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# Photovoltaic System Performance

# *Major General Emmett J. Bean Federal Center*

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The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

## DISCLAIMER



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# I. Executive Summary

General Service Administration Green Proving Ground (GPG) program assessed five different photovoltaic (PV) systems in Indiana's diffuse, four-season climate. The five systems, installed at the Major General Emmett J. Bean Federal Center in Indianapolis, are comprised of a single commercial-scale, 2-megawatt (MW), high-efficiency crystalline PV system plus four smaller *laboratory* systems, each roughly 3 kilowatts (kW) in size and utilizing a different photovoltaic material, construction, or design. The GPG study of the commercial-scale system investigated the practicality of on-site, large-scale renewable energy generation on a Federal property in a Midwestern climate. The GPG *laboratory* systems study evaluated whether claims that any of the four technologies—medium-efficiency crystalline, thin-film copper-indium-gallium-selenide (CIGS) cylindrical, thin-film cadmium telluride panel, or building integrated thin-film amorphous silicon—offered a clear performance advantage under cool, cloudy skies.

### A. HIGH-EFFICIENCY PV PROVIDES PRACTICAL SOLUTION TO ON-SITE ENERGY GENERATION

- Large PV system generated 7.9% of all energy used at the Bean Federal Center.
- Reduction of greenhouse gas (GHG) emissions was equivalent to taking approximately 434 cars off the road.
- Simple payback of 19 years (within the technology's demonstrated lifespan).

### B. PARITY AMONG *LABORATORY* SYSTEMS UNDER CLOUDY SKIES

- Performance differences between the three thin-film and two crystalline PV module technologies under cloudy conditions did not lead to recommendation of one technology over another.
- The thin-film CIGS cylindrical PV technology evaluated produced more energy and more energy per installed watt than the other *laboratory* technologies—this is due to its unique cylindrical design.

### C. SYSTEM MODELING PROVIDES AN ACCURATE PERFORMANCE GUIDE

- Today's system modeling tools produce accurate simulation results for both sunny and cloudy climates.
- All systems performed within reasonable expectations based on nameplate ratings.

### D. PRICE SHOULD DRIVE PV SYSTEM SELECTION

- Parity among the *laboratory* systems suggests that commodity price (cost per watt), warranty and manufacturer reliability should drive PV system selection.
- If rooftop space is a concern and renewable energy production an objective, efficiency per square foot should also be considered.

# II. Introduction

### A. PROBLEM STATEMENT

The U.S. General Services Administration (GSA) Green Proving Ground (GPG) program leverages the agency's real estate portfolio to evaluate innovative sustainable building technologies. With collaboration from the Department of Energy's National Laboratories, projects within the GPG program provide enhanced testing, monitoring, and evaluation so that results support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry.

This report summarizes results from the assessment of photovoltaic (PV) technology at the Major General Emmett J. Bean Federal Center (Bean Federal Center). This GPG technology assessment was designed to answer questions regarding the performance and economics of solar energy technologies deployed in hot summer /cold winter, cloudy climates, such as the Midwest of the United States. Well-managed case studies of PV system performance and economics have generally been lacking for this climate.

This GPG assessment was implemented in two parts. The first part of the assessment was developed to answer the question: what is the cost effectiveness of a real-world (fully commercial) PV system in a climate zone typical of the U.S. Midwest. For this purpose, a large 2-megawatt (MW) system was procured and installed at the Bean Federal Center.

The second part of the assessment was designed to answer a more technology-specific question. Manufacturers of some PV technologies have made claims of superior performance (versus competing technologies) in cloudy environments. This part of the program utilized four small PV systems – each based on a different, active PV material or collector design - to perform side-by-side exposure testing to identify any inherent advantages offered by one technology over another in the cloudy Midwest climate.

Both studies shared the common goal of generating independent, measured results to assist building managers and procurement specialists in evaluating vendor claims and implementing informed PV purchase decisions.

### B. OPPORTUNITY

GSA's Public Buildings Service (PBS) has jurisdiction, custody or control over 9,683 assets and is responsible for managing an inventory of diverse Federal buildings totaling 374.6 million square feet ($ft^2$) of building stock.

Since the mid 1970s, GSA has sought to identify and deploy appropriate, cost-effective, energy-efficient solutions. More recently, the enactment of executive orders and legislation, including the Energy Policy Act of 2005, the Energy Independence and Security Act of 2007 (EISA), Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management ", and Executive Order 13514 "Federal Leadership in Environmental, Energy, and Economic Performance", have led GSA to establish a leadership role among federal agencies seeking to implement cost effective strategies for meeting the energy efficiency and renewable energy goals in this legislation and policy. Based on the sheer size of the public buildings portfolio, there exists a huge opportunity for potential energy and cost savings.

This GPG demonstration project was hosted by GSA's Great Lakes Region (Region 5), which includes Illinois, Wisconsin, Minnesota, Michigan, Ohio, and Indiana. The Bean Federal Center is located in northeast Indianapolis - Lawrence, Indiana - a short distance outside the I-465 ring. This vast structure contains 1.6 million square feet of federal tenant space on a 52-acre site and is among the Nation's largest federal buildings.

Photovoltaics, the conversion of sunlight directly to electricity, isn't new. The photovoltaic effect was first discovered by French scientist Edmond Becquerel in 1839. Modern PV technology was born in 1954 at Bell Labs with the production of the first silicon PV cell. Early silicon cells first saw application in the Vanguard I space satellite in 1958 and continue to be used for space applications today. However, advances in technology and increases in manufacturing scale have resulted in a steady decrease in PV cost, and a steady increase in PV energy conversion ratio. In addition, after more than 20 years of research and development, thin-film solar cells are beginning to be deployed in significant quantities. Because they use less material to convert sunlight into electricity, thin-film solar cells could potentially provide lower cost electricity than crystalline silicon wafer-based solar cells.

This report documents and evaluates the first year of operation of five different PV power systems installed and tested at the Bean Federal Center. The five Bean Federal Center PV systems fall into two categories: one large, high efficiency crystalline silicon (c-Si) PV system ("main" system) and four smaller, thin-film and medium efficiency crystalline silicon PV systems ("laboratory" systems). The *main* and *laboratory* PV systems were installed with different research objectives in mind.

The *main* system (Figure 1) is typical of large, commercial-scale systems (with ratings from hundreds of kilowatts to several megawatts) currently being installed in great numbers on warehouses, big box stores, and other commercial properties throughout the U.S. It utilizes one of the highest efficiency, c-Si PV module types available for terrestrial use.

The potential for using commercial-scale solar energy in the U.S. Midwest and similar climates is large, but many building designers and operators lack experience with PV in this climate. The Bean Federal Center *main* system PV technology assessment program was designed to support designers and building operators through study of actual PV systems comparing various technologies that reveal their real-world performance capabilities and economics.

The *laboratory* systems (Figure 2) include the three leading thin-film PV technologies: amorphous silicon (a-Si), cadmium telluride (CdTe) and copper-indium-gallium-selenide (CIGS). A fourth technology, medium efficiency crystalline silicon, was included to serve as a control for both the advanced thin-film technologies, and as a comparison for the large, high-efficiency crystalline silicon array.

Thin-film technology has been developing rapidly and some manufacturers claim that these technologies offer an inherent advantage in energy production in cloudy climates. The Bean Federal Center *laboratory* system PV technology assessment program was designed to inform designers, building operators and vendors through evaluation of the real-world performance capabilities of thin-film technologies in a cloudy environment.

# III. Technology Tested

### A. TECHNOLOGY DESCRIPTION AND TEST METHODOLOGY– PROGRAM PART 1

Part One of this GPG technology assessment program was the study of energy and economics of a 2-megawatt PV system at the Bean Federal Center. This system is referred to as the *High Efficiency Crystalline PV* system or *main* PV system. The *main* PV system array consists of 6,152 PV modules, each rated at 318 watts. GSA selected PV modules that are among the highest efficiency models available for terrestrial use. Figure 1 shows one section of the *High Efficiency Crystalline PV* system at the Bean Federal Center.

**Figure 1: Section of the *High Efficiency Crystalline (Main) PV* system at the Bean Federal Center**

What determines the efficiency of a PV module? First, the composition of the semiconductor material (crystalline silicon, in this case) defines the basic conversion efficiency possible for the cells within the modules. In this case, the use of high quality silicon cells means that these modules inherently have higher than average conversion efficiencies before other factors are considered. After this, other elements of the design determine the magnitude of any losses that the module incurs during operation. For example, the cells of most crystalline PV modules require metal gridlines on their front surface to channel generated current into the array wiring. Metal gridlines obscure the cell surface beneath them and, in aggregate, reduce the module's conversion efficiency. By contrast, the cells within the *High Efficiency Crystalline PV* modules use a back contact design that requires no metal gridlines on the front surface. This and other advanced design features combine to produce modules with an effective conversion efficiency of 19% (13-14% is typical of most crystalline PV modules). PV module data sheets are included in Appendix E.

For this study of performance, economics and avoided emissions, three types of information are required. First, are the economic parameters associated with the system. These include the purchase price, any financing costs (not applicable in this case), and the cost of all operations, maintenance or replacement parts. For this study, these parameters were made available by careful record keeping during the procurement, installation, and operational phases of the system.

The second component needed for this study is a record of the energy generated by the PV system over time. In evaluating the *High Efficiency Crystalline PV* system, energy production was provided by revenue-grade utility meters installed by the local utility, Indiana Power and Light (IPL). GSA and IPL made the on-line meter records available for the preparation of this report.

The final component needed to conduct the study comes from several institutional parameters associated with the site and the system. These include such parameters as the billing tariff under which GSA purchases electricity for the Bean Federal Center and the incentive tariff the utility pays for the energy produced at the Bean Federal Center. The analysis also makes use of tables of emissions resulting from electricity production compiled by the Energy Information Administration (EIA) for every state each year.

Detailed information describing the above parameters is contained in Appendices A, C and D.

## B. TECHNOLOGY DESCRIPTION AND TEST METHODOLOGY– PROGRAM PART 2

Part 2 of this GPG technology assessment program was designed to answer a technology-specific question: among the various PV technologies, are there any that demonstrate an inherent advantage when operating in a climate with cold winters, hot summers and a majority of cloudy days, such as the U.S. Midwest? To answer this question, four 3-kW laboratory-scale (*laboratory*) PV systems were procured and installed side-by-side on the southeast portion of the roof of the Bean Federal Center. The four different PV technologies selected for this study include: medium efficiency crystalline silicon (c-Si) flat plate modules, amorphous silicon (a-Si) laminates, copper-indium-gallium-selenide (CIGS) cylindrical tubes, and cadmium telluride (CdTe) flat plate modules. Figure 2 shows the four *laboratory* PV systems installed on the Bean Federal Center.

The first *laboratory system*, *Medium Efficiency Crystalline* PV, contains the most common type of PV modules in use today – crystalline (or poly-crystalline) PV. These modules utilize poly-crystalline cells produced by a string ribbon process that yield performance in the 13% range. For this study, the *Medium Efficiency Crystalline* PV system served as a control against which less common, thin-film PV technologies were compared. The *Medium Efficiency Crystalline* PV array is mounted in a single south-facing row with a tilt angle of approximately 10 degrees. Figure 3 shows the *Medium Efficiency Crystalline* PV array.

**Figure 2: Four *Laboratory* PV systems at the Bean Federal Center**

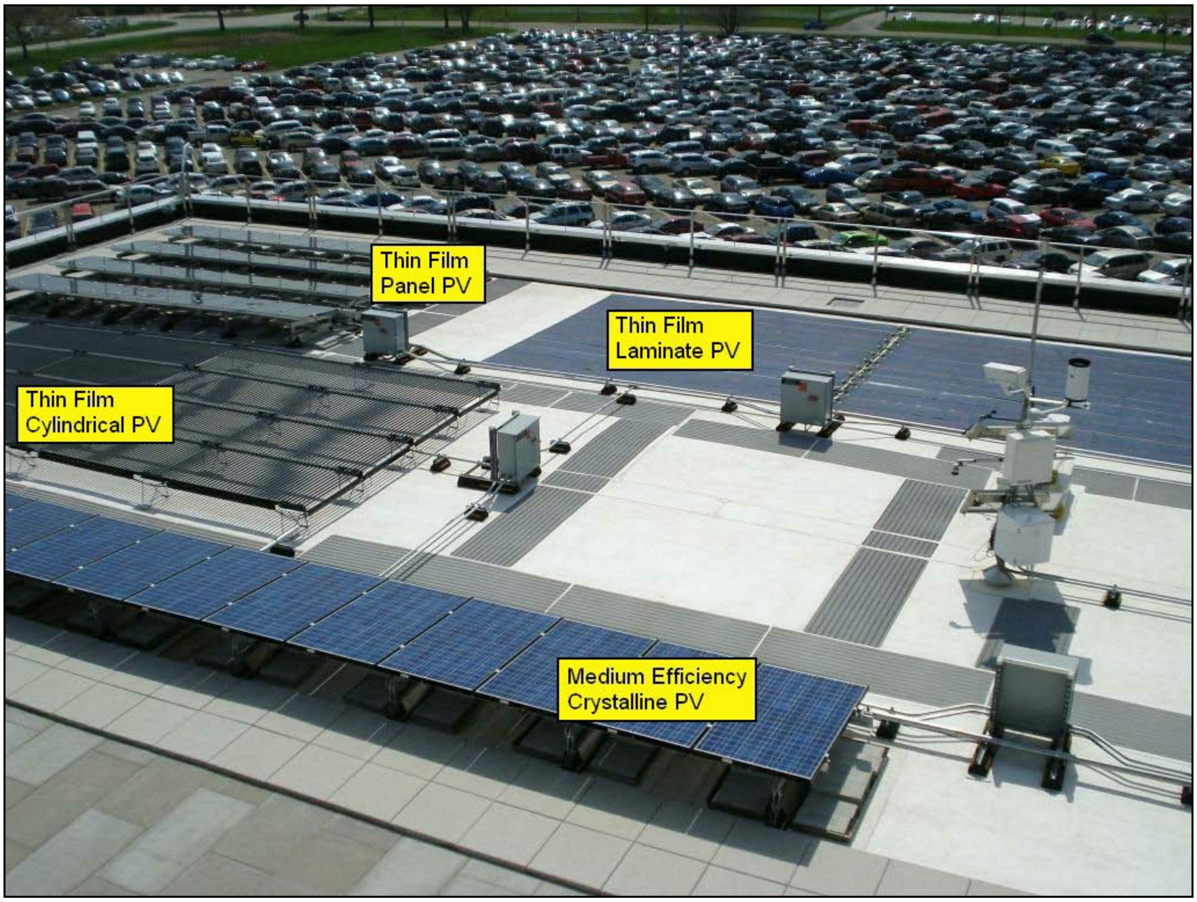



**Figure 3: *Medium Efficiency Crystalline* PV Array, *Laboratory* PV systems, Bean Federal Center**

The module type used in the second *laboratory* system, *Thin-film CIGS Cylindrical* PV utilizes copper-indium-gallium-selenide (CIGS) as the active PV material. CIGS is more efficient and stable than other thin-film materials (e.g. cadmium telluride or amorphous silicon) but is highly sensitive to moisture ingress, so reliability is a concern over the expected 25-year module lifetime. The shape of this module is unique in that it is not planar (either flat plate or laminate). The active material is deposited within a cylindrical tube so that it presents a curved surface facing the sky while also enabling this module to collect sunlight that is reflected from the roof's surface beneath the array. The *Thin-film CIGS Cylindrical* PV modules are mounted on light-weight racks parallel to the roof's surface with the long-axis of the cylindrical tubes oriented in the north-south axis. Figure 4 shows the entire Thin-film CIGS Cylindrical PV array. Figure 5 shows a close-up view of the cylindrical tubes that comprise this array.

**Figure 4: *Thin-film CIGS Cylindrical* PV Array, *Laboratory* PV systems, Bean Federal Center**

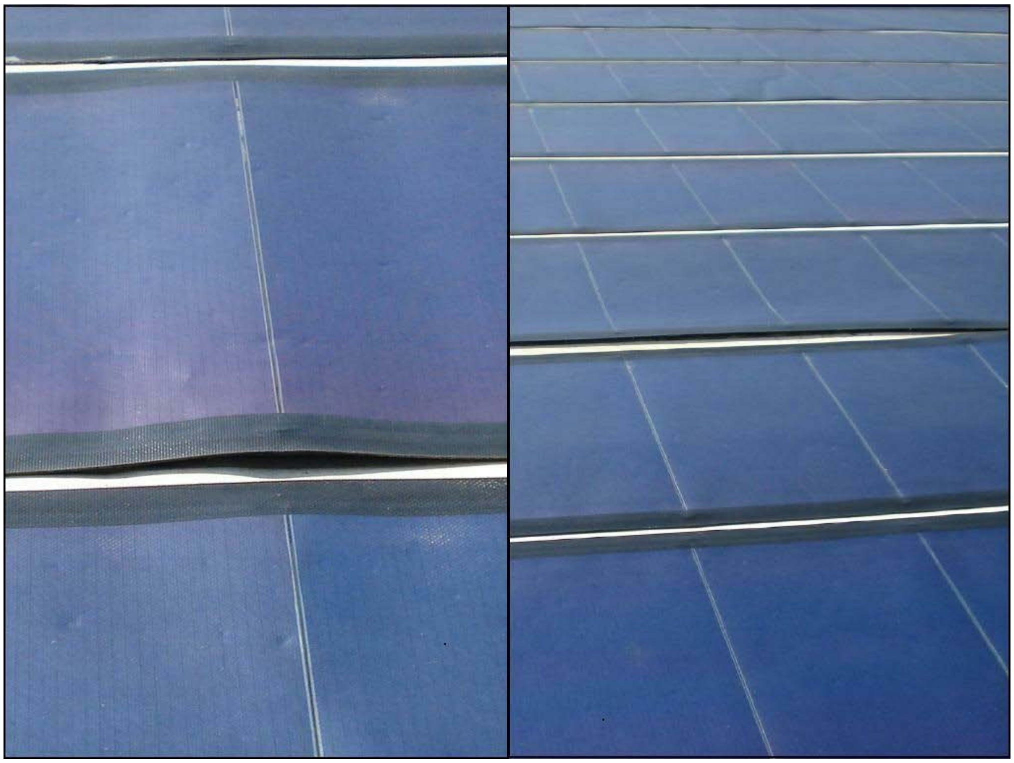
The third *laboratory system*, *Thin-film a-Si Laminate* PV, utilizes amorphous silicon (a-Si) as the active material. Amorphous silicon has the longest production record of the three thin-film materials evaluated. It is susceptible to an initial, irreversible degradation period following its first exposure to the sun. The *Thin-film a-Si Laminate* PV modules are light and flexible, contain no glass, and are adhered directly to the surface of the membrane roof. The orientation of this array is horizontal, mounted flush to the roof's surface. Figure 6 shows the *Thin-film a-Si Laminate* array.

**Figure 5: Close-up view of *Thin-film CIGS Cylindrical* PV Modules, *Laboratory* PV systems, Bean Federal Center**

**Figure 6: *Thin-film a-SI Laminate* PV Array, *Laboratory* PV systems, Bean Federal Center**

After one year of service, the *Thin-film a-Si Laminate* array shows many minor ripples and bubbles that indicate the adhesion between laminate and roof membrane has gaps. Figure 7 shows some of these adhesion failures in closer detail.  Despite these gaps, adhesion of all laminates to the roof membrane is secure.

**Figure 7: Close-up view of *Thin-film a-Si Laminate* PV Array, *Laboratory* PV systems, Bean Federal Center**



The fourth *laboratory system*, *Thin-film CdTe Panel* PV, uses cadmium telluride (CdTe) as the active PV material.  CdTe is less efficient than CIGS but more efficient than a-Si.  Like CIGS, reliability and stability are the long-term concerns for CdTe PV modules.  The *Thin-film CdTe Panel* PV array faces south at an approximate tilt angle of 10 degrees. Figure 8 shows the *Thin-film CdTe Panel* array.

Dedicated ac and dc power meters were installed to record the production of each *laboratory* system. Each *laboratory* array (except the *Thin-film CIGS Cylindrical* PV) was also instrumented with a pyranometer (solar radiation measurement device) mounted in the plane of the PV modules and a temperature sensing thermocouple mounted on the back of select modules. This combination of instrumentation enables the *laboratory* systems to be compared based on overall energy production and enables comparative determination of each array's conversion efficiency under clear or cloudy conditions during the period of study.

**Figure 8: *Thin-film CdTe Panel* PV Array, *Laboratory* PV systems, Bean Federal Center**

# IV. Methodology

GSA coordinated with engineers and scientists from the U.S. Department of Energy (DOE), Sandia National Laboratories (SNL), and New Mexico State University (NMSU) in the design of the Bean Federal Center PV system studies.

To provide accurate production and performance data for the two studies (*main* and *laboratory* systems), a dedicated, laboratory-grade data acquisition system (DAS) was built and installed by New Mexico State University. This DAS monitors research parameters such as PV module temperature and plane of array irradiance (sunlight intensity) utilizing spectrally matched reference cells that are beyond the requirements of ordinary PV system monitoring. Supplementing the DAS instruments are revenue meters installed by the local utility, Indiana Power and Light (IPL) that record the total ac energy production of the PV systems for billing/revenue purposes.

The *main* PV system study utilizes both the DAS instruments and revenue meter data to achieve the following research objectives:

- record system energy production,
- calculate system efficiency per installed watt and per unit area,
- validate pre-installation performance projections,
- determine fraction of on-site energy generation versus total site load,
- calculate system payback period (in years),
- calculate avoided GHG emissions.

The *laboratory* PV systems study focuses on performance comparisons among the four PV systems under test. The *laboratory* PV systems study utilized DAS instruments to monitor the irradiance in the plane of each PV array and the operating temperature of each module type (with the exception of the cylindrical PV for which the temperature of the PV material cannot be directly measured). The research objectives associated with the *laboratory* PV systems were the following:

- side-by-side comparison of energy production for the four different PV technologies under test,
- comparison of clear-sky and cloudy-sky performance efficiencies among the four systems,
- calculation of overall efficiency of each system per installed watt and per unit area of roof covered.

# V. Results

### A. RESULTS OF PROGRAM PART 1 – ENERGY AND ECONOMICS OF A 2-MW PV SYSTEM

The objectives of studying the *main* PV system centered on energy production, economics, and emissions reductions. Table 1 presents the key energy production and economic results for the *main* PV system. These are compared to values predicted prior to installation.

**Table 1: Bean Federal Center *Main* PV System Annual Results**

| Bean Federal Center *Main* PV System | Predicted | Actual | Comments |
|---|---|---|---|
| Electric Energy Production | 2,289,280 [1] kWh | 2,384,138 kWh | Actual production exceeded predicted value by 4.1% |
| Percentage of Building Load Met by the *Main* PV system | 6.82 % | 7.90 % | Percentage of site load met by PV exceeded predictions. Note: 2011 site load was 10% less than 2008 reference year due to re-roofing and other improvements |
| Annual Revenue Value of Energy Produced | | $524,510 | Revenue is the sum of avoided energy purchase and IPL renewable energy incentive |
| Simple Payback | 19.1 years | 19 years[2] | Good agreement between Actual and Predicted values |

The large *main* PV system produced slightly more annual energy than predicted by pre-installation modeling. Accurate modeling like this is representative of what energy engineers and building energy managers can expect from the projections of qualified PV system installers and professionals. The percentage of the Bean Federal Center's site load met by this PV generation was also larger than initially predicted. In this case, additional improvements to the Bean Federal Center, including solar hot water, improved insulation, and replacement of much of the building's roof, combined to reduce the 2011 site load by 10% from its 2008 value (on which predictions were based).

Two different components combine to make up the revenue value of the energy generated on-site at the Bean Federal Center. First is the avoided cost of the energy not purchased as a result of on-site generation. Each kilowatthour (kWh) of on-site generation avoids the necessity of purchasing this energy from the utility at the price of 2 cents/kWh. In addition, IPL offers a 20 cent/kWh incentive for on-site generation projects

[1] Figure supplied by GSA in the 30-day filing document between GSA and IPL, May 13, 2011. See Appendix A.

[2] The IPL Renewable Energy Production (REP) rate will expire in ten years. Its status after this is not determined. Payback calculation is based on renewal of the rate.

like this. Therefore, the revenue value of energy generated on-site at the Bean Federal Center is $0.22/kWh. Over the course of the year, the total revenue value of all energy produced by the *main* PV system was $524,510. Based on this figure, it will require a total of 19 years to reach a simple payback value equal to the initial purchase price of the PV system. The 19-year payback period is within the 25-year power warranty period that comes with these PV modules (though not the inverters). In general, payback determination is a function of several factors, including purchase price, financing costs, purchase incentives or rebates, revenue value of annual energy production (climate driven), and cost of maintenance, repairs, and replacements.

Determining GHG reductions was one of the objectives of this program. In Indiana, over 90% of in-state electricity generation is derived from the burning of coal. For this reason, on-site generation at the Bean Federal Center via the *main* PV system eliminates a large amount of greenhouse gas production (compared with states that utilize a higher fraction of hydro or nuclear power). Table 2 presents the avoided emissions resulting from on-site PV generation of electricity at the Bean Federal Center. The electricity generation by the *main* PV system at the Bean Federal Center (rather than by coal) reduced $CO_2$ emissions by 2,441 tons. This is equivalent to taking approximately 434 cars off the road. [3]

**Table 2: Bean Federal Center *Main* PV System Estimated Avoided Emissions**

| Emission | Reference Value for Indiana | Annual Emissions Reduction due to PV |
|---|---|---|
| $CO_2$ | 2,048 lbs/MWh | 2,441.3 tons |
| $SO_x$ | 6.8 lbs/MWh | 8.1 tons |
| $NO_x$ | 2.1 lbs/MWh | 2.5 tons |

## B. RESULTS OF PROGRAM PART 2 – ENERGY AND ECONOMICS OF LABORATORY SYSTEMS

The objectives of studying the *laboratory* PV systems centered around energy comparisons between different technologies with emphasis on determining which, if any, offered performance favorability in the cloudy Midwest climate. For this study, the *Medium Efficiency Crystalline* PV system served as a control against which less common, thin-film PV technologies were compared.

Table 3 presents the annual energy produced by each of the four *laboratory* PV systems. Over the course of the 12-month study period, the *laboratory* system that produced the most energy was the *Thin-film CIGS Cylindrical* PV system. This was closely followed by the *Medium Efficiency Crystalline Silicon* PV system, next the *Thin-film CdTe Panel* PV system, and finally by the *Thin-film a-Si Laminate* PV system.

These results are summarized in Table 3, but require careful interpretation to differentiate between the production capability of the module technology and the contribution of the module's system design and

[3 ] http://www.epa.gov/cleanenergy/energy-resources/refs.html

installation. Besides a PV module's conversion efficiency, solar geometry plays a big role in determining how much energy a given array will produce. Production is a strong function of the incidence angle between the sun's rays and the module's surface. For any planar array, the greatest energy production occurs when solar rays arrive perpendicular - or at zero incidence angle - to the array surface (this is known as "normal" incidence). Energy production decreases as the sun moves away from perpendicular to higher incidence angles. This is why most arrays are oriented to face South at a *tilt* angle that maximizes the amount of time the sun is near normal incidence. For this reason, it was expected that the horizontally mounted, *Thin-film a-Si Laminate* PV system would produce the least energy of the four systems, since its orientation results in greatest average solar incidence angles over the course of a year (in fact, this array conforms to the roof's surface which has a slight pitch of a few degrees to the north to promote drainage, further increasing incidence angles over a perfectly horizontal array). In contrast, the unique design of the *Thin-film CIGS Cylindrical* PV modules allows maximum exposure of its active material to the sun throughout most of the day resulting in greater energy production than any of the flat plate technologies.

**Table 3: Bean Federal Center *Laboratory* PV Systems Annual Energy Comparison**

| Energy Total | *Medium Efficiency Crystalline Silicon* | *Thin-film CIGS Cylindrical* | *Thin-film a-Si Laminate* | *Thin-film CdTe Panel* |
|---|---|---|---|---|
| May 1, 2011 through April 30, 2012 | 3,855.6 kWh | 4,001.2 kWh | 3,462.2 kWh | 3,572.3 kWh |

Figure 9, below, shows the effects of solar incidence angle on performance graphically. Figure 9 presents the useful parameter, final PV system yield, $Y_f$, which is the net energy output of each system divided by the nameplate dc power of its array. The system yield parameter normalizes the energy produced by different systems with respect to the system rating. It is a convenient way to compare the energy produced by systems of different sizes. Note that in general, the highest peak yield is realized in June when the average incidence angles to each array are the lowest, while the lowest yield is achieved in December when the average incidence angles are the highest.

For these typical sunny days, the *Thin-film CIGS Cylindrical* array began producing energy sooner in the morning and continued later into the afternoon than the tilted or horizontal planar arrays. And, though it produced less energy at mid-day than one or more of the planar arrays, this effect integrated over the course of the year resulted in the *Thin-film CIGS Cylindrical* PV system producing the most energy of the four *laboratory* systems under test.

Solar geometry is not a determining factor when comparing the two south-facing, tilted arrays, *Medium Efficiency Crystalline Silicon* and *Thin-film CdTe Panel PV*, to each other. Both systems received identical solar radiation throughout the year and differences in their energy production are the result of performance differences of their active PV materials. In this case, the *Medium Efficiency Crystalline Silicon* PV outperformed the *Thin-film Panel PV*.

Representative clear and cloudy days were selected throughout the year to illustrate relative performance of the four *laboratory* PV system technologies under these conditions. Note that "clear" and "cloudy" are not rigorous definitions. Cloudless days were determined through study of the recorded irradiance data and selected clear (cloudless) days were chosen. Since the term “cloudy” is not precise and can describe sky conditions with clouds of various physical extent and opacity, a definition of “cloudy” was adopted. For this report, sample cloudy days were selected that met the requirement that all recorded irradiance readings were one-third or less than equivalent readings recorded on the day of the month with the greatest integrated solar radiation.

Figure 9 shows energy production from each of the four *laboratory* PV systems for typical clear days in March, June, and December. Figure 10 shows similar data for typical cloudy days selected in March, June, and December. Data are again presented as *system yield* in which production is converted to units of kWh/kW of installed PV to normalize out any differences in the actual ratings of the four systems.

**Figure 9: PV System Yield, $Y_f$, Typical Clear Days in March, June, and December, Bean Federal Center *Laboratory* PV Systems**

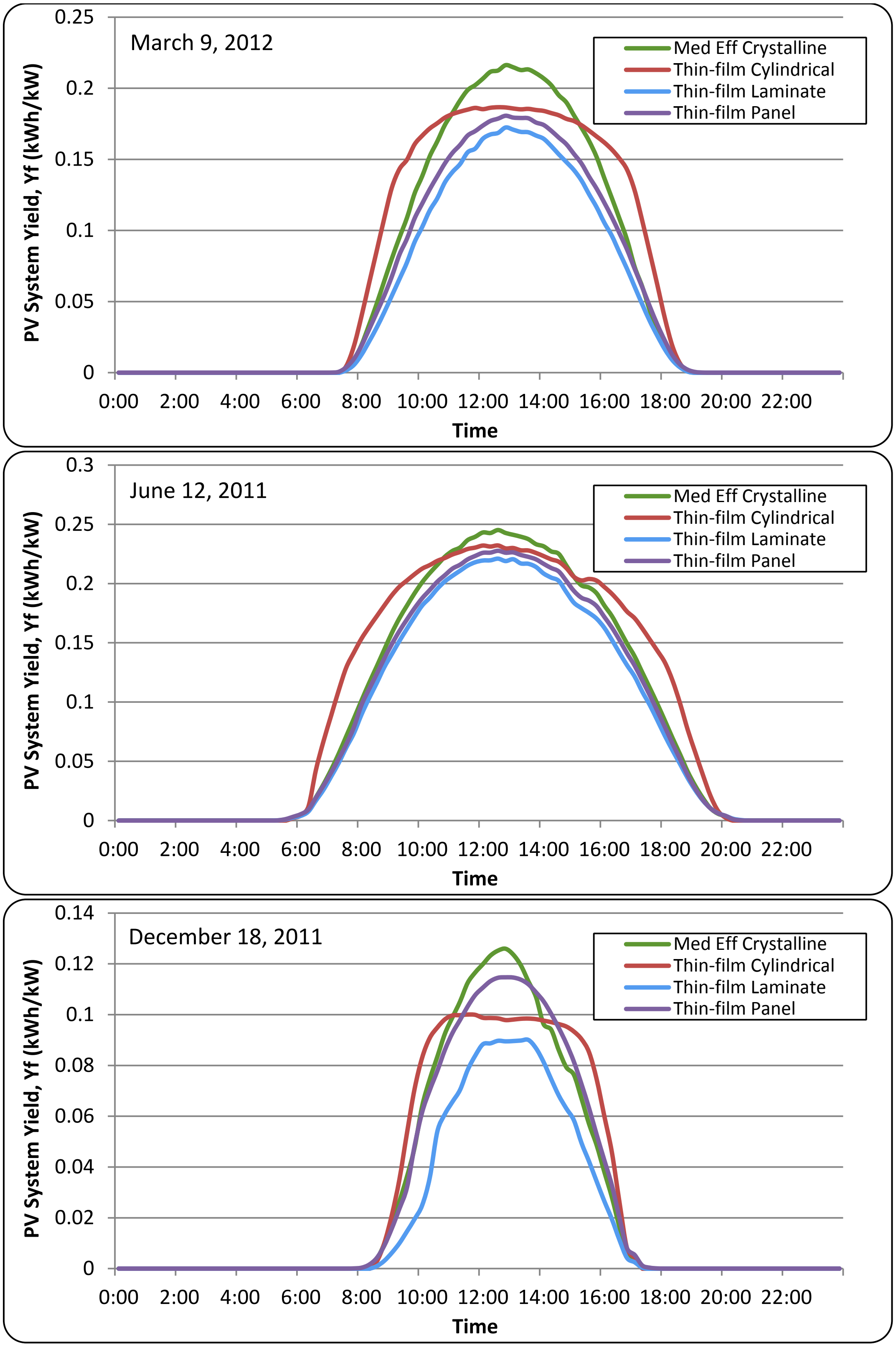
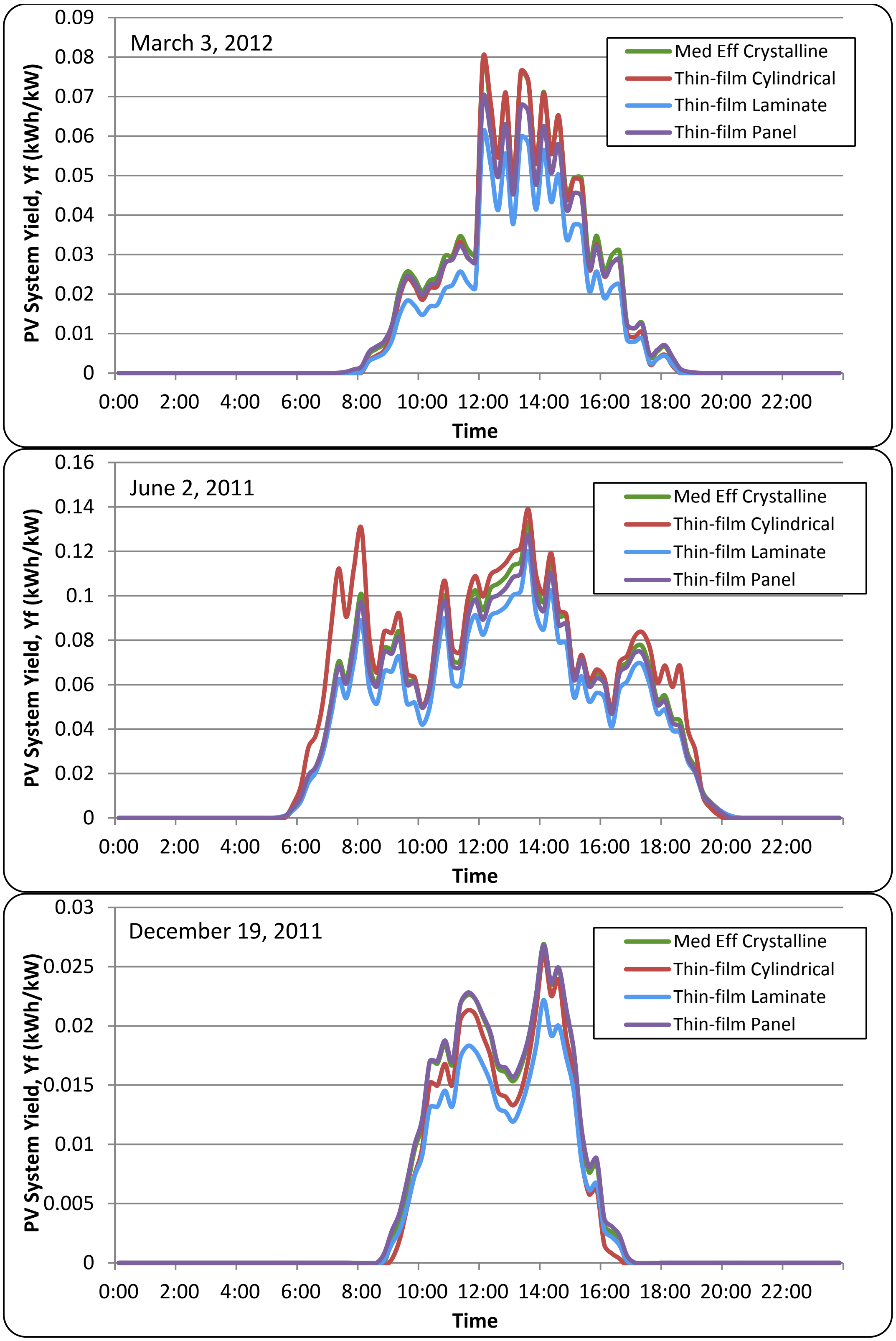


**Figure 10: PV System Yield, $Y_f$, Typical Cloudy Days in March, June, and December, Bean Federal Center *Laboratory* PV Systems**



Data for the three clear days show the effect that the unique shape of the *Thin-film CIGS Cylindrical* PV modules has in enabling this system to respond to the sun sooner in the morning and later into the afternoon. In addition, the tubular modules are the only modules to receive energy from sunlight reflected by the white roof surface below the array. Table 4 presents numerical totals of the daily PV System Yield for the four *laboratory* systems during the three selected clear days. The *Thin-film CIGS Cylindrical* system produced more energy than the other thin-film systems and the *Medium Efficiency Crystalline Silicon* system. For the system with the least production, *Thin-film Laminate* PV, the driving factor for its low system yield is its near-horizontal orientation (flush with the roof) that receives less incident sunlight in the plane of the array than the other systems.

**Table 4: PV System Yield (kWh/kW), Four *Laboratory* PV Systems, Three Typical Clear Days, Bean Federal Center**

| | *Medium Efficiency Crystalline Silicon (kWh/kW)* | *Thin-film CIGS Cylindrical (KWh/kW)* | *Thin-film a-Si Laminate (kWh/kW)* | *Thin-film CdTe Panel (kWh/kW)* |
|---|---|---|---|---|
| **Clear Day (March 9, 2012)** | 5.86 | 6.29 | 4.53 | 5.03 |
| **Clear Day (June 12, 2011)** | 8.37 | 9.31 | 7.50 | 7.86 |
| **Clear Day (December 18, 2011)** | 2.54 | 2.62 | 1.78 | 2.50 |

The effects of solar incidence angle on PV performance are found to be very weak on cloudy days. Clouds scatter the sun's rays so that they arrive at the earth's surface from many angles rather than predominantly from the sun's disc. Of greater importance to the production of PV modules under cloudy conditions is the spectral content of solar energy transmitted through clouds. Clouds do not have a uniform effect on all solar wavelengths and generally attenuate the longer wavelengths of the solar spectrum more than the shorter ones [4]. Because thin-film devices are more responsive to shorter wavelengths (they have what physicists call higher bandgap energy) than standard crystalline silicon, thin-film PV has been purported to offer a potential advantage over crystalline PV under cloudy conditions.

Table 5 presents the numerical totals of the daily PV System Yields for the four *laboratory* systems during the three selected cloudy days. From the data, we see that no single system (thin-film or crystalline silicon) regularly outperformed the others. Whatever spectral-related performance advantages exist for thin-film PV modules under cloudy conditions did not result in additional energy production when integrated over complete days, months, or years.

[4] Song, Miller, Garmire, *Experimental Study of Solar Spectrum Impact on Solar Cells*, Clean Technology 2010, ISBN 978-1-4398-3419-0

**Table 5: PV System Yield (kWh/kW), Four *Laboratory* PV Systems, Three Typical Cloudy Days, Bean Federal Center**

| | *Medium Efficiency Crystalline Silicon (kWh/kW)* | *Thin-film CIGS Cylindrical (KWh/kW)* | *Thin-film a-Si Laminate (kWh/kW)* | *Thin-film CdTe Panel (kWh/kW)* |
|---|---|---|---|---|
| **Cloudy Day (March 3, 2012)** | 1.39 | 1.33 | 1.05 | 1.29 |
| **Cloudy Day (June 2, 2011)** | 3.85 | 4.31 | 3.37 | 3.72 |
| **Cloudy Day (December 19, 2011)** | 0.46 | 0.41 | 0.37 | 0.47 |

# VI. Summary Findings and Conclusions

### A. OVERALL TECHNOLOGY ASSESSMENT OF THE *MAIN* PV SYSTEM

The large *main* PV system installed at the Bean Federal Center produced results in good agreement with pre-installation modeling. The system generated 2,384,138 kWh in the 12-month study period, 4.8% more energy than modeling suggested. This represented 7.9% of all energy used at the Bean Federal Center and is enough energy to supply the electricity needs for 216 average Indianapolis homes. System modeling tools available to building energy managers and PV system professionals today are adequate to produce accurate simulation results for both sunny and cloudy climates.

On-site energy generation by the *main* PV system offset the purchase of utility generated electricity that is produced in large part by the burning of coal, resulting in avoided GHG emissions equivalent to taking 434 cars off the road.

An incentive tariff offered by Indiana Power and Light enables the *main* PV system to achieve simple payback in approximately 19 years based on current energy prices. However, if the price for conventional fossil energy or the utility's incentive tariff changes, these numbers will need to be adjusted accordingly. Regardless, the system is a practical, on-site energy generation solution.

### B. OVERALL TECHNOLOGY ASSESSMENT OF THE *LABORATORY* PV SYSTEMS

Study of the four *laboratory* PV systems installed at the Bean Federal Center resulted in the finding that small differences in the performance of one product versus another under cloudy conditions do not equate to overall favorability in annual energy production. Annual energy production totals are driven by periods when skies are mostly clear and the greatest amounts of solar energy are available for conversion to electricity.

The one system that outperformed the others did so as a result of its unique shape and construction. The *Thin-film CIGS Cylindrical* PV product produced more energy in the morning and afternoon hours than any of the flat plate systems. This effect, summed over the course of the year, resulted in this system producing more energy and more energy per installed watt than the other products under test. This one-of-a-kind product, however, is no longer marketed at this time.

# VII. Appendices

### A. MAIN SYSTEM PERFORMANCE DATA

### B. *LABORATORY* SYSTEMS PERFORMANCE DATA

### C. INDIANA POWER AND LIGHT RATE HL (HIGH LOAD FACTOR TARIFF)

### D. INDIANA POWER AND LIGHT RATE REP (RENEWABLE ENERGY PRODUCTION TARIFF)

### E. PV MODULE DATA SHEETS

1. *High efficiency crystalline Si Panel PV*
2. *Medium efficiency crystalline Si Panel PV*
3. *Thin-film CIGS Cylindrical PV*
4. *Thin-film a-Si Laminate PV*
5. *Thin-film CdTe Panel PV*

### F. GLOSSARY

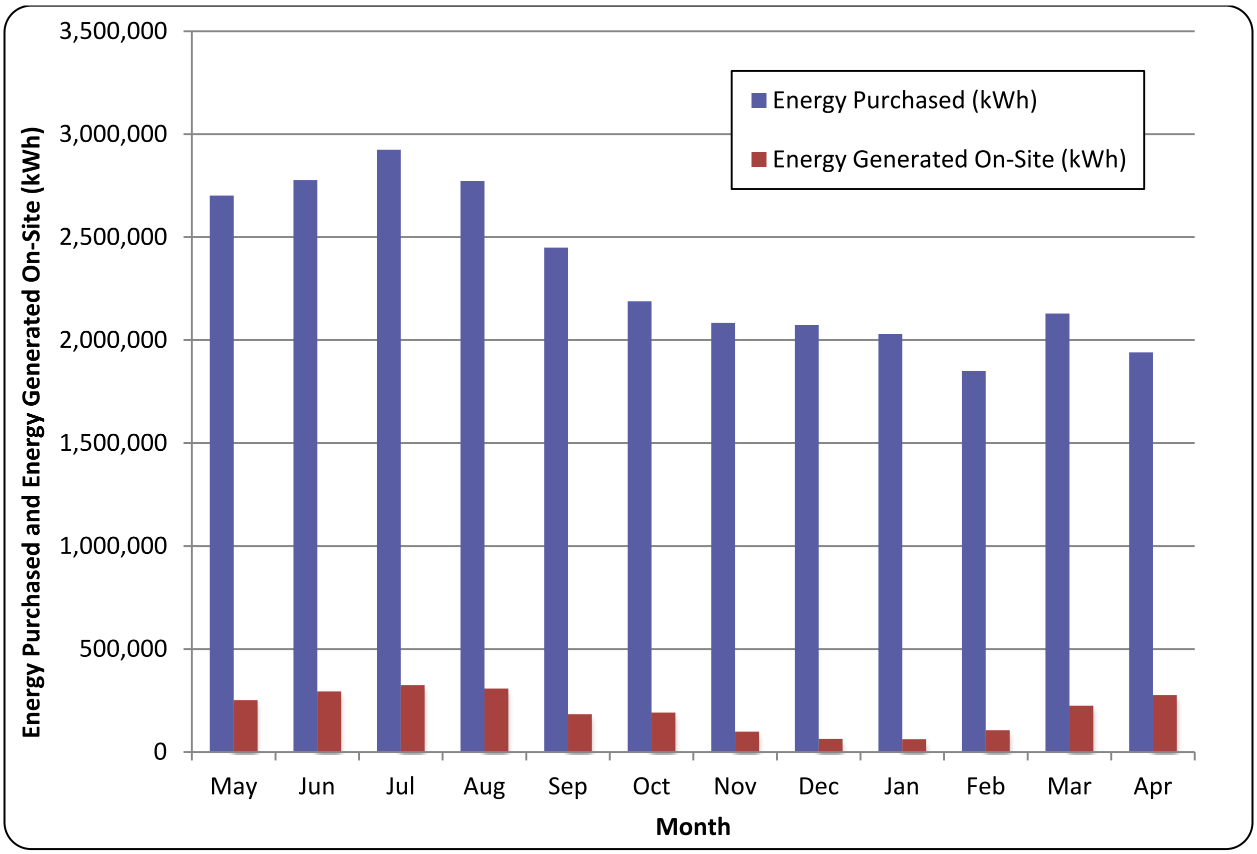
The U.S. Department of Energy Sunshot Initiative maintains a large, comprehensive Solar Energy Glossary on-line. The solar glossary contains definitions for technical terms related to solar power and PV technologies, including terms having to do with electricity, power generation, and concentrating solar power. Use the following link to connect to this glossary for definitions of the terms used in this report or elsewhere: http://www1.eere.energy.gov/solar/sunshot/glossary.html

# APPENDIX A - *MAIN* SYSTEM PERFORMANCE DATA

### ENERGY PURCHASED AND GENERATED ON-SITE BY THE MAIN PV SYSTEM

Figure A1 shows the monthly electrical energy purchased and the monthly PV energy generated at the Bean Federal Center over the 12-month period from May 2011 through April 2012. At no time during the 12-month period of study did on-site generation exceed the site load. Therefore, the total energy used on-site at all times is the sum of the purchased utility energy plus the energy generated on-site by PV. Table A1 presents a tabular summary of the data.

**Figure A1: Bean Federal Center Monthly Energy Purchase and On-site Generation**



Summing all energy purchased plus all on-site generation for the 12-month period results in a total site load for the Bean Federal Center of 30,721,419 kWh. On-site generation is responsible for 7.9% of the total.

**Table A1: Bean Federal Center Monthly Energy Purchased, Energy Generated On-site, and Percentage of Load Met by On-site Generation**

| Month | *Energy Purchased (kWh)* | *Energy Generated On-site (kWh)* | *% of Load Produced by On-site Generation* |
|---|---|---|---|
| **May** | 2,702,612 | 251,430 | 8.5% |
| **Jun** | 2,776,771 | 293,991 | 9.6% |
| **Jul** | 2,924,824 | 324,487 | 10.0% |
| **Aug** | 2,772,167 | 307,915 | 10.0% |
| **Sep** | 2,449,749 | 183,077 | 7.0% |
| **Oct** | 2,188,700 | 191,447 | 8.0% |
| **Nov** | 2,084,471 | 98,723 | 4.5% |
| **Dec** | 2,072,961 | 63,861 | 3.0% |
| **Jan** | 2,029,098 | 62,049 | 3.0% |
| **Feb** | 1,850,505 | 105,646 | 5.4% |
| **Mar** | 2,129,581 | 224,528 | 9.5% |
| **Apr** | 1,940,143 | 276,983 | 12.5% |
| | | | |
| **Total** | 27,921,582 | 2,384,137 | 7.9% |

### SYSTEM COST, O&M COST, AND REVENUE FROM ON-SITE GENERATION BY THE *MAIN* PV SYSTEM

The price paid for the 2-MW *High Efficiency Crystalline (main) PV System* was $8,700,000. This equates to $4.45/W dc installed. In summer 2012, GSA awarded a contract to a third-party engineering firm for annual operation and maintenance (O&M) of the PV systems at the Bean Federal Center worth $25,000 per year.

Two components must be included to calculate the revenue value of the energy generated on-site at the Bean Federal Center. One is the avoided cost of the energy produced on-site. The Bean Federal Center pays for energy under IPL tariff HL (*HIGH LOAD FACTOR - PRIMARY DISTRIBUTION, SUB-TRANSMISSION AND TRANSMISSION VOLTAGES*). Tariff HL (Appendix C) specifies that the monthly cost of utility service will be the sum of some small service charges (e.g. customer charge, fuel cost adjustment, and environmental compliance cost recovery) plus a charge for the energy (kWh) used plus a charge for maximum demand (kW) assessed for the month. The energy charge is 2 cents for each kilowatt-hour purchased. The demand charge is determined from a formula based on a multiplier times the first 4 MW of demand plus a second multiplier times the magnitude of demand over 4 MW. The way the tariff is implemented, on-site generation does not reduce demand charges. So, each kWh of on-site generation represents a total of 2 cents of avoided cost to GSA.

The second revenue component of on-site generation derives from the compensation IPL pays for this energy. The IPL REP (*RENEWABLE ENERGY PRODUCTION)* tariff (Appendix D) specifies that IPL will compensate the Bean Federal Center at a rate of 20 cents per kWh for all on-site generation. Therefore, based on avoided cost and compensation from the IPL REP rate, the value of on-site energy produced is equal to $0.22/kWh. Table A2 summarizes the economic results associated with the main PV system at the Bean Federal Center PV systems. Some of these results were obtained using the software program Building Life Cycle Cost, BLCC 5.3-11, developed by the National Institute of Standards for use by the Federal Energy Management Program of the Department of Energy.

**Table A2: Summary of Economic Results for *Main* PV System at Bean Federal Center**

| *Bean Federal Center Main PV System Economics* | |
|---|---|
| PV System Size | 2 MW |
| Annual Energy Produced | 2,384,138 kWh |
| | |
| PV System Cost | $8,700,000 |
| Annual O&M Cost | $25,000 |
| Annual Revenue Value of Energy Produced On-site | $524,510 |
| | |
| Simple Payback | Year 19 |
| Discounted Payback | Not Reached |

### AVOIDED EMISSIONS ASSOCIATED WITH ON-SITE GENERATION BY THE *MAIN* PV SYSTEM

In Indiana, over 90% of in-state electricity generation is derived from the burning of coal. Indiana ranks 5$^{th}$ among states in $CO_2$ emissions and 4$^{th}$ in both $SO_x$ and $NO_2$ emissions. The DOE's Energy Information Administration (EIA) produces annual tables of energy generation and emissions production for each state. The EIA state historical tables for Indiana 2010 generation and emissions were used to calculate the numbers presented in Table A3 for emissions reduction associated with the PV systems installed at the Bean Federal Center.

**Table A3: Annual Avoided Emissions Associated with the *Main* PV System at Bean Federal Center**

| *Emission* | *Reference Value for Indiana (Calendar Year 2010)* | *Annual Avoided Emissions Associated with the Main PV System* |
|---|---|---|
| $CO_2$ | 2,048 lbs/MWh | 2,441.3 tons |
| $SO_x$ | 6.8 lbs/MWh | 8.1 tons |
| $NO_2$ | 2.1 lbs/MWh | 2.5 tons |

# APPENDIX B - *LABORATORY* SYSTEM PERFORMANCE DATA

## PHYSICAL PARAMETERS AND SPECIFICATIONS FOR THE FOUR *LABORATORY* PV TECHNOLOGIES

The four *laboratory* PV technologies represent different designs and utilize different active materials. Two of the systems are of conventional design with either front cover glass and metal frames or double glass laminate. One is a flexible laminate that contains no glass and one uses modules composed of glass tubes resembling fluorescent light bulbs. Table B1 lists some of the important physical parameters for the modules and the complete arrays of the four *laboratory* systems.

**Table B1: Physical Parameters for the Four *Laboratory* PV Technologies**

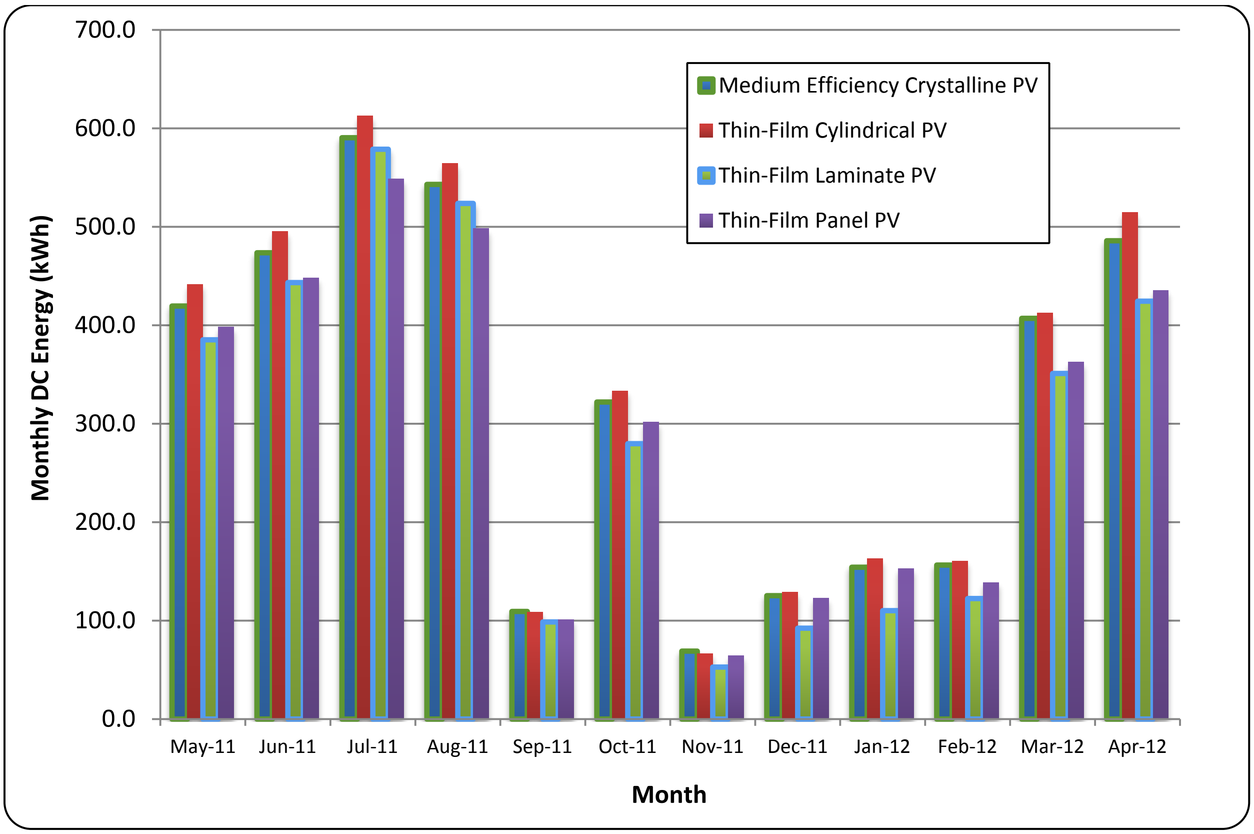
| | | *Medium Efficiency Crystalline Si PV* | *Thin-film CIGS Cylindrical PV* | *Thin-film a-Si Laminate PV* | *Thin-film CdTe Panel PV* |
|---|---|---|---|---|---|
| MODULE | | | | | |
| | Power (Wdc) | 210 | 191 | 136 | 65 |
| | Length (ft) | 5.4 | 7.5 | 18.0 | 3.9 |
| | Width (ft) | 3.1 | 3.6 | 1.3 | 2.9 |
| | Area (sq. ft) | 16.9 | 26.8 | 23.3 | 7.8 |
| | Weight (lb) | 41.0 | 69.0 | 17.0 | 26.5 |
| | Efficiency (%) | 13.4 | 7.7 | 6.3 | 9.0 |
| ARRAY | | | | | |
| | Number of Modules | 15 | 16 | 24 | 48 |
| | Array Rating (W dc) | 3,150 | 3,056 | 3,264 | 3,120 |
| | Array Area as Installed (sq. ft) | 261 | 428 | 612 | 432 |

The weights for the total arrays are not given in Table B1. For two of the systems, the array weight will be very close to the weight of the modules alone. The *Thin-film a-Si Laminate PV* array uses no rack or feet of any kind, and the *Thin-film CIGS Cylindrical PV* array needs only light-weight metal racks that add little to the overall weight of the array. The remaining two systems, *Medium Efficiency Crystalline-Si -PV* and *Thin-film CdTe Panel PV,* each use metal racks and heavy blocks for ballast. Therefore, these arrays weigh considerably more than the modules alone. In practice, the amount of ballast required for an installation is determined by the design wind speed for the region. A typical value is 90 mph, but this is higher in many regions. Also affecting the amount of ballast needed is the desired tilt angle of the array. Modules at higher tilt catch more wind and require more ballast. Both ballasted *laboratory* arrays are installed at a tilt angle of ten degrees.

### ENERGY PRODUCTION BY EACH OF THE FOUR *LABORATORY* PV SYSTEMS

The four *laboratory* PV systems were monitored by a single data acquisition system (DAS). Intermittent instrument power and communications problems prevented DAS data collection during some periods of operation. These problems were resolved in early 2012. Comparisons between systems can still be made, however, because the same number of days of operation was collected for each system. Figure B2 shows the monthly electrical energy recorded for each of the four *laboratory* systems at the Bean Federal Center over the 12-month period from May 2011 through April 2012.

**Figure B2: Monthly Energy Production by the Four *Laboratory* PV Systems**




Economic analysis of the four *laboratory* systems is not included in this report. The four *laboratory* systems were specified and installed only for research into the physical performance of these technologies and thus were not optimized for lowest cost.

# APPENDIX C

# INDIANA POWER AND LIGHT RATE HL (HIGH LOAD FACTOR TARIFF)

RATE HL
(HIGH LOAD FACTOR -
PRIMARY DISTRIBUTION, SUB-TRANSMISSION AND TRANSMISSION VOLTAGES)

AVAILABILITY:
Available for power and lighting service at standard primary distribution, sub-transmission or transmission line voltages. Delivery voltage to be determined by the Company. Minimum contract two thousand (2,000) kilowatts of demand. Not for resale.

CHARACTER OF SERVICE:
Standard Characteristics: Three phase, sixty cycle alternating current, delivered and metered at one point on Customer's premises, at primary distribution voltage (approximately 4160 or 13,200 volts), sub-transmission voltage (approximately 34,500 volts), or transmission voltage (approximately 138,000 or 345,000 volts). All distribution transformers, lines and other equipment on the Customer's side of the point of delivery shall be installed, owned, operated and maintained by the Customer.

Non-Standard Characteristics: If the Customer desires service necessitating transformers (including circuit breakers, supporting structure and supplementary equipment) which do not conform to the standards of the Company as to design, voltage ratio or capacity, or if the Customer desires the exclusive use and/or control of the transformers (whether standard or non-standard), such transformers shall be installed, owned, operated and maintained by the Customer, and the point of delivery in either case shall be at the high voltage side of the transformers.

RATE:
The Customer Charge; plus the sum of the Demand Charge and the Energy Charge adjusted according to the "Power Factor" clause shown hereafter; plus the Demand Side Management Adjustment, the Fuel Cost Adjustment, the Environmental Compliance Cost Recovery Adjustment and the Core and Core Plus Demand-Side Management Adjustment calculated in accordance with Rider No. 3, Rider No. 6, Rider No. 20 and Rider No. 22, respectively.

Customer Charge $310.67

Demand Charge

For service at primary distribution voltage (4160 or 13,200 volts)

| | | |
|---|---|---|
| First | 4000 KW of billing demand per month @ | $11.11 net per KW |
| Over | 4000 KW of billing demand per month @ | $10.57 net per KW |

For service at sub-transmission voltage (34,500 volts)

| | | |
|---|---|---|
| First | 4000 KW of billing demand per month @ | $10.95 net per KW |
| Over | 4000 KW of billing demand per month @ | $10.60 net per KW |

For service at transmission voltage (138,000 or 345,000 volts)

| | | |
|---|---|---|
| First | 4000 KW of billing demand per month @ | $10.65 net per KW |
| Over | 4000 KW of billing demand per month @ | $ 9.90 net per KW |

Energy Charge

| | |
|---|---|
| For service at primary distribution voltage | 2.07¢ net per KWH |
| For service at sub-transmission voltage | 1.99¢ net per KWH |
| For service at transmission voltage | 1.99¢ net per KWH |

Second step of two step increase. Effective March 30, 2010

RATE HL (Continued)

DETERMINATION OF BILLING DEMAND:
The billing demand shall be the average of the three (3) highest fifteen (15) minute interval demands, expressed in kilowatts, established by the Customer during the billing month under consideration, but not less than seventy-five percent (75%) of the highest billing demand that has been established in any of the immediately preceding eleven (11) months, and in no case less than two thousand (2,000) kilowatts.

POWER FACTOR:
The Customer's bill will be adjusted by multiplying the sum of the demand and energy charges by the multiplier set out in the table below whenever the average monthly power factor of his operation varies from eighty-five percent (85%) lagging, as determined by suitable instruments connected at the point where the energy and the demand are measured for billing purposes. In determining the average power factor for the month, no credit will be given for leading power factor. Any equipment installed to control or to correct the power factor shall be of such design, and it shall be so controlled and operated at all times, that its use will not create any undesirable operating characteristics (including voltage rise) in the supply circuits, beyond the limits of good practice.

| POWER FACTOR | MULTI-PLIER | POWER FACTOR | MULTI-PLIER | POWER FACTOR | MULTI-PLIER | POWER FACTOR | MULTI-PLIER |
|---|---|---|---|---|---|---|---|
| 1.00 | .951 | .87 | .9919 | .74 | 1.0563 | .61 | 1.1661 |
| .99 | .9535 | .86 | .9958 | .73 | 1.0627 | .60 | 1.1785 |
| .98 | .9562 | .85 | 1.0000 | .72 | 1.0694 | .59 | 1.1897 |
| .97 | .9590 | .84 | 1.0041 | .71 | 1.0764 | .58 | 1.2025 |
| .96 | .9618 | .83 | 1.0085 | .70 | 1.0835 | .57 | 1.2159 |
| .95 | .965 | .82 | 1.0131 | .69 | 1.0913 | .56 | 1.2300 |
| .94 | .9677 | .81 | 1.0178 | .68 | 1.0992 | .55 | 1.2455 |
| .93 | .9709 | .80 | 1.0230 | .67 | 1.1075 | .54 | 1.2607 |
| .92 | .9741 | .79 | 1.0277 | .66 | 1.1161 | .53 | 1.2773 |
| .91 | .9774 | .78 | 1.0330 | .65 | 1.1255 | .52 | 1.2950 |
| .90 | .981 | .77 | 1.0386 | .64 | 1.1347 | .51 | 1.3136 |
| .89 | .9844 | .76 | 1.0442 | .63 | 1.1447 | .50 | 1.3335 |
| .88 | .9881 | .75 | 1.0500 | .62 | 1.1551 | | |

MINIMUM CHARGE PER MONTH:
The Demand Charge to be in no case for less than two thousand (2,000) kilowatts.

STANDARD CONTRACT RIDERS APPLICABLE:

| | |
|---|---|
| No. 1 | see Page 150 |
| No. 3 | see Page 153 |
| No. 4 | see Page 154 |
| No. 6 | see Page 157 |
| No. 8 | see Page 160 |
| No. 9 | see Page 161 |
| No. 14 | see Page 166 |
| No. 15 | see Page 171 |
| No. 16 | see Page 172 |
| No. 17 | see Page 175 |
| No. 18 | see Page 178 |
| No. 20 | see Page 179.2 |
| No. 21 | see Page 179.3 |
| No. 22 | see Page 179.5 |

Second step of two step increase. Effective March 30, 2010

RATE HL (Continued)

PAYMENT:
The above rates and charges are net. If the net bill is not paid within seventeen (17) days after its date of issue, a collection charge will be added in the amount of ten percent (10%) of the first Three Dollars ($3.00) plus three percent (3%) of the excess of Three Dollars ($3.00).

STANDARD TERM:
Five years.

RULES:
Service hereunder shall be subject to the Company's Rules and Regulations for Electric Service, and to the Rules and Standards of Service for the Electrical Public Utilities of Indiana prescribed by the Indiana Utility Regulatory Commission, as the same are now in effect, and as they may be changed from time to time hereafter.

Second step of two step increase.		Effective July 1, 1996

## APPENDIX D

## INDIANA POWER AND LIGHT RATE REP (RENEWABLE ENERGY PRODUCTION TARIFF)

RATE REP
RENEWABLE ENERGY PRODUCTION

AVAILABILITY:
Available to any Customer of Indianapolis Power & Light Company (the "Company") that operates within the Company's service territory a Qualifying Renewable Energy Power Production Facility subject to the Company's rules and regulations and, any terms, conditions and restrictions imposed by any valid and applicable law or regulation. This tariff is submitted pursuant to the requirements of the Commission's regulations and shall cease to be effective if such regulations are set aside, withdrawn or for any reason cease to be applicable to the Company. An Existing Qualifying Renewable Energy Power Production Facility is eligible to the benefits of this Rate REP except as otherwise expressly forbidden by law.

DEFINITIONS:

(a) Qualifying Renewable Energy Power Production Facility (the "Facility") means an arrangement of equipment for the production of electricity with capacity no less than 50 kW (20 kW for solar) and no greater than 10 MW. The Facility shall be located at one site and is not the aggregation of more than one site each less than 50 kW (20 kW for solar) and which produces electric power through the use of 100% renewable resources or fuel. Such resources or fuels include:
   a. Solar photovoltaic cells and panels
   b. Wind
   c. Dedicated crops grown for energy production
   d. Organic waste biomass
   e. Biomass will be consistent with the State's definition in IC 8-1-8.8-10.

(b) Purchase means the purchase of electric energy or capacity or both from the Facility by the Company and is also inclusive of all environmental attributes.

(c) Sale means the sale of electric energy or capacity or both by the Facility to the Company and is also inclusive of all environmental attributes.

(d) Environmental Attributes means Renewable Energy Credits ("REC"), carbon credits, greenhouse gas offsets or any other environmental credit, commodity or classification that may be associated with the production of renewable energy from the Facility.

(e) Interconnection Costs means the reasonable costs of connection, switching, metering, transmission, distribution, safety provisions, and administrative costs incurred by the Company directly related to the installation and maintenance of the physical facilities necessary to permit interconnected operations with a Facility, to the extent such costs are in excess of the corresponding costs which the Company would have incurred if it had not engaged in interconnected operations, but instead generated an equivalent amount of electric energy itself or purchased an equivalent amount of electric energy or capacity from other sources. Interconnection Costs do not include any costs included in the calculation of Avoided Costs.

(f) System Emergency means a condition on the Company's system which is liable to result in imminent significant disruption of service to Customers or in substantial deviation from normal service standards or which is imminently liable to endanger life or property.

(g) Commission means the Indiana Utility Regulatory Commission.

(h) FERC means Federal Energy Regulatory Commission.

(i) Peak Period means the time between 6 a.m. and 10 p.m. (April through September) or between 7 a.m. and 11 p.m. (October through March) on all days except Saturdays and Sundays, which daily time period will be subject to change from time to time at the Company's option. This change would occur after no less than ten (10) days notice has been given to all Customers who would be affected, and to the Commission.

(j) Off Peak Period means the time not included in the Peak Period.

Second step of two step increase. Effective March 30, 2010

RATE REP (Continued)

PURCHASE AND SALE:

Purchases and sales shall also be subject to the following general terms and conditions:

a. The Company shall not be obligated to purchase or sell at a time of System Emergency.
b. The Customer shall sell the total production of the Facility to the Company.
c. The Customer shall receive service for their load at the appropriate retail rate from the Company. The applicable rate is not impacted by the Customer's participation in Rate REP.
d. The Company may limit total participation under this Rate REP to 1% of the Company's retail electric kWh sales from the prior calendar year.

INTERCONNECTION CONDITIONS AND COSTS:

(a) The Company, subject to prior compliance by the Facility with all applicable Federal and State laws and regulations, shall make parallel interconnection with the Facility in such a way as to accomplish purchases and sales as described in Sections (b) through (f).

(b) The Facility shall comply with the National Electrical Safety Code, as supplemented, the applicable requirements of 170 IAC 4-4.3, and the Company's rules and regulations for electric service.

(c) Interconnection Costs from the Facility to the Company's distribution or transmission system, including those costs of (d) and (e) below, shall be borne by the Facility. There shall be no obligation on the Company to finance such interconnection.

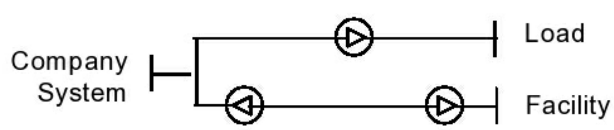
(d) The Facility shall install, operate, and maintain in good order such relays, locks and seals, breakers, automatic synchronizer, and other control and protective apparatus as shall be designated by the Company for operation parallel to its system. The Facility shall bear full responsibility for the installation and safe operation of this equipment.

(e) Breakers capable of isolating the Facility from the Company shall at all times be immediately accessible to the Company. The Company may isolate the Facility at its own discretion if the Company believes continued parallel operation with the Facility creates or contributes to a System Emergency. System Emergencies causing discontinuance of parallel operation are subject to verification by the Commission.

(f) To properly record numbers of kilowatthours for, respectively, purchase and sale, the following configurations shall be the basis for metering.

(1) Where such measurement is appropriate for measurement of energy, the circuit shall include at minimum one monodirectional meter between, at one side, the Company system and, on the other side, the load and a bidirectional meter between, at one side, the Company system and on the other side, the Facility and any load associated with it

(2) Where such measurement is appropriate for measurement of energy, the circuit shall include a monodirectional meter between the on-site load and the Company and, in a series arrangement, two monodirectional meters between the Facility and the Company system:




Second step of two step increase. Effective March 30, 2010

RATE REP (Continued)

(3) The meter measuring purchases by the Company shall be of a design to record time periods, and shall be capable of electronically transmitting instantaneous readings.

(4) Other metering arrangements shall be the subject of negotiations between the Company and the Customer.

RATE REP PURCHASE RATES:

The rate the Company will pay each Customer for energy and capacity purchased from their Facility will be established in advance by written contract with the Company as filed and approved by the Commission and will be based on the RATE REP PURCHASE RATES. the RATE REP PURCHASE RATES may be adjusted by the Company as circumstances warrant through the IURC's 30-day administrative filing process. Unless otherwise agreed, the RATE REP PURCHASE RATES shall be:

(a) Solar
- a. Capacity — None
- b. Energy
  - (a) For Facilities generating 20 kW to 100 kW: 24.0¢ per KWH
  - (b) For Facilities generating more than 100 kW: 20.0¢ per KWH

(b) Wind
- a. Capacity — None
- b. Energy
  - (a) For Facilities generating 50 kW to 100 kW: 14.0¢ per KWH
  - (b) For Facilities generating 100 kW to 1 MW: 10.5¢ per KWH
  - (c) For Facilities generating more than 1 MW: 7.5¢ per KWH

(c) Biomass
- a. Capacity — $6.18 per KW per month
- b. Energy — 8.5¢ per KWH

The Company and the Customer may negotiate terms and a rate for energy or capacity which differs from the filed rates by the Company. The length of any contract shall not exceed ten (10) years. The Company and the Customer may agree to increase or decrease the rate in recognition of the following factors:

(1) The extent to which scheduled outages of the Facility can be usefully coordinated with scheduled outages of the Company's generation facilities;
(2) The relationship of the availability of energy from the Facility to the ability of the Company to avoid costs, particularly as is evidenced by the Company's ability to dispatch the Facility;
(3) The usefulness of the Facility during System Emergencies, including the ability of the Facility to separate its load from its generation;
(4) The impact of tax credits, grants and other financial incentives that when combined with the rate would produce excessive profits for the Facility.
(5) Rates and adjustments prescribed in the contract shall remain in effect notwithstanding changes made to the RATE REP PURCHASE RATES from time to time.

Second step of two step increase. Effective March 30, 2010

RATE REP (Continued)

RATES FOR SALE BY COMPANY:
Back-up Power shall be provided under Standard Contract Rider No. 10. Maintenance Power shall be provided under Standard Contract Rider No. 11. Supplementary Power shall be provided under Standard Contract Rider No. 12. A Customer may not simultaneously qualify for Rate REP, Rate CGS Cogeneration and Small Power Production, Standard Contract Rider No. 9, Net Metering, and Standard Contract Rider No. 8 for off-peak service.

STANDARD CONTRACT RIDERS APPLICABLE:

| | |
|---|---|
| No. 1 | see Page 150 |
| No. 10 | see Page 162 |
| No. 11 | see Page 163 |
| No. 12 | see Page 164 |

## APPENDIX E - PV MODULE DATA SHEETS

### *MAIN* SYSTEM (HIGH EFFICIENCY CRYSTALLINE SI PANEL PV)

SUNPOWER

# E19 / 318 SOLAR PANEL

MAXIMUM EFFICIENCY AND PERFORMANCE

E19 SERIES

**BENEFITS**

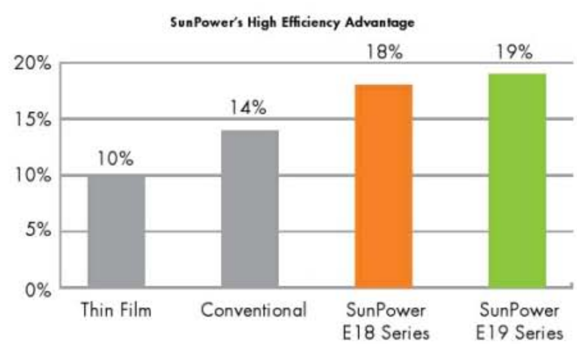
**Highest Efficiency**
SunPower™ Solar Panels are the most efficient photovoltaic panels on the market today.

**More Power**
Our panels produce more power in the same amount of space—up to 50% more than conventional designs and 100% more than thin film solar panels.

**Reduced Installation Cost**
More power per panel means fewer panels per install. This saves both time and money.

**Reliable and Robust Design**
Proven materials, tempered front glass, and a sturdy anodised frame allow panel to operate reliably in multiple mounting configurations.

**The planet's most powerful solar panel.**
The SunPower™ 318 Solar Panel provides today's highest efficiency and performance. Utilising 96 back-contact solar cells, the SunPower 318 delivers a total panel conversion efficiency of 19.5%. The 318 panel's reduced voltage-temperature coefficient, anti-reflective glass and exceptional low-light performance attributes provide outstanding energy delivery per peak power watt.




SPR-318E-WHT-D

# SUNPOWER

# E19 / 318 SOLAR PANEL

MAXIMUM EFFICIENCY AND PERFORMANCE

## Electrical Data

Measured at Standard Test Conditions (STC): Irradiance 1000W/m², AM 1.5, and cell temperature 25° C

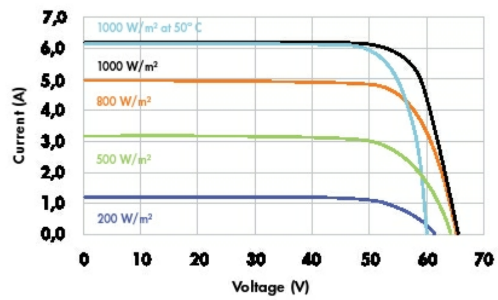
| | | |
|---|---|---|
| Nominal Power (+5/-3%) | $P_{nom}$ | 318 W |
| Efficiency | η | 19.5 % |
| Rated Voltage | $V_{mpp}$ | 54.7 V |
| Rated Current | $I_{mpp}$ | 5.82 A |
| Open Circuit Voltage | $V_{oc}$ | 64.7 V |
| Short Circuit Current | $I_{sc}$ | 6.20 A |
| Maximum System Voltage | IEC | 1000 V |
| Temperature Coefficients | Power (P) | -0.38% / K |
| | Voltage ($V_{oc}$) | -176.6mV / K |
| | Current ($I_{sc}$) | 3.5mA / K |
| NOCT | | 45° C +/-2° C |
| Series Fuse Rating | | 15 A |
| Limiting Reverse Current (3-strings) | $I_R$ | 15.5 A |

## Electrical Data

Measured at Nominal Operating Cell Temperature (NOCT): Irradiance 800W/m², 20° C, wind 1 m/s

| | | |
|---|---|---|
| Nominal Power | $P_{nom}$ | 236 W |
| Rated Voltage | $V_{mpp}$ | 50.4 V |
| Rated Current | $I_{mpp}$ | 4.69 A |
| Open Circuit Voltage | $V_{oc}$ | 60.6 V |
| Short Circuit Current | $I_{sc}$ | 5.02 A |

## I-V Curve




Current/voltage characteristics with dependence on irradiance and module temperature.

## Tested Operating Conditions

| | |
|---|---|
| Temperature | -40° C to +85° C |
| Max load | 550 kg / m² (5400 Pa), front (e.g. snow) w / specified mounting configurations |
| | 245 kg / m² (2400 Pa) front and back - e.g. wind |
| Impact Resistance | Hail – 25 mm at 23 m/s |

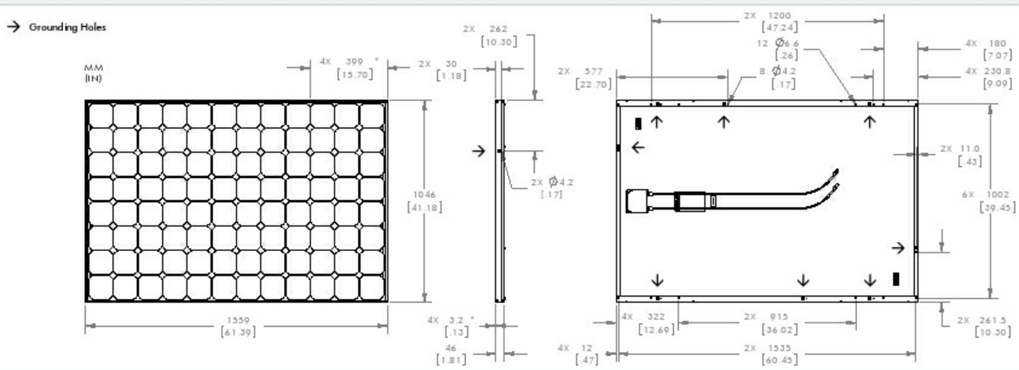
## Warranties and Certifications

| | |
|---|---|
| Warranties | 25 year limited power warranty |
| | 10 year limited product warranty |
| Certifications | IEC 61215 Ed. 2, IEC 61730 (SCII) |

## Mechanical Data

| | | | |
|---|---|---|---|
| Solar Cells | 96 SunPower all-back contact monocrystalline | Output Cables | 1000mm length cables / MultiContact (MC4) connectors |
| Front Glass | High transmission tempered glass with anti-reflective (AR) coating | Frame | Anodised aluminium alloy type 6063 (black) |
| Junction Box | IP-65 rated with 3 bypass diodes | Weight | 18.6 kg |
| | 32 x 155 x 128 (mm) | | |

## Dimensions




**CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.**

Visit sunpowercorp.com for details

sunpowercorp.com
Australia: sunpowercorp.com.au



Document #001-60625 Rev** / A4_EN

## *LABORATORY* SYSTEM (MEDIUM EFFICIENCY CRYSTALLINE SI PANEL PV)

# ES-A SERIES
photovoltaic panels

200, 205 & 210 W

evergreensolar.

Made in the USA

## MORE electricity

Our ES-A series panels have the best power tolerance in the industry (-0/+5 W) and consistently deliver more electricity than competitors in field tests.

**GUARANTEED POWER**[1]
The minimum guaranteed power is the nameplate so you never get less power than you paid for.

**INDEPENDENTLY VERIFIED POWER**[2]
Four independent test labs regularly check panel power so you get the power we promise.

**ANTI-REFLECTIVE GLASS**
Delivering 2–3% more electricity compared to panels with standard glass.

**TEMPERATURE RATINGS OVER 90%**[3]
Maintaining up to 4% higher output than most other crystalline silicon panels under hot conditions.

**HIGH RANKINGS IN FIELD TESTS**[4]
Long-term Photon and TÜV field tests prove Evergreen panels produce more electricity (kWh/kW).

## LESS impact

String Ribbon™ panels have the smallest carbon footprint and fastest energy payback of any silicon-based solar panel ever made.

**SMALLEST CARBON FOOTPRINT**[5]
Our String Ribbon™ wafers are made with a fraction of the emissions that result from making conventional silicon panels.

**12-MONTH ENERGY PAYBACK**[5]
Our panels begin generating truly clean electricity faster than any other silicon-based panel on the market.

**100% CARDBOARD-FREE REUSABLE PACKAGING**
Reduces disposal costs and on-site manpower while eliminating tons of landfill.

**LEAD-FREE SOLAR CELLS**
Our panels make clean electricity and the way we make them is clean too.

**1** Guaranteed upon initial delivery of the panel to the customer, maximum power up to 4.99 W above nameplate rating; **2** Evergreen power testers calibrated by taking the straight average of test data from NREL, TÜV Rheinland PTL, TÜV Rheinland Cologne and Fraunhofer ISE; **3** Based on comparing PTC/STC ratings of major competing multi-crystalline silicon panel brands published by the California Energy Commission in May 2009; **4** 2008 Module Tests conducted by Photon and published in Photon International February 2009, TÜV Rheinland tests run from April to September 2008

**5** Evaluation completed by the Energy Research Foundation of the Netherlands (ECN), May 2009

STRING RIBBON™ SOLAR PANELS OFFERING EXCEPTIONAL PERFORMANCE AND INDUSTRY-LEADING ENVIRONMENTAL CREDENTIALS. IN SHORT, MORE ELECTRICITY AND LESS IMPACT.

*All Evergreen panels come with a 5 year workmanship and 25 year limited power warranty. For full details see the* ***Evergreen Solar Limited Warranty*** *available upon request or online. This product is certified to UL 1703, UL 4703, UL Fire Safety Class C, IEC 61215 Ed.2, IEC 61730 Class A, FSEC and KTL standards.* ***String Ribbon*** *is a trademark of Evergreen Solar, Inc. Evergreen Solar's wafer manufacturing technology is patented in the United States and other countries.* 

CE IEC

## ELECTRICAL characteristics

### Standard Test Conditions (STC)[1]

| | ES-A-200 -fa3* | ES-A-205 -fa3* | ES-A-210 -fa3* | |
|---|---|---|---|---|
| $P_{mp}$ [2] | 200 | 205 | 210 | W |
| $P_{tolerance}$ | -0/+4.99 (-0/+2.5) | -0/+4.99 (-0/+2.5) | -0/+4.99 (-0/+2.5) | W (%) |
| $P_{mp, max}$ | 204.99 | 209.99 | 214.99 | W |
| $P_{mp, min}$ | 200.00 | 205.00 | 210.00 | W |
| $P_{ptc}$ [3] | 180.6 | 185.2 | 189.8 | W |
| $\eta_{min}$ | 12.7 | 13.1 | 13.4 | % |
| $V_{mp}$ | 18.1 | 18.2 | 18.3 | V |
| $I_{mp}$ | 11.05 | 11.27 | 11.48 | A |
| $V_{oc}$ | 22.6 | 22.7 | 22.8 | V |
| $I_{sc}$ | 11.80 | 11.93 | 12.11 | A |

### Nominal Operating Cell Temperature Conditions (NOCT)[4]

| | | | | |
|---|---|---|---|---|
| $T_{NOCT}$ | 45.4 | 45.4 | 45.4 | °C |
| $P_{max}$ | 146.4 | 150.1 | 153.8 | W |
| $V_{mp}$ | 16.5 | 16.6 | 16.7 | V |
| $I_{mp}$ | 8.87 | 9.04 | 9.21 | A |
| $V_{oc}$ | 20.8 | 21.0 | 21.1 | V |
| $I_{sc}$ | 9.44 | 9.57 | 9.76 | A |

### Low Irradiance

The typical relative reduction of panel efficiency at an irradiance of 200 W/m² both at 25°C cell temperature and spectrum AM 1.5 is 0%.

### Temperature Coefficients

| | | |
|---|---|---|
| $\gamma\ P_{mp}$ | -0.43 | % /°C |
| $\beta\ V_{mp}$ | -0.40 | % /°C |
| $\alpha\ I_{mp}$ | -0.03 | % /°C |
| $\beta\ V_{oc}$ | -0.31 | % /°C |
| $\alpha\ I_{sc}$ | +0.05 | % /°C |

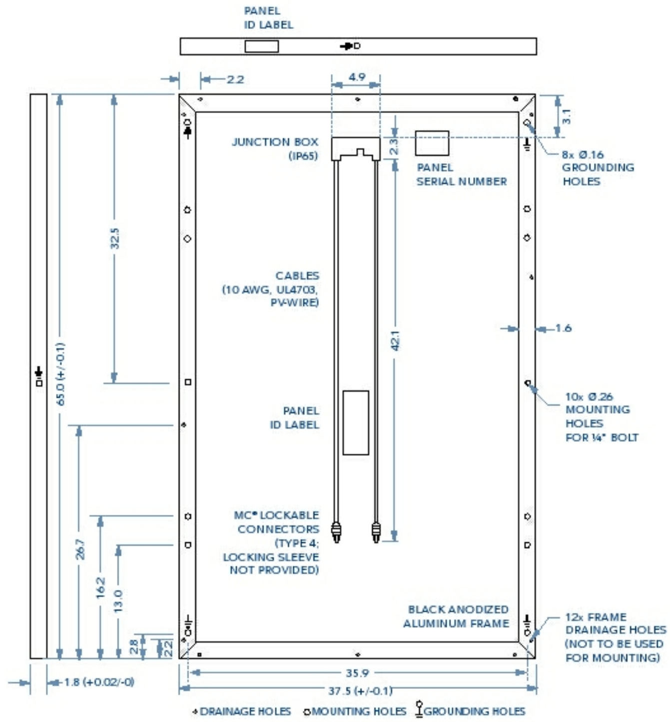
### System Design

| | |
|---|---|
| Series Fuse Rating | 20 A |
| Maximum DC System Voltage (UL) | 600 V |
| Maximum Combined Wind and Snow Load[5] | 60 lbs/ft² |

*1 1000 W/m², 25°C cell temperature, AM 1.5 spectrum; 2 Maximum power point or rated power; 3 At PV-USA Test Conditions 1000 W/m², 20°C ambient temperature, 1 m/s wind speed; 4 800 W/m², 20°C ambient temperature, 1 m/s wind speed, AM 1.5 spectrum; 5 When the panel is mounted using Mounting Method A (offset mounting) with rails 13 in (±1 in) from each short side of the panel as described in the Mounting Guide for this product; * f-framed, a-low voltage, 3-matt blue (textured) cells and black anodized frame.*

ELECTRICAL EQUIPMENT
CHECK WITH YOUR INSTALLER

## MECHANICAL specifications




ALL DIMENSIONS IN INCHES; PANEL WEIGHT 41 LBS (18.6 KG)

The above drawing is a graphical representation of the product; for engineering quality drawings please contact Evergreen Solar. MC® is a registered trademark of Multi-Contact AG. Product constructed with 114 multi-crystalline silicon String Ribbon™ solar cells, anti-reflective tempered solar glass, EVA encapsulant, polymer back-skin and a black anodized double-walled aluminum frame.

Product packaged 28 per pallet and tested to International Safe Transit Association (ISTA) Standard 2B. All specifications in this product information sheet conform to EN 50380. See the Evergreen Solar Safety, Installation and Operation Manual, Mounting Guide and Inverter Selection Guide for further information on approved installation and use of this product.

Due to continuous innovation, research and product improvement, the specifications in this product information sheet are subject to change without notice. No rights can be derived from this product information sheet and Evergreen Solar assumes no liability whatsoever connected to or resulting from the use of any information contained herein.

### PARTNER

*ES-A-200-205-210-fa3-US-010609; effective June 1st 2009*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### *LABORATORY* SYSTEM (THIN-FILM CIGS CYLINDRICAL PV)

# Product Specifications*

200 SERIES

## Electrical Data

Measured at Standard Test Conditions (STC) irradiance of 1000 W/m², air mass 1.5, and cell temperature 25° C

| Model Number | | SL-200-182 | SL-200-191 | SL-200-200 | SL-200-210 | SL-200-220 available Q3-2011 |
|---|---|---|---|---|---|---|
| PowerRating ($P_{mp}$) | Wp | 182 | 191 | 200 | 210 | 220 |
| Power Tolerance (%) | %/Wp | +/-4 | +/-4 | +/-4 | +/-4 | +/-4 |
| $V_{mp}$ (Voltage at Maximum Power) | Volts | 85.1 | 88.6 | 91.7 | 95.1 | 98.4 |
| $I_{mp}$ (Current at Maximum Power) | Amps | 2.14 | 2.16 | 2.18 | 2.21 | 2.23 |
| $V_{oc}$ (Open Circuit Voltage) | Volts | 119.6 | 122.8 | 124.6 | 125.3 | 125.8 |
| $I_{sc}$ (Short Circuit Current) | Amps | 2.33 | 2.34 | 2.35 | 2.36 | 2.37 |
| Temp. Coefficient of $V_{oc}$ | %/°C | -.28 | | | | |
| Temp. Coefficient of $I_{sc}$ | %/°C | -.02 | | | | |
| Temp. Coefficient of Power | %/°C | -.38 | | | | |

## System Information

| | |
|---|---|
| Cell type | Cylindrical CIGS |
| Maximum System Voltage | Universal design: 1000V (IEC) & 600V (UL) systems |
| Dimensions | Panel: 2.28 x 1.09 x 0.06 m (89.8 x 42.9 x 2.36 in)<br>Height: 0.36 m (14.4 in) to top of panel on mounts |
| Mounts | Non-penetrating, steel-reinforced, high-performance engineered plastic |
| Connectors | 4 Tyco SOLARLOK™; 20 cm (8 in) cable |
| Series Fuse Rating | 24.4 Amps |
| Roof Load | 13.9 kg/m² (2.8 lb/ft²) panel and mounts |
| Panel Weight | 31.8 kg (69 lb) without mounts |
| Snow Load Maximum | 1850† Pa / 1200 Pa (38.6 lb/ft² / 25.1 lb/ft²) |
| Hailstone Impact | 25 mm, 7.53 g at 23 m/s per IEC 61646 |
| Wind Performance | 208 kph (130 mph) maximum<br>Self-ballasting with no attachments |
| Operating and Storage Temp | -40°C to +85°C |
| Normal Operating Cell Temperature (NOCT) | 44°C at 800 W/m², Temp = 20°C, Wind = 1m/s |
| Certifications/Listings | UL1703, IEC 61646, IEC 61730, Protection Class II<br>Application Class A per IEC 61730-2<br>Fire Class C, CE Mark, CEC listing, MCS/BRE (UK) |
| Warranty | 25 year limited power warranty<br>5 year limited product warranty |

**ALL NEW**

Solyndra 200 Series panels come with the panel mounts and cable management hardware needed to build a typical array. Additional mounts and hardware are available.

| Headquarters | Regional Support Contacts |
|---|---|
| Solyndra LLC<br>47488 Kato Road<br>Fremont CA 94538 | Belgium 0800 50735<br>customersupportbe@solyndra.com |
| | EMEA 353 61 79 1124<br>customersupporteu@solyndra.com |
| | France 0800 942896<br>customersupportfr@solyndra.com |
| | Germany 0800 0004366<br>customersupportde@solyndra.com |
| Solyndra International AG<br>Lindenstrasse<br>16 6340 Baar,<br>Switzerland | Greece 00800 3973 4547<br>customersupporteu.solyndra.com |
| | Italy 800 125604<br>customersupportit@solyndra.com |
| | Spain 900 800566<br>customersupportes@solyndra.com |
| | US/Canada 877-511-8436<br>customersupport@solyndra.com |
| | UK 0800 368-0423<br>customersupportuk@solyndra.com |

*PRODUCT SPECIFICATIONS ARE ONLY VALID WHEN USING THE PRODUCT IN ACCORDANCE WITH SOLYNDRA'S DESIGN AND INSTALLATION GUIDELINES USING SOLYNDRA SUPPLIED MOUNTS AND INTERCONNECTING HARDWARE. PRODUCT SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT NOTICE.

†1850 Pa snow rating requires optional Snow Mount

SOLYNDRA
The new shape of solar™



Revision: 3 / Released: 2011-04-01
Part: 0900-30089-001

## *LABORATORY* SYSTEM (THIN-FILM A-SI LAMINATE PV)

# PowerBond™ PVL

**TECHNICAL DATA SHEET**
**PVL-136**

- High Temperature and Low Light Performance
- 5-Year Limited Product Warranty
- Limited Power Output Warranty:
  92% at 10 years, 84% at 20 years, 80% at 25 years (of minimum power)
- Quick-Connect Terminals and Adhesive Backing
- Bypass Diodes for Shadow Tolerance

### Performance Characteristics

| | |
|---|---|
| Rated Power ($P_{max}$): | 136 Wp |
| Production $P_{max}$ Tolerance: | ± 5 % |

### Construction Characteristics

| | |
|---|---|
| Dimensions: | Length: 5486 mm (216"), Width: 394 mm (15.5"), Depth: 4 mm (0.2"), 16 mm (0.6") including potted terminal housing assembly |
| Weight: | 7.7 kg (17.0 lbs) |
| Output Cables: | 4 $mm^2$ (12 AWG) cable with weatherproof DC-rated quick-connect terminals 560 mm (22") length |
| Bypass Diodes: | Connected across every solar cell |
| Encapsulation: | Durable ETFE high light-transmissive polymer |
| Adhesive: | Ethylene propylene copolymer adhesive sealant with microbial inhibitor |
| Cell Type: | 22 triple junction amorphous silicon solar cells 356 mm x 239 mm (14" x 9.4") connected in series |


### Qualifications and Safety

UL 1703 Listed by Underwriters Laboratories for electrical and fire safety (Class A Max. Slope 2/12, Class B Max. Slope 3/12, Class C Unlimited Slope fire ratings) for use in systems up to 600 VDC.

IEC 61646 and IEC 61730 certified by TÜV Rheinland for use in systems up to 1000 VDC.

### Laminate Standard Configuration

Photovoltaic laminate with potted terminal housing assembly with output cables and quick-connect terminals on top.

### Application Criteria*

- Installation temperature between 10 °C - 40 °C (50 °F - 100 °F)
- Maximum roof temperature: 85 °C (185 °F)
- Minimum slope: 3° (1/2:12)
- Maximum slope: 60° (21:12)
- Approved substrates include certain membrane and metal roofing products.
  See United Solar for details.

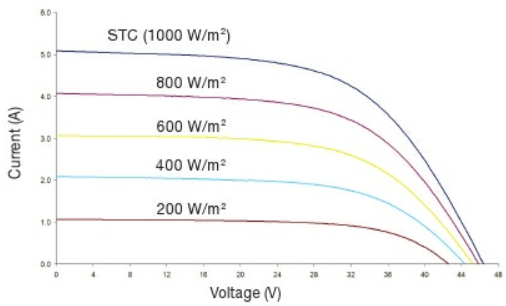
**Detailed installation requirements are specified in United Solar's installation manuals.*

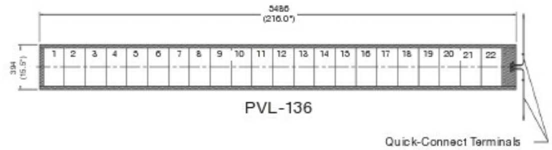
**#AA4-3697-05**

# PowerBond™ PVL

**TECHNICAL DATA SHEET**
**PVL-136**

IV Curves at various Levels of Irradiance at Air Mass 1.5 and 25 °C Cell Temperature




All measurements in mm
Inches in parentheses
Tolerances: Length: ± 5 mm (1/4"), Width: ± 3 mm (1/8")

## Electrical Specifications

### STC

(Standard Test Conditions)
(1000 W/m², AM 1.5, 25 °C Cell Temperature)

Maximum Power ($P_{max}$): 136 W
Voltage at Pmax ($V_{mpp}$): 33.0 V
Current at Pmax ($I_{mpp}$): 4.13 A
Short-circuit Current ($I_{sc}$): 5.1 A
Open-circuit Voltage ($V_{oc}$): 46.2 V
Maximum Series Fuse Rating: 10 A (UL), 8 A (IEC)

### NOCT

(Nominal Operating Cell Temperature)
(800 W/m$^2$, AM 1.5, 1 m/sec. wind)

Maximum Power ($P_{max}$): 105 W
Voltage at Pmax ($V_{mpp}$): 30.8 V
Current at Pmax ($I_{mpp}$): 3.42 A
Short-circuit Current ($I_{sc}$): 4.1 A
Open-circuit Voltage ($V_{oc}$): 42.2 V
NOCT: 46 °C

## Temperature Coefficients

(at AM 1.5, 1000 W/m$^2$ irradiance)

Temperature Coefficient (TC) of $I_{sc}$: 0.001/K (0.10%/°C)
Temperature Coefficient (TC) of $V_{oc}$: -0.0038/K (-0.38%/°C)
Temperature Coefficient (TC) of $P_{max}$: -0.0021/K (-0.21%/°C)
Temperature Coefficient (TC) of $I_{mpp}$: 0.001/K (0.10%/°C)
Temperature Coefficient (TC) of $V_{mpp}$: -0.0031/K (-0.31%/°C)

*y = yreference • [1 + TC • (T- Treference)]*

Notes:

1. During the first 8-10 weeks of operation, electrical output exceeds specified ratings. Power output may be higher by 15%, operating voltage may be higher by 11% and operating current may be higher by 4%.
2. Production tolerance for $P_{max}$ at standard test conditions (STC) is +/-5% and for other electrical parameters is +/-10%. Electrical specifications are based on measurements performed at standard test conditions of 1000 W/m² irradiance, Air Mass 1.5, and cell temperature of 25 °C after stabilization.
3. Actual performance may vary up to 10% from rated power due to low temperature operation, spectral and other related effects. Maximum system open-circuit voltage not to exceed 600 VDC per UL, 1000 VDC per IEC regulations.
4. Specifications subject to change without notice.

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A subsidiary of Energy Conversion Devices, Inc.
(Nasdaq: ENER)



**#AA4-3697-05**

## *LABORATORY* SYSTEM (THIN-FILM CD-TE PANEL PV)

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www.abound.com

phone +1.970.619.5340
fax +1.970.488.3237
email sales@abound.com

# AB1 Series

Thin-Film Photovoltaic Module

*Each module features a white barcode (shown at bottom left) to allow for tracking throughout manufacturing and isolation scribes (parallel to the 1200mm dimension).

### Designed to meet the unique needs of large-scale installations

Abound Solar's AB1-Series offers high-performance, cost-effective modules employing next-generation thin-film solar technology tailored to minimize total cost of electricity generation.

### High energy output in range of operating environments

- Better performance in low-light and high-temperature conditions than crystalline silicon

### Tight power output bins (+2.5 / -0 W)

- Better field performance
- Eliminates risk of underperformance

### TruLock™ seal against the elements

- Enhanced dual moisture / vapor barrier
- Increases reliability and module life for long-term installations

### Lower voltages at given power output

- Enables longer module strings and lower balance of system costs

### Fully-automated end-to-end manufacturing based in the USA

- Reduces manufacturing cost while maximizing reliability

### Industry leading warranty

- 5 year materials and workmanship
- 25 year power output guarantee for 90% of nominal output during first 10 years and 80% over 25 years

### Abound Solar´s Collection and Recycling program eliminates recycling costs and residual liability for module owners.

- Product designed for recyclability
- Collection and recycling of modules at end-of-life
- Pre-funded at purchase

# AB1 Series

Thin-Film Photovoltaic Module

## Electrical Specifications

**Performance at STC (1000W/m², 25°C, AM 1.5)**

| Product Class | | AB1-65 | AB1-67 | AB1-70 | AB1-72 | AB1-75 |
|---|---|---|---|---|---|---|
| Nominal Power (+2.5/-0W) | $P_{MPP}$(W) | 65.00 | 67.50 | 70.00 | 72.50 | 75.00 |
| Voltage at $P_{MPP}$ | $V_{MPP}$(V) | 33.00 | 33.60 | 34.10 | 34.70 | 35.60 |
| Current at $P_{MPP}$ | $I_{MPP}$(A) | 1.99 | 2.03 | 2.08 | 2.10 | 2.11 |
| Short Circuit Current | $I_{SC}$(A) | 2.47 | 2.48 | 2.48 | 2.48 | 2.49 |
| Open Circuit Voltage | $V_{OC}$(V) | 45.70 | 46.00 | 46.20 | 46.40 | 46.90 |

**Performance at NOTC (800W/m², 20°C, AM 1.5)**

| Product Class | | AB1-65 | AB1-67 | AB1-70 | AB1-72 | AB1-75 |
|---|---|---|---|---|---|---|
| Nominal Power | $P_{MPP}$(W) | 47.50 | 49.50 | 51.30 | 52.50 | 54.50 |
| Voltage at $P_{MPP}$ | $V_{MPP}$(V) | 29.80 | 30.40 | 30.90 | 31.30 | 32.2 |
| Current at $P_{MPP}$ | $I_{MPP}$(A) | 1.59 | 1.63 | 1.66 | 1.68 | 1.69 |
| Short Circuit Current | $I_{SC}$(A) | 1.98 | 1.98 | 1.99 | 1.99 | 1.99 |
| Open Circuit Voltage | $V_{OC}$(V) | 41.34 | 41.55 | 41.74 | 41.97 | 42.40 |

**System Properties (at STC)**

| | | |
|---|---|---|
| Maximum System Voltage | $V_{SYS}$(V) | 1000 |
| Limiting Reverse Current | $I_R$(A) | 4A |
| Maximum Series Fuse | $I_{CF}$(A) | 4A (UL) |

**Thermal Properties (at STC)**

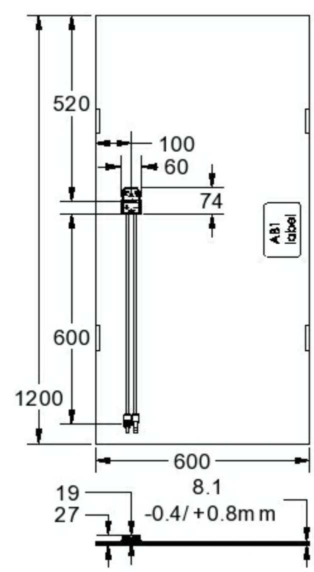
| | | |
|---|---|---|
| Temperature Coefficient of $P_{MPP}$ | % / °C | -0.25 |
| Temperature Coefficient of $V_{OC}$ | % / °C | -0.10<10 °C, -0.32>10 °C |
| Temperature Coefficient of $I_{SC}$ | % / °C | +0.04 |

**Certifications**

UL (1703) – Class C, CE Mark, IEC (61646), IEC (61730) – Class A, MCS, CEC

## Mechanical Specifications

| | |
|---|---|
| Length x Width | 1200 mm x 600 mm |
| Weight | 12 kg |
| Thickness | 8.1 mm |
| Front glass | 3.1 mm heat strengthened glass |
| Back glass | 3.1 mm tempered glass |
| Frame | None |
| Cell type | Cadmium Telluride (CdTe) |
| Cell orientation | Parallel to the 1200 mm dimension |
| Bypass diode | Integrated in junction box |
| Cable length | 600 mm |
| Connectors | Multi-Contact MC4 |
| Encapsulation | TruLock™ dual moisture / vapor barrier edge seal |




Unless otherwise indicated, all electrical characteristics +/-10%. Product classes are defined by positive binning (+2.5/-0W) according to measured $P_{MPP}$ under STC. The accuracy of this measurement is ±5%. Specifications subject to change without notice. No rights can be derived from this product datasheet and Abound Solar, Inc. assumes no liability connected to or resulting from the use of any information contained herein. All details regarding Abound Solar's offering including Warranty are subject to the terms and conditions set forth in Abound Solar's agreement with its customers.

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