National Renewable Energy Laboratory
Innovation for Our Energy Future

National PV Cost Values, for:
NARUC 7-Member Consortium for PV Resource Characterization[1]
December 21, 2009

Executive Summary

This report captures current national PV cost values from several sources, for the seven-state NARUC member PV Resource Characterization Consortium through the U.S. Department of Energy. Where available, cost data specific to Consortium states are also provided in the attached excel file. Currently in the U.S., the average cost of installing a PV system - prior to receipt of any direct financial incentives or tax credits – is approximately $5-10.50/ watt (DC-STC) for residential systems, $4.50-6.25/watt for commercial systems, and $3-5/watt for utility-scale systems.[2] In terms of levelized cost of energy (LCOE), the DOE estimates that for typical installed system costs, under a range of financing assumptions and locations, and including the federal investment tax credit (ITC), the LCOE is approximately $0.16/kWh-$0.25/kWh for residential PV systems, $0.16/kWh-$0.31/kWh for commercial systems, and $0.10/kWh - $0.18/kWh for utility-scale systems.

To understand PV costs, it's crucial that data from multiple sources be compared directly and that variables and assumptions supporting any cost data be explicit, to avoid an "apples-to-oranges" problem. No single data source has full, accurate real-time data available for PV costs, in part because the market is immature and is changing rapidly. The dynamic nature of the PV industry has been clearly demonstrated during the past 15 months where prices of PV modules have been declining very rapidly, particularly at the wholesale level. There are several variables that inter-play to determine the installed and levelized cost of a PV system, including the following:

- Variations in the sourcing of and volume of purchases for major system components, i.e., modules, inverters, and balance of system components.
- Variations in systems design and installation practices (both within and across market segments, i.e., residential, commercial and utility-scale installations).
- Variations in local incentives, regulatory structures, licensing, inspection, and interconnection requirements.
- Variations in local availability of trained installers and distribution channels.
- Variation in financing mechanisms and terms.
- Variation in the available solar resource (and other factors).

[1] This consortium was established through a 2009 DOE RFP, and includes Co, Ky, Ga, Oh, Mi, Mo, Tn.

[2] Multiple sources. The most common rating used by PV incentive programs is the nameplate capacity of the PV modules, which is reported by manufacturers in terms of direct current (DC) watts under standard test conditions (STC) (Wiser et al 2009).

Installed Systems

Current DOE benchmarks for residential, commercial and utility-scale systems and their components prices may be found in **Table 1**. Based on a sample of installations gathered through NREL's PV Open Mapping Project (http://openpv.nrel.gov), the average installed cost of a PV system has declined from $12.5/watt in 1998 to about $8/watt in 2009 (**Figure 1**). While the overall trend has been downward over time, installed system costs vary considerably across locations and applications.

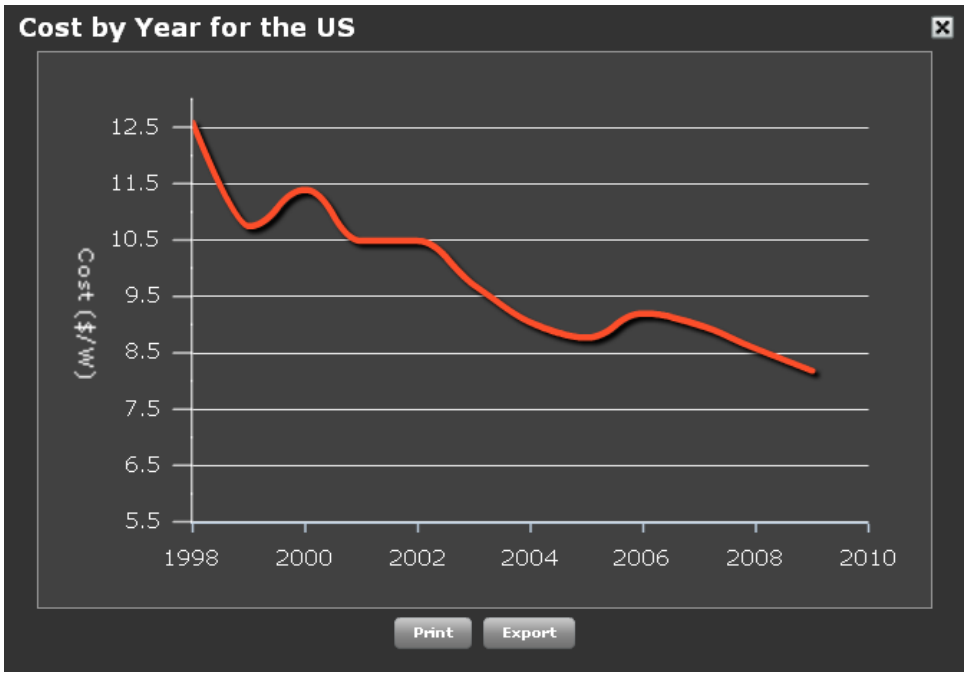


Figure 1: Average Installed PV System Cost, 1998-2009
Source: Open PV Mapping http://openpv.nrel.gov)

Cost	Residential[3]	Commercial[4]	Utility-Scale
Module Price ($/Watt)	$2.87	$2.65	$2.40[5]
Inverter Price ($/Watt)	$0.56	$0.44	$0.40[6]
1-axis Tracker Price ($/Watt)			$0.53[7]
Other Materials ($/Watt)	$0.56	$0.81	$0.34[8]
Installation Labor ($/Watt)	$0.72	$0.74	$0.22[9]
Overhead, Regulatory, Compliance & Other ($/Watt)	$2.32	$1.54	$1.11[10]
Installed System Price ($/Watt)	**$7.03**	**$6.18**	**$5.00[11]**

Table 1: Benchmark Cost components for PV, Dec. 2009
Source: U.S. Department of Energy Solar Energy Technologies Program

To date, among the seven states in the Resource Characterization Consortium NARUC, only Colorado has reported enough recent PV installations' cost data to NREL's Open PV mapping project to reliably indicate in-state installed system costs in recent years.[12] In Colorado, 163 facilities installed in 2008-09 reported an average cost of $8.19/W to NREL's Open PV. To date, data from installations in the other 6 Consortium states were insufficient to form indicative averages. Going forward, NREL will work with Consortium members to explore encouragement of installer and other participation in Open PV http://openpv.nrel.gov/.

Among residential and small commercial systems of 10 kW or less in 14 U.S. states reporting data to Lawrence Berkeley National Lab for PV installed from 1998 – 08, "average costs range from a low of $7.3/W in Arizona to a high of $9.9/W in Pennsylvania and Ohio. …. The variation in average installed costs across states may partially be a consequence of the differing size and maturity of the PV markets, where larger markets stimulate greater competition and hence greater efficiency in the delivery chain, and may also allow for bulk purchases and better access to lower-cost products. It therefore is perhaps not surprising that California, the largest PV

[3] Module cost based on an average c-Si module price of $2.40, from the July 8, 2009 UBS Solar Spot Price Tracker, with 20% markup for residential customers. Other component costs are based on proportional costs from LBNL survey of PV installers on component costs: http://eetd.lbl.gov/ea/EMS/reports/lbnl-1516e-web.pdf. System cost of $7.03 is weighted average residential installed system cost from Q2 2009 Citigroup installer survey, July 13, 2009.
[4] Module cost based on an average c-Si module price of $2.40, from the July 8, 2009 UBS Solar Spot Price Tracker, with 10% markup for commercial customers. Other component costs are based on proportional costs from LBNL survey of PV installers on component costs: http://eetd.lbl.gov/ea/EMS/reports/lbnl-1516e-web.pdf. System cost of $6.18 is weighted average commercial installed system cost from Q2 2009 Citigroup installer survey, July 13, 2009.
[5] Based on the average c-Si module price from the July 8, 2009 UBS Solar Spot Price Tracker.
[6] Based on proportional costs from Tucson Electric Power Company's 3.5 MW Springerville, AZ facility.
[7] Midpoint of 2009 tracking price estimates from J.P. Morgan, "Estimating the Cost Reduction Potential of Solar Energy by Technology Type", January 15, 2009.
[8] Based on proportional costs from Tucson Electric Power Company's 3.5 MW Springerville, AZ facility.
[9] Based on proportional costs from Tucson Electric Power Company's 3.5 MW Springerville, AZ facility.
[10] Based on proportional costs from Tucson Electric Power Company's 3.5 MW Springerville, AZ facility.
[11] 2009 installed system cost based on the necessary installed cost to meet California's Market Price Referent.
[12] See Open PV state-specific datasets, attached.

market in the U.S., has among the lowest average costs, lending some credence to the premise behind state policies and programs that seek to reduce the cost of PV by accelerating deployment."[13]

Among the sample reporting to Lawrence Berkeley, capacity-weighted average system installed costs declined from $10.8/W in 1998 to $7.5/W in 2008 **(Figures 2),** for an average annual reduction of $0.3/W (3.6% per year in real dollars).[14] On a simple average basis, the costs declined from just over $12/W to just over $8/W during the same period. The long-term decline in installed costs from 1998 to 2008 is primarily attributable to a drop in *non-module* costs. Non-module costs declined from approximately $5.90/W in 1998 to $3.80/W in 2008, a drop of $2.10/W. Most of this decline occurred before 2006.[15] Over this 11-year period, module prices dropped by only $1.30/W; their prices declined more sharply in 2009. Non-module costs can include inverters, other hardware, labor, permitting and fees, shipping, overhead, and profit; they are the difference between average total installed cost and module cost. [16]

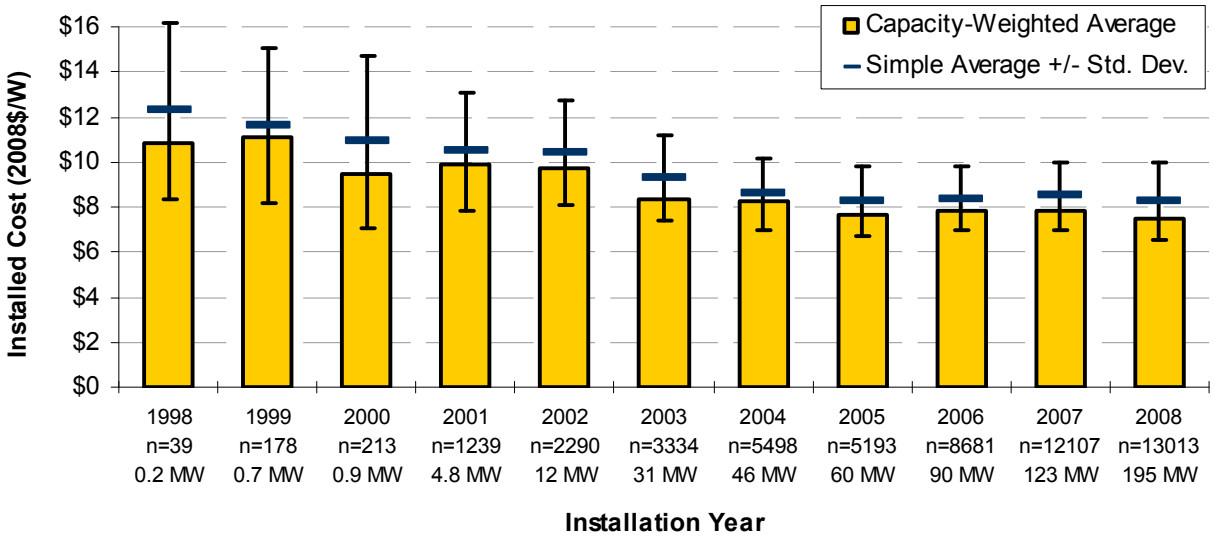
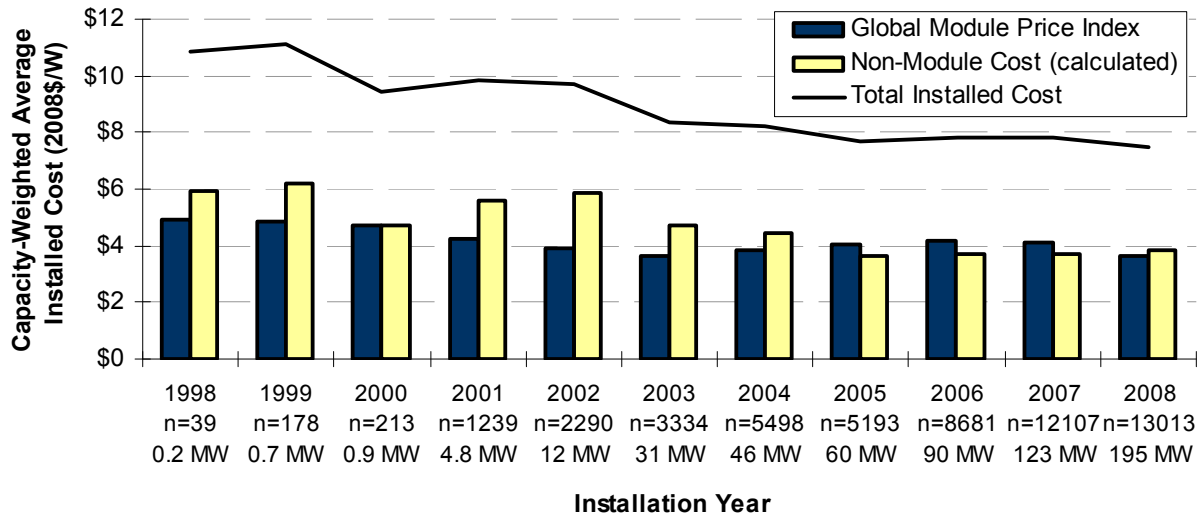


Figure 2. Installed Cost Trends over Time
Source: Lawrence Berkeley National Lab. (Wiser et al 2009)[17]

[13] Wiser, et al , "Tracking the Sun II. The Installed Cost of Photovoltaics in the U.S. from 1998-2008," http://eetd.lbl.gov/ea/EMS/re-pubs.html,
[14] Wiser, et al , "Tracking the Sun II. The Installed Cost of Photovoltaics in the U.S. from 1998-2008," http://eetd.lbl.gov/ea/EMS/re-pubs.html,, p.10.
[15] From 2005 through 2008, however, non-module costs remained relatively stable; from 2007 to 2008, non-module costs increased slightly while module costs declined by $0.5/W.

[16] The average annual price of power modules published by Navigant Consulting 2008 is used.
[17] This data on PV installation cost trends was provided by Wiser et al 2009, of LBNL, before the publication of their full report, "Tracking the Sun II. The Installed Cost of Photovoltaics in the U.S. from 1998-2008," http://eetd.lbl.gov/ea/EMS/re-pubs.html,.



Note: Non-module costs are calculated as the reported total installed costs minus the global module price index.

Figure3: Module and Non-Module Cost Trends over Time
Source: Lawrence Berkeley National Lab. (Wiser et al 2009)

Modules

Current global module costs range from approximately $1.80-4.31/watt, with large declines in 2009 that are largely due to the precipitous decline in global demand for PV and recessionary credit markets. At the high end of this range, module prices are down 53 cents per watt in the U.S. (December 2008 to December 2009). [18] The low end of the range reflects high-volume purchases. From August – October, 2009, average U.S. module prices were approximately $2.20-3.50/watt.[19]

Figure 4 shows module price trends over time for the purchase of a single module; these module prices are significantly higher than "factory gate" prices or volume purchase prices. In some cases, current module costs have fallen in recent months by 50% or more, to less than $2/watt, for modules sold in large volume and/or wholesale markets.[20] In 2008, modules represented between 56% and 58% of total installed costs.[21] Based on the range of $1.90-4.31/watt for modules, installed system costs would be approximately $3-3.50/watt for the low end of the range, i.e. large utility-scale module-based systems, and $7-8/watt for residential module-based systems on the higher end. These costs are consistent with the approximately $5.60/watt cost averages across all systems captured through eight other sources in the NREL Strategic Energy Analysis Center cost data page http://www.nrel.gov/analysis/costdata.html (and attached

[18] SolarBuzz, http://solarbuzz.com/. The European index is down 45 euro cents (SolarBuzz). Modules for large utility-scale installations will be on the low end of this cost range, with the high end reflecting the current price for the purchase of a single module.
[19] Q3 2009 Citigroup installer survey, October 15, 2009.
[20] Q3 2009 Citigroup installer survey, October 15, 2009.
[21] *Tracking the Sun II* http://eetd.lbl.gov/ea/EMS/emp-pubsall.html. Lawrence Berkeley National Lab - Ryan Wiser, Galen Barbose, Carla Peterman, Naïm Darghouth, p. 16.

spreadsheet). Other (non-module) costs are much more constant than modules across system size.[22]

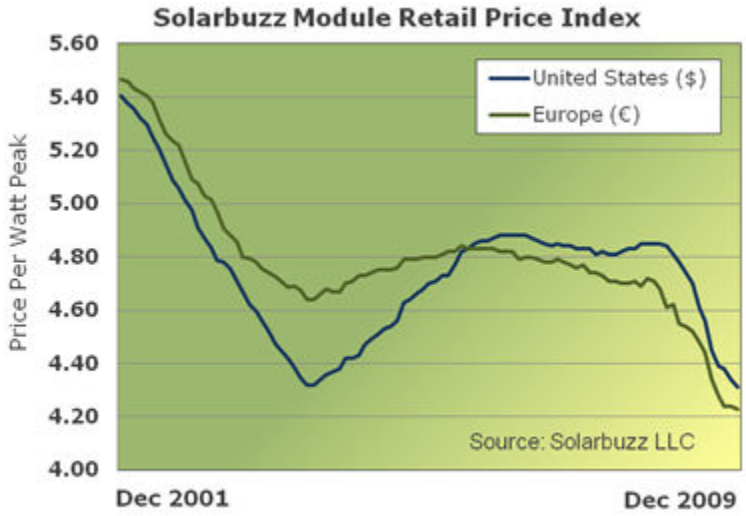


Figure 4: SolarBuzz Module Retail Price Index, 2001-2009

Source: http://www.solarbuzz.com/ModulePrices.htm

Inverters

Current costs for inverters are approximately $0.72 per continuous Watt and have held mainly constant for the past 18 months.[23] SolarBuzz tracks these data through industry surveys. http://www.solarbuzz.com/Inverterprices.htm.

[22] *Tracking the Sun II* http://eetd.lbl.gov/ea/EMS/emp-pubsall.html. Lawrence Berkeley National Lab - Ryan Wiser, Galen Barbose, Carla Peterman, Naïm Darghouth, p. 16.

[23] SolarBuzz. http://www.solarbuzz.com/Inverterprices.htm.

LCOE

To assess the value of procuring solar energy, utilities assess the solar energy system's average annual cost of energy (the levelized cost of energy, or LCOE), for comparison against alternative sources of electricity. Utilities must also assess the daily and monthly production of a solar energy system, to compare against its load profile and cost structure. As solar's production profile often overlaps times of higher load, solar can reduce procurement of more costly intermediate or peak power. In some utility service territories, solar energy is already less expensive than peak power. LCOE is a function of many variables and assumptions, most notably the quality of the solar resource, installed cost, and financing assumptions.

For residential and commercial installations, preliminary DOE analyses show U.S. LCOE for PV in the range of approximately $0.16/kWh to about $0.31/kWh (when calculated with the federal ITC, but *without* state, utility, or local incentives).[24] As of August 2009, Lazard estimated LCOE at 0.16/kWh to $0.20/kWh for crystalline silicon PV installations and $0.13/kWh to $0.18/kWh for thin-film, with the federal ITC incorporated into both those estimates.[25] For utility-scale installations, LCOE is likely significantly less: 0.10/kWh to $0.18/kWh, according to recent DOE analyses.[26] For indicative purposes, **Figure 5** shows some LCOE values in 2008 for residential PV systems in selected U.S. Cities.

[24] Data based on current DOE analyses still in process, which assumes $7/w installed system cost for residential installations. Without the ITC, the range for these same cities is about $0.28/kWh to $0.46/kWh. In the analyses to date, range is 0.16/kWh to $0.25/kWh for residential PV, and 0.16/kWh to $0.31/kWh for commercial systems. http://www.solarbuzz.com/solarprices.htm has current LCOE values as follows: $.0.35/kWh for residential systems, $0.25/kWh for commercial systems, and $0.20/kWh for industrial systems.

[25] Lazard, "LEVELIZED COST OF ENERGY ANALYSIS – VERSION 3.0," August 2009. P. 2. Reflects production tax credit, investment tax credit and accelerated asset depreciation, as applicable. Assumes 2008 dollars, 20-year economic life, 40% tax rate and 5-20 year tax life. Assumes 30% debt at 8.0% interest rate, 40% tax equity at 8.5% cost and 30% common equity at 12% cost for Alternative Energy generation technologies. Assumes 60% debt at 8.0% interest rate and 40% equity at 12% cost for conventional generation technologies. Assumes coal price of $2.50 per MMBtu and natural gas price of $6.00 per MMBtu. For crystalline installations, low end of range represents single-axis tracking crystalline. High end represents fixed installation. Crystalline installation range represents estimated implied levelized cost of energy in 2012, assuming a total system cost of $3.50 per watt for single-axis tracking crystalline. Thin-film estimates represent a leading thin-film company's targeted implied levelized cost of energy in 2012, assuming a total system cost of $2.00 per watt.

[26] Several factors may result in lower LCOE for utility-scale installations, e.g. lower operations and maintenance costs and inverter replacement costs. This range assumes a straight installed system price of $5/watt, including one-axis tracking at a little above $.50/watt.

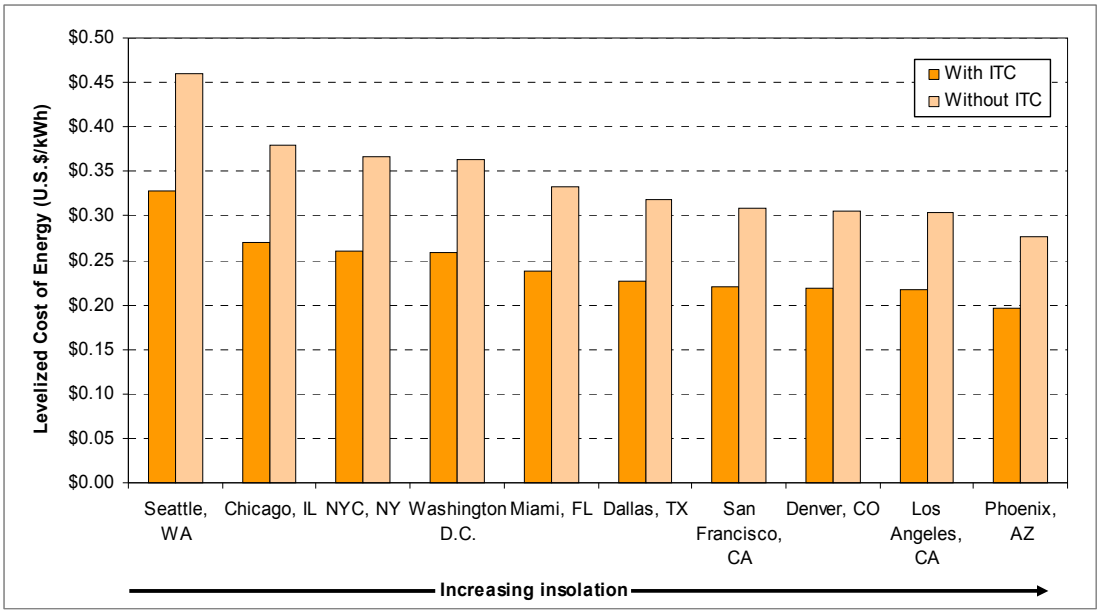


Figure 5. LCOE for residential PV systems in several U.S. cities in 2008, with and without the federal investment tax credit
Source: NREL 2009[27]

In-state solar PV resource and average in-state capacity factors **(Table 2)** are significant variables in determining LCOE. NREL delivered these data to Consortium states on October 20, 2009. (Consortium Deliverable #1, from Donna Heimiller of NREL). In the first quarter of calendar 2010, NREL will work with individual PUC Consortium members on further analysis on in-state LCOEs and the variables informing them. Among the cities in Figure 5, only Denver is among the Consortium cities.

State	Avg. Rsce	Avg. CF
CO	5.7	0.238
GA	5	0.208
KY	4.6	0.192
MI	4.2	0.175
MO	4.8	0.2
OH	4.3	0.179
TN	4.7	0.196

Table 2: Average PV Resource (KWh/m2/day) and Average PV Capacity Factor, By State for 7-State Resource Characterization Consortium

Source: NREL (Assumes tilt = Latitude)

[27] Assumptions: residential market, 30-year analysis period, 30-year mortgage, 100% financed, 6% interest rate, 6% discount rate, marginal tax rate 35%, installed cost $7.5/W, $300 inverter replacement at year 10, $280 inverter replacement at year 20, panel degradation 0.5%/year, ITC covers 30% of initial cost, no state or local incentives.

Data Sources

This report captures current PV cost values from several sources:

- NREL Open PV mapping project http://openpv.nrel.gov/ - for regional, state, and installation-specific data.

  Released in October 2009 by the U.S. Dept. of Energy and the National Renewable Energy Laboratory, the goal of this open mapping project is to collect information about all PV systems in the United States. A variety of state entities and utilities, including those in the 7-State Consortium, have contributed the bulk of the current number of systems captured by the database. To date, the database contains 59,504 systems totaling 633 MW. The database can be viewed at the national level *and* the state and 5-digit zipcode levels. The system can show cost trends by year, by system size, and by location for the country.

  Seeded by data from a large number of state and municipal sources that track PV system data for subsidy reasons, the goal of this tool is to capture total system cost, size, location and other data for all U.S. PV installations.

- NREL Strategic Energy Analysis Center cost data page (itself capturing several cost data sources) http://www.nrel.gov/analysis/costdata.html

  In 2009, NREL formalized and consolidated cost and performance data collection efforts from a variety of sources. On an ongoing basis, these data are compared and reconciled.

- NREL 2008 DOE Annual Solar Market Trends Report [not yet publically released]

- Lawrence Berkeley National Lab, *Tracking the Sun II* http://eetd.lbl.gov/ea/EMS/emp-pubsall.html, by Ryan Wiser, Galen Barbose, Carla Peterman, Naïm Darghouth, October 2009.

- SolarBuzz http://solarbuzz.com/

  Private consulting firm that gathers data on PV component parts based on monthly industry survey, good source of current data.

- Lazard, *Levelized Cost of Energy Analysis - Version 3.0,*" August 2009.

Addendum: Relevant PV Data, from Projects Reporting Data to Open PV Mapping Project