



# Output Performance and Payback Analysis of a Residential Photovoltaic System in Colorado

## Preprint

Steve Johnston

*Presented at the 2012 IEEE Photovoltaic Specialists Conference  
Austin, Texas  
June 3–8, 2012*

**NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.**

**Conference Paper**  
NREL/CP-5200-54114  
June 2012

Contract No. DE-AC36-08GO28308

## NOTICE

The submitted manuscript has been offered by an employee of the Alliance for Sustainable Energy, LLC (Alliance), a contractor of the US Government under Contract No. DE-AC36-08GO28308. Accordingly, the US Government and Alliance retain a nonexclusive royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for US Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at <http://www.osti.gov/bridge>

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy  
Office of Scientific and Technical Information

P.O. Box 62  
Oak Ridge, TN 37831-0062  
phone: 865.576.8401  
fax: 865.576.5728  
email: <mailto:reports@adonis.osti.gov>

Available for sale to the public, in paper, from:

U.S. Department of Commerce  
National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22161  
phone: 800.553.6847  
fax: 703.605.6900  
email: [orders@ntis.fedworld.gov](mailto:orders@ntis.fedworld.gov)  
online ordering: <http://www.ntis.gov/help/ordermethods.aspx>

Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721



Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.

# Output Performance and Payback Analysis of a Residential Photovoltaic System in Colorado

Steve Johnston

National Renewable Energy Laboratory; 15013 Denver West Parkway; Golden, CO 80401, USA

**Abstract** — Cost of installation and ownership of a 9.66-kilowatt (kW) residential photovoltaic system is described, and the performance of this system over the past 3 years is shown. The system is located in Colorado at 40° latitude and consists of arrays on two structures. Two arrays are installed on a detached garage, and these are each composed of 18 Kyocera 130-W modules strung in series facing south at an angle of 40° above horizontal. Each 18-panel array feeds into a Xantrex/Schneider Electric 2.8-kW inverter. The other two arrays are installed on the house and face south at an angle of 30°. One of these arrays has twelve 205-W Kyocera panels in series, and the other is made up of twelve 210-W Kyocera panels. Each of these arrays feeds into Xantrex/Schneider Electric 3.3-kW inverters. Although there are various shading issues from trees and utility poles and lines, the overall output resembles that which is expected from PVWatts, a solar estimate program. The array cost, which was offset by rebates from the utility company and federal tax credits, was \$1.17 per watt. Considering measured system performance, the estimated payback time of the system is 9 years.

**Index Terms** — photovoltaic cells, silicon.

## I. INTRODUCTION

Solar energy in a large portion of the U.S. is expected to become cheaper than conventional power from the grid by 2017. Costs of solar panels and installation continue to decrease, while the cost of electricity continues to rise. The solar market will be driven by grid parity within regions. While federal incentives provide a good foundation for the expansion of solar, state-level incentives seem to truly make solar energy competitive. At the moment, the U.S. is the 4th largest solar market in the world, and that market grew from ~900 MW in 2010 to 2 GW in 2011.

## II. PHOTOVOLTAIC SYSTEM PERFORMANCE

A 9.66-kilowatt (kW) residential photovoltaic system is located in Colorado at 40° latitude and consists of four arrays on two structures. Two arrays are installed on the house and face south at an angle of 30° above horizontal, as shown in Figs. 1 and 2. The east array has twelve 205-W Kyocera panels in series, and the west array is made up of twelve 210-W Kyocera panels. Each of these arrays feeds into Xantrex/Schneider Electric 3.3-kW inverters.



Fig. 1. Photograph of east-facing house where two arrays are installed on the south-facing roof.



Fig. 2. Photograph of the house as viewed from the southeast corner where the two arrays are visible.

Three rows of panels are installed on a detached garage, as shown in Fig. 3. Each row is composed of 12 Kyocera 130-W modules facing south at an angle of 40° above horizontal. The rows are spaced apart so that, even in winter, panels are not shadowed by the row in front of them. The three rows are strung into two arrays of 18 panels each that feed into Xantrex/Schneider Electric 2.8-kW inverters. One array consists of the back row, shown in Fig. 4, and the right half of the middle row. The other array includes the front row with the left half of the middle row.



Fig. 3. Photograph of detached back garage in the backyard where two arrays in three rows are installed.



Fig. 4. Photograph of the back row of panels on the detached garage showing the 40° tilt.

Although the back row array is sufficiently spaced away from trees and poles, there are shading issues from trees,

utility poles, and power lines for the front array on the detached garage, as shown in Fig. 5.



Fig. 5. Photograph shows shadows of power lines that are cast across the panels in the late afternoon.

In the winter, the snow slides off the arrays on the back garage quite easily, because for each row, there is open space below the panels. However, on the house arrays, there is roof space below the arrays where snow tends to pile up after sliding down the arrays. This piled-up snow continues to shade significant areas of the panels on the bottom rows and severely inhibits the performance of the array. Manual removal of some of this snow quickly accelerates melting and restores array production.

Energy output of each array over the past 3 years (2009–2012) has been averaged and plotted in Fig. 6. The plots show the average amount of energy in kilowatt-hours (kWh) per day over the course of a year. The modeled amount of energy is calculated from a program called PVWatts, which is available at [www.nrel.gov/rredc/pvwatts](http://www.nrel.gov/rredc/pvwatts). The 3-year-averaged data follow the modeled output quite well, with the exception of the detached garage's front array. Integrated energy output over the course of a year is compared to that predicted by PVWatts. As plotted in the bottom graphs of Fig. 6, the house east array has an annual average output of 3503 kWh compared to the predicted value of 3556 kWh. The west array has produced 3555 kWh out of the predicted 3644 kWh. The periodically shadowed front array on the detached garage has produced 2823 kWh of its predicted 3400 kWh amount, while the back array, which is hardly affected by shadowing, has produced 3428 kWh of the predicted 3400 kWh. In total, the system has annually been producing 13,309 kWh of the predicted 14,000 kWh, which is 95%.

The solar panels and system components were bought and installed between 2006 and 2009. At this time, the average prices paid for the solar panels and inverters were \$4.13 and \$0.74 per watt, respectively. With the recent rapid drop in prices for photovoltaic components due to economies of

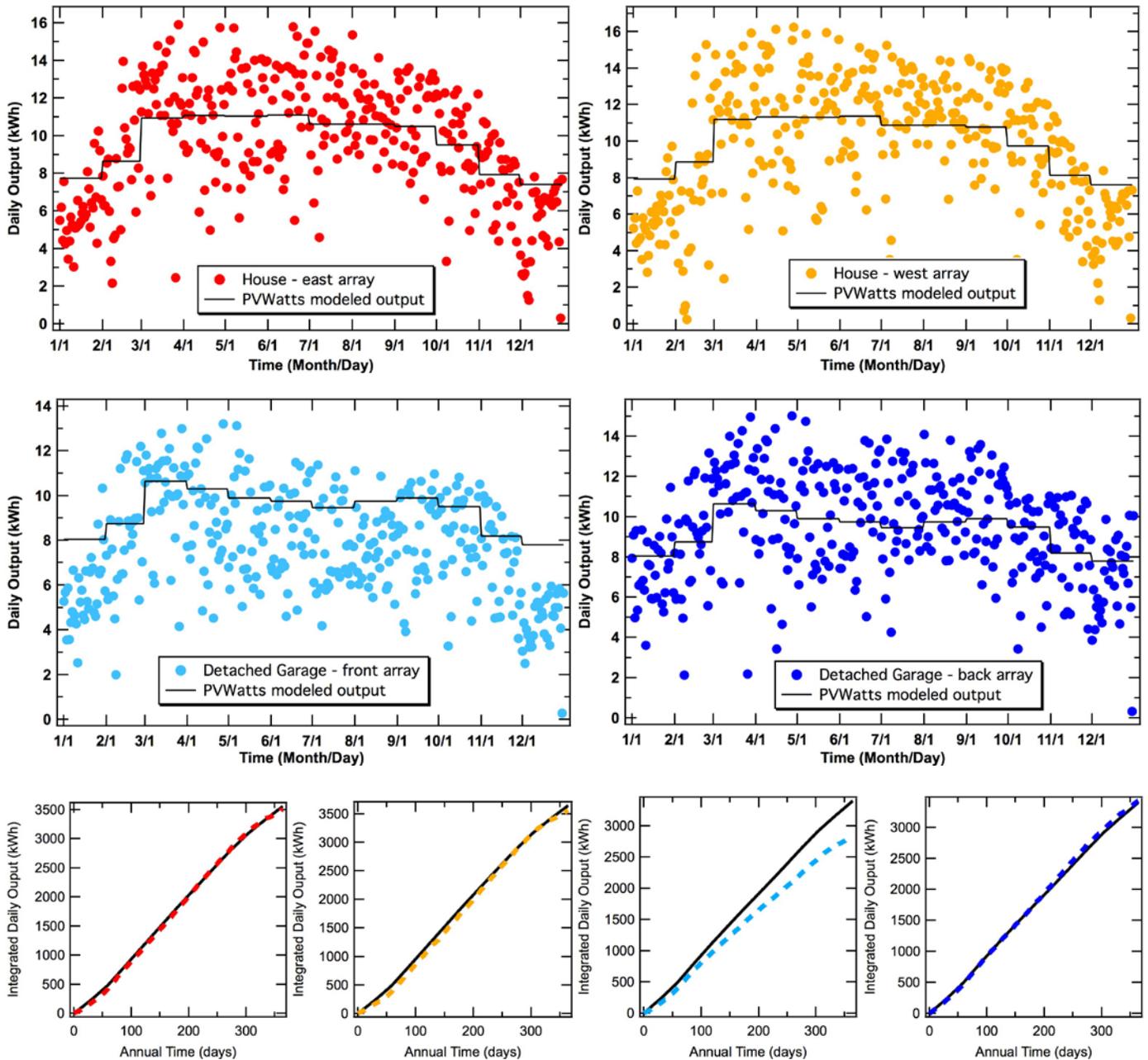


Fig. 6. The top two rows of plots show the 3-year averaged output of each array over the course of a year compared to the values predicted by PVWatts. The bottom row of graphs shows integrated output over the course of a year for each array (colored line) as compared to the PVWatts modeled output (black line).

scale and fierce global competition, prices in early 2012 are down to \$1.40 (modules) and \$0.57 (inverters) per watt. Other costs (in \$/watt) include installation hardware, such as Unistrut for mounts (0.438); wiring, electrical enclosures, conduit, and other electronic materials (0.211); shipping costs (0.174); sales taxes (0.0978); and permits (0.0632). Normally, installation would be a significant cost, but since this system was self-installed, there are no labor costs.

In November of 2004, Colorado passed Amendment 37, which requires utilities to provide 10% of their electricity generation from renewable energy sources by 2020. In 2010, this goal was increased to 30%. The utility companies (Xcel Energy, in this case) have offered rebates to those customers that install solar to help meet this goal. Rebates have followed the cost of solar panels, so in this time period, the Xcel rebates received for these installed modules averaged \$4.156 per watt. The federal government also offered tax incentives for

renewable energy systems. The tax credit was 30% of the balance of the net cost, and these credits were \$0.529 per watt.

The total cost of \$5.854 per watt less the rebates and credits of \$4.685 per watt leads to a net cost of \$1.17 per watt. This value is near to the \$1 per watt goal of the U.S. Department of Energy's SunShot Initiative, where the targeted cost of electricity is 6 ¢/kWh. Using the total estimated annual energy output of these arrays (including shading) of 13,309 kWh, and the current cost of electricity of 9.3 ¢/kWh, the annual revenue is \$1,240 per year. System cost divided by annual revenue gives a payback time of 9.0 years for this system. If the system produces the annual amount of electricity for 20 years, the cost of electricity based on the \$1.17 per watt system cost is 4.21 ¢/kWh, but the inverters

may not last the 20 years expected of the panels. If inverters must be replaced after 10 years, and the cost is roughly \$0.57 per watt, then the extra cost leads to a 6.26 ¢/kWh cost of electricity over the 20-year period.

### III. CONCLUSION

Colorado's state incentive has made the cost of photovoltaic solar energy competitive with that of electricity currently purchased from the grid. Including U.S. federal tax credits, the cost of a photovoltaic solar array was \$1.17 per watt, which leads to a 9-year system payback and a cost of electricity ranging from 4.2 to 6.3 ¢/kWh over a 20-year period.