientation to the sun (thus capacity factor), the longer the shadows created and therefore the further apart panels must be placed to avoid panel to panel shading.

To deliver the best utility-scale PV LCOE one must balance land use with the system capacity factor. SunPower addresses this optimization problem by manufacturing the world's highest efficiency PV panels along with tracking systems that efficiently use land while increasing energy production. SunPower's tracker offerings include the T20 Tracker, which maximizes capacity factor in an efficient land footprint, and the T0 Tracker, which optimizes land use for constrained sites while still providing a high capacity factor.

Figure 13 illustrates the land consumption versus capacity factor for a power plant producing 1 TWh / year in a high insolation location. One can see in this example that:

- With high-efficiency PV panels, up to 75 percent less land is required for a given capacity factor configuration.
- With high-efficiency PV panels mounted on trackers, up to 30 percent higher capacity factors are attainable while using a similar or lower amount of land per quantity of energy produced than low and medium efficiency panels mounted on fixed tilt systems. This means that lower LCOE configurations are achievable without prohibitively increasing the amount of land required.

Figure 13
Land use and Capacity Factors[11] for 1 TWh Production Configurations



4. GRID INTERCONNECTION COSTS

Grid interconnection costs relate to the inverter, transformer, switchgear, medium voltage substation and electrical interconnect, the high-current electrical backbone bringing power in from the array and ultimately the transmission back to the central grid in the case of a power plant requiring a transmission upgrade for grid integration. These costs are driven by the price of the manufactured components, the skilled labor used to install and the price of copper, which drives much of the inverter and electrical wiring costs. Power transmission costs are driven down through scale economies, more intelligent system design and through improved plant utilization such as with solar tracking.

C. PV Power Plant Operating Expenses

The operation and maintenance (O&M) of a PV power plant is relatively straightforward because there are few moving parts and no cooling systems. O&M costs generally scale with three factors 1) system peak power dominated by inverter maintenance, 2) system annual energy production density, and (3) general site related items. Improving the capacity factor of a system directly reduces O&M

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[11] Note the listed capacity factors are based on the AC rating of the power plant at the point of grid interconnection, the DC nameplate capacity of the PV power plant will be approximately 20 percent higher than the AC rating depending on the PV panel type and system configuration.

costs through higher utilization rates of fixed assets. Figure 14 demonstrates this as it relates to the inverter requirements to generate 1TWh of annual energy in a PV power plant. In this example, 1 TWh of energy would require 335 inverters, each 1 MWp, with a SunPower T20 Tracker versus 442 inverters with a fixed tilt system at the same location. The use of a tracking system would therefore significantly reduce the inverter O&M cost.

Figure 14
Inverters Required for 1 TWh of Energy Production in the Southwest U.S. Desert

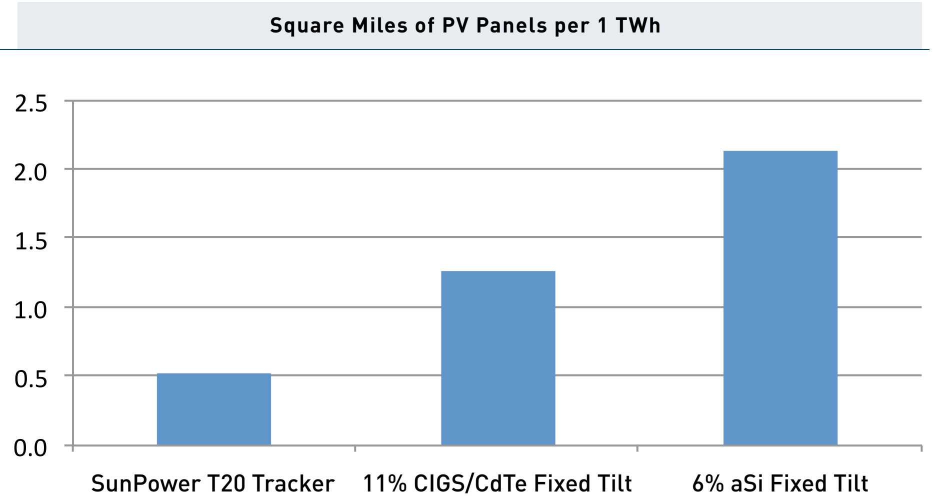
	T20 Tracker	**Fixed Tilt**
Capacity Factor	34.1%	25.8%
1 MWp Inverters per annual TWh	335	442
Inverter O&M Cost	100%	132%

Significant power related maintenance costs also exist with respect to transformers, switch gear and grid interconnection, and all benefit from a high capacity factor system configuration. Module cleaning, panel repair or replacement, mounting structure and wiring maintenance, and vegetation control all scale with the annual energy production density of the panels. The annual energy production density is a critically important factor for system economics (both O&M and overall LCOE). The annual energy production density is the kWh generation per unit area per year as measured as:

$$\textbf{Annual Energy Production Density} = \textbf{kWh} / \textbf{m}^2 / \textbf{year}$$

The impact of the annual energy production density can be substantial. Figure 15 shows the area of PV panels required in a high insolation solar power plant to generate 1 TWh of annual output.

Figure 15
PV Panels Required for 1 TWh of Annual Production



O&M costs which correlate with the area of PV panels used can thus be reduced using high-efficiency PV panels mounted on tracking systems. A simple example of these O&M savings is with the cost of cleaning panels. With a high annual energy production density panel, washing costs can be reduced by up to 75 percent. This allows for either a direct reduction of O&M costs or allows for panels to be washed more frequently and economically, increasing system annual energy production. Although often overlooked, washing and soiling can have a material impact to a PV power plant LCOE.

In a tracking system there is the added cost of motor and controller maintenance. But in SunPower's experience this cost is relatively small when compared to the other O&M cost savings the tracker provides. For example, the SunPower motor requires only annual lubrication and a single motor can control more than 300kWp of PV. Also, the tracker bearings require no lubrication and are designed for more than 25 years of use. The O&M cost of a utility-scale tracking system would be less than $0.001/kWh over a fixed configuration, which does not include the O&M savings from the increase in energy production.

Looking to the future, opportunities for O&M cost reduction include improved inverter reliability, scale economies from larger plant sizes, automated washing and water recycling tools, and sophisticated remote monitoring.

D. System Residual Value

Related to the previous section, solar PV financial models generally assign zero residual value to the project. The system however, could have a useful life of 50 years or more yielding a material residual value to the system after the 20- or 25-year financed term. Additionally, the PV power plant could increase in value if fossil-fuel based energy prices continue to rise.

Due to the time value of money, the LCOE impact of a system's residual value is diluted but could still materially reduce a PV power plant's LCOE.

It is conceivable that in the future PV systems will be treated as assets with an active secondary market. In the wind industry, secondary turbine sale and refurbishment has begun to occur.[12] SunPower has seen some value being placed on the future reclamation of the structural steel used in its power plants, but placing a value the residual energy of a PV power plant is still immature in the market.

E. SunPower's LCOE Forecasting Tool

SunPower has set a company goal of reducing the LCOE of its installed system cost by at least 50 percent by 2012 based on 2006 costs. Through its vertical integration, SunPower has a unique window into the detailed costs of a solar system – from quartz mining for metallurgical silicon to the construction and maintenance of a PV power plant.

To plan and track LCOE reductions by market and application around the world, SunPower has developed a Web-based database that aggregates hundreds of cost, performance and financial inputs from its projects. The project dovetails with SunPower's research and development work funded by the U.S. Department of Energy's Solar America Initiative (SAI). The SAI sets forth aggressive solar LCOE reductions through technological and process innovation.[13]

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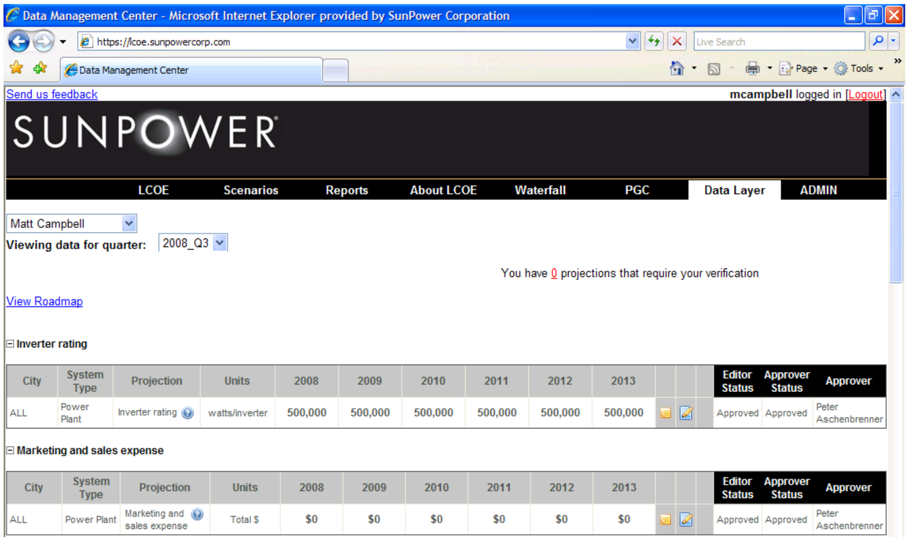
[12] J. Runyon, "Finding a Second Life For Retired Wind Turbines," http://www.renewableenergyworld.com, July 1, 2008

[13] www.eere.energy.gov/solar/solar_america/pdfs/solar_market_evolution.pdf



Matt Campbell

Viewing data for quarter: 2008_Q3

You have 0 projections that require your verification

View Roadmap

Inverter rating

City	System Type	Projection	Units	2008	2009	2010	2011	2012	2013				Editor Status	Approver Status	Approver
ALL	Power Plant	Inverter rating	watts/inverter	500,000	500,000	500,000	500,000	500,000	500,000	▭	✎		Approved	Approved	Peter Aschenbrenner

Marketing and sales expense

City	System Type	Projection	Units	2008	2009	2010	2011	2012	2013				Editor Status	Approver Status	Approver
ALL	Power Plant	Marketing and sales expense	Total $	$0	$0	$0	$0	$0	$0	▭	✎		Approved	Approved	Peter Aschenbrenner

Figure 16
SunPower's LCOE Forecasting Tool

The LCOE for an incremental PV power plant to be built in the future is influenced by a variety of external factors including exchange rates, labor prices in respective manufacturing and construction locations, scarcity of critical raw materials, the cost of capital, land prices, and many other factors. These risks are minimized by the use of a high-efficiency solar panel technology like SunPower's since the efficiency leverages almost all non-PV plant costs. Once built, the LCOE of energy coming from a silicon PV power plant is very predictable since the LCOE is heavily influenced by capital cost, location and systems technology choice.

Based on extensive LCOE scenario analysis with a range of cost and performance structures for incumbent and emerging solar technologies, SunPower believes that utility-scale, central station solar power plants built with high-efficiency silicon PV will deliver a competitive LCOE now and in the future.

III. Conclusions

We conclude that on the many dimensions of cost and performance that underpin the LCOE for a solar power plant, high-efficiency tracking PV offers a very compelling solution. To review, the LCOE is the net present value of total life cycle costs of the project divided by the quantity of energy produced over the system life.

$$\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

Key LCOE benefits for high-efficiency PV power plants include:
Lowest Total Life Cycle Cost

- High-efficiency panels minimize power plant capital costs through the reduction in the number of modules and scale of the mounting system and land required to generate a given amount of energy.
- Higher conversion efficiencies, more efficient use of silicon and larger scale manufacturing operations will drive continued high-efficiency panel cost reductions.
- Life cycle O&M costs are substantially lower for high-efficiency tracking PV due to up to four times the energy production per panel per year.
- A higher system residual value for a silicon PV plant drives total life cycle cost reduction.

Highest Total Lifetime Energy Production

- Through optimized solar tracking, SunPower PV power plants maximize the annual energy production of a system leading to high capacity factors and a lower LCOE.
- With a more than 20-year operating history, monocrystalline PV modules provide predictable energy production which reduces investor investment risk and enables longer financeable system lives.

LCOE analysis shows how SunPower's high efficiency silicon PV power plants generate electricity at a price competitive with other peak power resources. Based on comparison between published cost predictions for other technologies and our internal cost reduction roadmap and resultant LCOE forward cost curve, we expect to maintain this competitive position into the future.

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