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Letting the Sun Shine on Solar Costs: An Empirical Investigation of Photovoltaic Cost Trends in California

Executive Summary

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Disclaimer

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Executive Summary

Introduction

Markets for customer-sited photovoltaic (PV) systems are expanding rapidly, albeit from a small base. Government incentives aimed at encouraging reductions in the cost of PV over time are the principal drivers for the recent worldwide growth in grid-connected PV capacity.

This report provides an in-depth statistical analysis of PV system costs in California. Through mid-November 2005, a total of 130 MW_{AC} of grid-connected solar capacity was installed throughout California,[i] making that state the dominant market for PV in the United States, though it still stands a distant third on a worldwide basis behind Germany and Japan.

The results presented here are based on an analysis of 18,942 grid-connected PV systems totaling 254 MW_{AC},[ii] either installed, approved for installation, or waitlisted (approved but awaiting program funding) under what are currently the two largest PV programs in the state. This analysis provides insights on California's PV market by exploring cost trends, and by untangling the various factors that affect the cost of PV systems. Results also have important policy ramifications, as they address the interaction between incentive levels and installed costs, and the relative cost of different PV applications.

California's Solar Programs

California's PV market is driven by a mixture of state and local incentives. Most prominent are capital cost rebates – denominated in $ per Watt – offered to PV system installers or owners to "buy down" the installed cost of solar installations. The two most significant current rebate programs are overseen by the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC), and it is on these two programs that our analysis is based.

The CEC has administered a PV rebate program since March 1998, focusing more recently on grid-connected systems under 30 kW in size. The CPUC's program began accepting applications in July 2001, and provides rebates to PV systems of at least 30 kW in size. Both programs primarily target customers served by the state's investor-owned utilities.[iii] Over time, both programs have altered the structure and size of their incentives for PV installations, as shown in Figure ES-1. In particular, the CEC initiated five gradual reductions beginning in 2003, while the CPUC imposed a single large reduction in late 2004 and a more recent reduction in mid-December 2005. On January 12, 2006, the CPUC ordered a dramatic expansion of these programs with a $3.2 billion, 11-year program of declining incentives.

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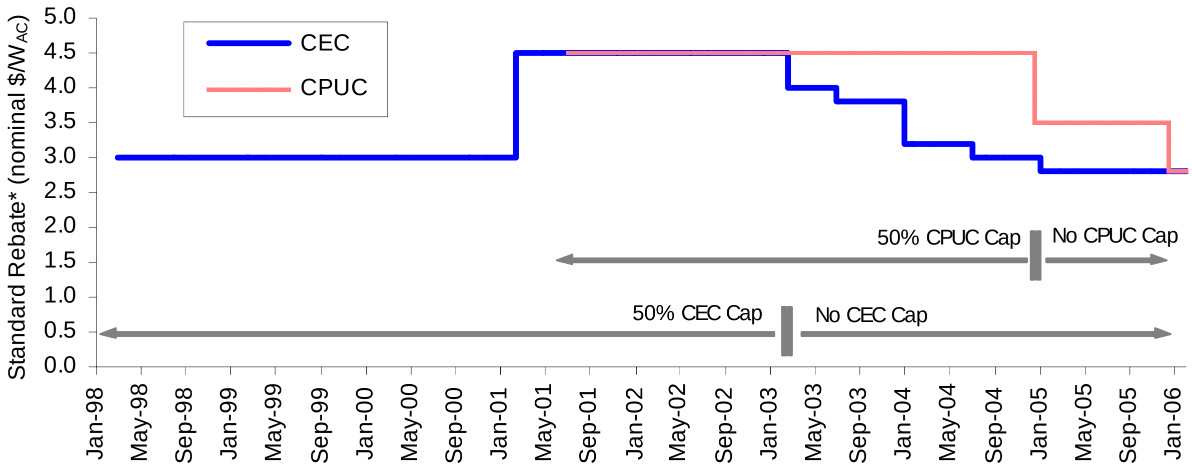
[i] This estimate of 130 MW_{AC} includes PV systems funded under municipal utility programs, in addition to the CEC and CPUC programs analyzed in this report.

[ii] Unless explicitly presented as otherwise, data on PV capacity and costs are expressed throughout this report in terms of W_{AC} (e.g., W_{AC}, kW_{AC}, MW_{AC}, $\$/W_{AC}$), which we convert (where necessary) from $W_{DC\text{-}STC}$ (DC Watts at standard test conditions) using a de-rate factor of 0.84. We acknowledge that many other solar programs and data sources use $W_{DC\text{-}STC}$, making comparisons of California data with those in other states and countries more difficult. Given, however, that our underlying system cost data is expressed in terms of W_{AC}, this is the standard that we use.

[iii] At various times, customers of publicly-owned utilities have also been eligible to participate.



* Within the CEC's program, systems installed on affordable housing and schools have, at times, received higher incentives; owner-installed systems have, at times, received lower incentives; systems >30 kW$_{AC}$ were eligible for rebates from program inception to February 2003; and systems >10 kW$_{AC}$ received $2.5/W$_{AC}$ (capped at 40%) from March 1999 to February 2001.

Figure ES-1. Standard Rebates for the CEC and CPUC Programs

Analysis Results

The CEC dataset used for our analysis was updated through April 2005, and contains 17,889 data records (72.8 MW$_{AC}$), including 12,856 completed systems (48.5 MW$_{AC}$) and 5,033 systems that had been approved for a rebate, but that were awaiting completion at the time we received the dataset (24.3 MW$_{AC}$). The CPUC program generally covers systems of at least 30 kW, and our dataset includes 1,053 data records (180.8 MW$_{AC}$), including 327 completed systems (35.7 MW$_{AC}$), 464 approved systems (73.4 MW$_{AC}$), and 262 waitlisted systems (71.7 MW$_{AC}$). Analysis of each dataset was conducted using multivariate regression techniques; the dependent variable was the pre-rebate installed cost of PV systems, in 2004 $/W$_{AC}$. Key findings include:

Solar Costs Have Declined Substantially Over Time, But Less So Under the CPUC's Program: In real dollar terms, average pre-rebate total installed costs under the CEC's program have declined substantially, from more than $12/W$_{AC}$ (2004 $) in 1998 to less then $9/W$_{AC}$ for 2004-05 (see Figure ES-2, where time is expressed in quarter-year intervals). Regression results show annual average cost reductions among the CEC-funded systems of approximately $0.70/W$_{AC}$, representing a 7.3% annual decline. Larger systems (e.g., 10-30 kW) funded by the CEC are found to have experienced more modest cost reductions than have smaller systems.

As suggested by Figure ES-2, some of the overall cost reductions within the CEC program are due to decreases in worldwide module costs (notwithstanding the recent increase in those costs).[iv] In fact, regression results confirm that changes in worldwide module costs have largely been passed through directly to PV system purchasers on a one-for-one basis. Much of the

[iv] Although the CEC database does, in some cases, contain disaggregated information on module, inverter, and labor costs, this information is only sparsely reported (and the CPUC database does not provide such information at all). As a result, we have used an external index of worldwide module costs over time from Strategies Unlimited to proxy module costs for each California system. Non-module costs are then simply the total system cost less the relevant module cost index value. Though it would be interesting to more narrowly pinpoint specific drivers of cost reductions, given current limitations in the data, the best we can do is to crudely split total costs into module and non-module costs. Collecting and analyzing more-detailed cost disaggregations data is an area ripe for future work.

overall cost reduction, however, has come from improvements in *non-module* costs – e.g., installation and balance of system costs.

This reduction in non-module costs for CEC-funded systems is encouraging. Unlike module costs, which are set in a worldwide market and are therefore heavily influenced by factors outside of the control of an individual PV program (e.g., demand for PV in Japan and Germany), non-module costs are potentially subject to the influence of local PV programs. And given (as noted above) that changes in worldwide module costs appear to simply flow through directly to total system costs, reducing non-module costs may be the most appropriate goal for local PV programs. Though we are unable to prove conclusively that non-module cost reductions in California have been *caused* by the state's incentive programs, our analysis results do show that non-module cost reductions have been significant.

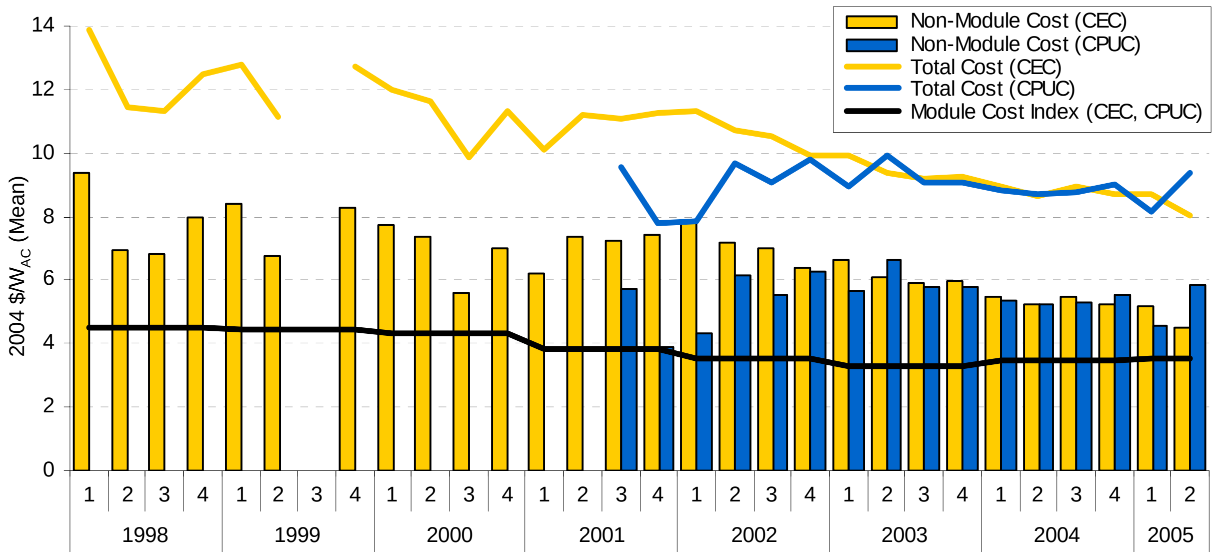


Figure ES-2. Costs Trends Over Time (CEC and CPUC)

In contrast to the longer-running CEC program, which exhibits clear downward cost trends over time, costs under the CPUC's program have declined more moderately (though Figure ES-2 does show a more substantial decline – in lock-step with the CEC program – since 2003). Compared to the \$0.70/W_{AC} (7.3%) average cost reduction in the CEC dataset, regression results show that systems funded by the CPUC have seen annual average reductions of \$0.36/W_{AC} (4.1%).[v] A regression of the *combined* CEC and CPUC datasets over the time period in which the two programs overlap shows similar annual reductions: \$0.91/W_{AC} (CEC) and \$0.36/W_{AC} (CPUC).

The more-aggressive (and visually apparent) CEC cost reductions may be due to the larger proportional labor and installation costs associated with smaller (< 30 kW) systems and the greater opportunities in that market segment for distribution and installation efficiency gains.[vi] Alternatively, it could be a result of policy design – whereas the CEC has (since 2003) gradually

[v] Though Figure ES-2 does not provide a clear visual trend of declining system costs over the entire duration of the CPUC program, the regression results – by controlling for other factors – are more reliable than the visual evidence provided in the Figure.
[vi] We find this same effect – smaller systems exhibiting greater cost reductions over time – not only across programs, but also within each of the two programs.

lowered its rebate over time, the CPUC has been slower to follow suit (see Figure ES-1). Though Figure ES-2 – which shows the CEC and CPUC costs declining lock-step since 2003 – would appear to discount these explanations, it is important to note the bivariate nature of Figure ES-2, and its failure to control for other variables (in contrast to multivariate regression analysis, which isolates the impact of each individual variable). Nonetheless, the quality of our data does not allow us to definitively explain the difference in cost reductions between the two programs, or even prove that the programs themselves are responsible for the cost reductions.[vii] We recommend that future work explore these questions in more detail.

Policy Incentives and Rebate Levels Impact Pre-Rebate Installed Costs: Figure ES-3 shows a tight relationship between standard rebate levels and average pre-rebate installed costs among the CEC-funded systems since mid-2000. This close relationship is confirmed through regression analysis. In particular, we find that each $1/$W_{AC}$ change in the rebate level has, on average, yielded a $0.55-0.80/$W_{AC}$ change in pre-rebate installed costs (with the range representing results from different regression models). In other words, when the CEC increased its rebate level by $1.5/$W_{AC}$ in early 2001, system purchasers may have only realized $0.3-$0.7/W_{AC} of that increase on average, with the remaining $0.8-$1.2/W_{AC} being "captured" by system retailers or installers through correspondingly higher prices. By the same token, regression results suggest that as the CEC has gradually reduced its rebate level since early 2003, system retailers have absorbed some of the decrease by reducing prices.

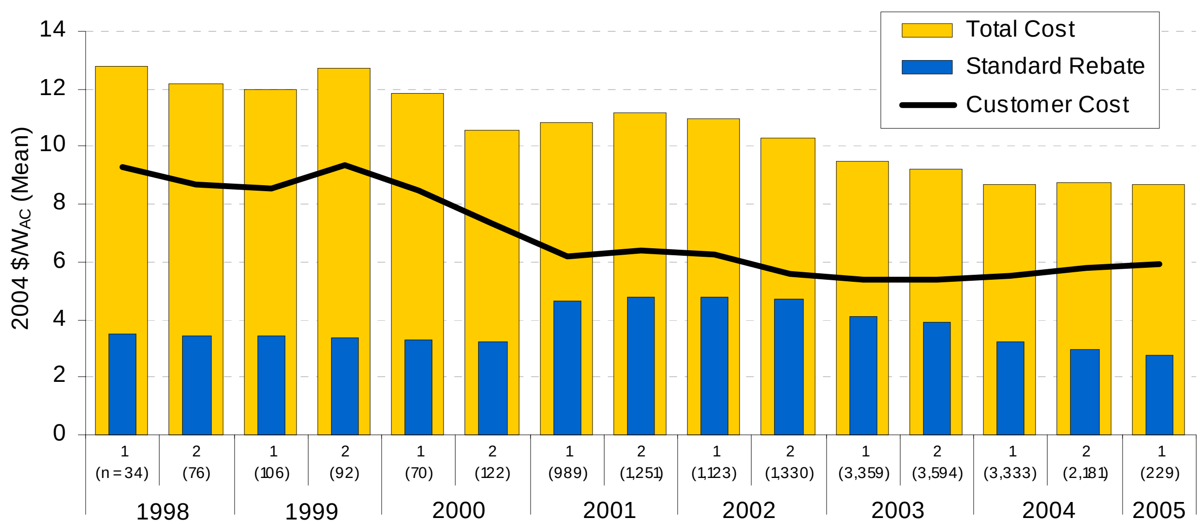


Figure ES-3. Impact of Standard Rebate Level on Average Installed Costs (CEC)

We also find some evidence that the existence of the percentage rebate cap prior to 2003 may have increased pre-rebate system costs somewhat under the CEC program. This result is

[vii] Though it is perhaps logical to assume that California's PV programs have caused, or at least contributed to, the empirical cost reductions, nothing in our analysis enables us to assign causation – i.e., we are unable to definitively conclude that the California programs are driving the cost reductions. To be able to assign causation, we would need to similarly analyze a "control" market – i.e., one in which no PV incentive programs exist. Identifying such a market for PV may be difficult or impossible, given the widespread public support that PV has garnered, but future work could at least analyze other markets in which PV is subsidized, but to a different extent or in a different manner than in California.

consistent with widespread speculation that this cap – which limited the size of the rebate to 50% of total eligible costs in an attempt to ensure that the program did not over-subsidize lower-cost eligible technologies (such as small wind) – has, perversely, encouraged artificial cost *inflation* as a way to maximize the dollar amount of the rebate.

Analysis of the CPUC dataset yields results that are substantially less policy-rich than those from the CEC's dataset. Nonetheless, we find evidence to support the oft-heard claim in California that the CPUC's richer incentives in recent years ($4.5/W_{AC}$ until December 2004, with a 50% cap) have not motivated system cost reductions to the same extent as under the CEC's program (the CEC's program also offered $4.5/W_{AC}$, but reduced that incentive earlier and more rapidly than did the CPUC – see Figure ES-1). As supported by Figure ES-4, regression results show that, among similar sized systems (20-40 kW), those funded by the CPUC's program have had pre-rebate installed costs that are on average roughly $0.60/W_{AC}$ higher than those funded by the CEC. Furthermore, some of the systems in the CPUC dataset received sizable local incentives (of more than $2/W_{AC}$), *in addition* to those offered under the CPUC's program. These systems recorded higher average costs of roughly $0.60/W_{AC}$ than did equivalent systems that did not have access to additional incentives. We also find some evidence (though not through the regression analysis) that the percentage rebate cap in place prior to December 2004 affected PV pricing during that period.

California has also offered a state income tax credit for systems under 200 kW in size, ranging from 7.5% to 15% of installed costs, depending on the year of installation. Statistical analysis of both the CEC and CPUC datasets offers evidence that the existence and size of the state tax credit has increased pre-rebate installed costs to some degree. Retail electricity rates, on the other hand, are not found to affect pre-rebate total installed costs, though as discussed in the body of the report, our retail electricity rate variable is imperfect.

In aggregate, these results suggest that heavy subsidies dampen, to some degree, the motivation of installers to provide, and/or customers to seek, lower installed costs.[viii]

Economies of Scale Drive Down Costs as System Size Increases: Focusing on the period in which both the CPUC and CEC programs were operating simultaneously, Figure ES-4 shows that average system costs fall substantially for larger systems (i.e., there are economies of scale) in both datasets, though both datasets also show a leveling off of those economies among larger system sizes. Regression results confirm these trends. The largest systems in the CEC dataset are roughly $2.5/W_{AC}$ cheaper than 1 kW installations. Meanwhile, the largest CPUC-funded systems are roughly $1.5/W_{AC}$ less expensive than the smaller systems funded by that program.[ix]

[viii] Though some might be inclined to read into these results an argument for switching from capacity-based to performance-based incentives, we note that there is nothing in our dataset or analysis that allows us to comment on the relative superiority of one incentive type over another.

[ix] The up tick in average installed costs for CPUC systems sized between 60 and 100 kW is somewhat of an anomaly, being heavily influenced by 59 identical applications (out of 209 total applications in this size range), all submitted on the same day, by the same installer, and at the same estimated installed cost of $9.82/W_{AC}$ (2004$).

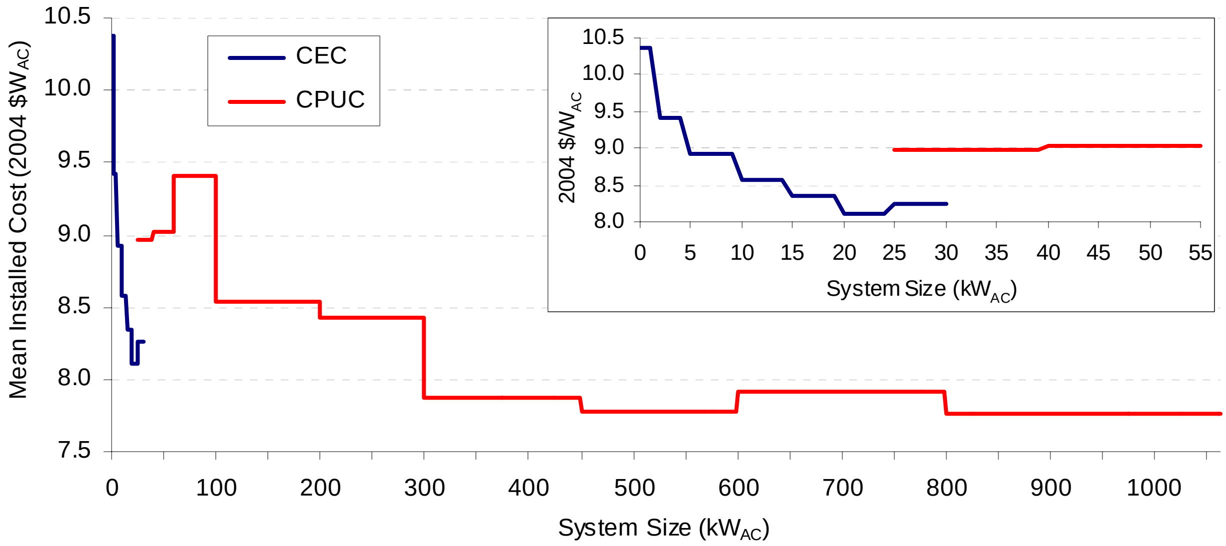


Figure ES-4. Installed Cost, by System Size (CEC and CPUC)

Systems Installed in Large New Home Developments and in Affordable Housing Projects Experience Much Lower Costs: Regression results show that systems installed (or planned for installation) under the CEC's program in large new residential developments (totaling 1,946 systems) have lower costs of approximately $\$1.2/W_{AC}$, on average, compared to the general retrofit market. Similarly, the 340 systems used in affordable housing applications, which often involve new construction and presumably enable bulk system installation, exhibit costs that are $\$1.9/W_{AC}$ lower than the general retrofit market. Systems installed in single new homes (or small clusters of new homes) exhibit modestly higher costs of approximately $\$0.18/W_{AC}$, perhaps due to the custom-designed nature of many of these systems, as well as a lack of the economies of scale possible in larger new home developments. Systems installed at schools (most are retrofits) do not have statistically significant differences in cost compared to the general retrofit market.

Installer Experience and Type Affects Costs: Within the CEC program, more-experienced installers and retailers are found to charge slightly more for their services – approximately $\$0.29/W_{AC}$ and $\$0.17/W_{AC}$, respectively – relative to those with less experience. In contrast, more-experienced installers under the CPUC's program have priced their systems at *lower* levels than less-experienced installers, with a differential of nearly $\$0.70/W_{AC}$ on average. The reason for this discrepancy between the two programs is unclear. Meanwhile, owner-installed systems in the CEC program (n=862) are found to have considerably lower reported costs than contractor-installed systems, with a $\$1.8/W_{AC}$ savings on average. Similarly, the sixteen CPUC-funded systems installed at fairgrounds by the California Construction Authority have come in at a substantially lower cost than other systems, with a cost differential of roughly $\$4/W_{AC}$, on average.[x] These results suggest that the CEC's current practice of providing reduced incentives for owner-installed systems is appropriate.

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[x] The California Construction Authority (CCA) is a Joint Powers Authority organized in August 1988 to provide financing, design, inspection and construction management services for fairgrounds throughout California. The low cost of the CCA systems is perhaps partially attributable to bulk equipment purchases for multiple fairground

The Impact of Module Type Varies By Program: In the CEC dataset, projects using thin film PV technology – of which there are 318 – are found to have had systematically lower costs than those relying on traditional crystalline silicon, with a differential of roughly $0.70/$W_{AC}$ on average, though this cost differential has narrowed over time. Though only bordering on statistical significance, projects using thin film technology in the CPUC dataset – of which there are 111 – are found to have slightly *higher* costs on average over the course of that program (~$0.20/$W_{AC}$). The reason for this discrepancy between the two programs is unclear.

System Location Has Impacted Costs: The population density of the location of installation appears to have some effect on system costs in the CEC dataset, with more densely populated areas experiencing higher average costs. This finding is consistent with the idea that population density may be a proxy for the cost of living, and therefore labor costs. Meanwhile, CEC-funded systems installed outside of PG&E's service territory report lower average pre-rebate costs than those installed within PG&E's service territory. In contrast, CPUC-funded systems installed outside of PG&E's territory report higher pre-rebate costs on average. Further analysis would be required to understand why costs vary by service territory, and why these effects vary between the CEC- and CPUC-funded systems.

Conclusions and Recommendations

Results presented here reveal a number of expected, and some unexpected, trends. Perhaps of most importance, we find substantial reductions in PV system costs over time, especially among systems funded by the CEC's program. Although our analysis cannot, without comparison to a control group, definitively conclude that the CEC and CPUC programs *caused* these cost reductions, it is clear that – despite the lack of continuity and stability experienced by both programs – pre-rebate installed costs have come down.

Several policy recommendations derive from our analysis:

- ***Reducing non-module costs should be a primary goal of local PV programs.*** Unlike module costs, which are set in a worldwide market and are therefore heavily influenced by factors outside of the control of an individual PV program, non-module costs are potentially subject to the influence of local programs. State policymakers may wish to undertake programmatic activities aimed specifically at reducing non-module costs, which could range from targeted approaches to building local supply infrastructure (e.g., providing business development funding to installers, supporting standardized PV products, or offering installer training and certification), to something as simple as making PV system cost and performance data more publicly accessible to further encourage supply competition.

- ***Sustained, long-term programs may enable more significant cost reductions.*** Sustained, sizable, and stable markets for PV may be the most direct way of reducing non-module costs because such markets will presumably attract suppliers and encourage those suppliers to

projects. Some have also speculated that the CCA is able to install systems at apparently lower costs than the PV industry at large due to the fact that it has no marketing, sales, or overhead costs, and/or that certain internal costs are not reported. In other words, CCA-installed systems in the CPUC program are essentially the equivalent of owner-installed systems in the CEC program.

create an efficient delivery infrastructure. Though PV cost reductions in California are significant, at least among CEC-funded systems, experience from Japan suggests that deeper cost reductions are possible with a more sustained policy effort. In mid-January 2006, the CPUC issued an order that intends to create such a market with an 11-year, ~$3.2 billion program of declining incentives. A goal of the adopted program is to reduce rebate levels by roughly 10% each year, in nominal terms, which will require installed PV costs to continue to drop over time.

- ***The structure and size of PV incentives should encourage cost reduction, not cost inflation.*** We find some troubling evidence that policy design has adversely impacted the cost of PV systems in California. For example, the 50% cap on the size of the rebate employed by both programs at one time or another appears to have, at best, impeded cost reductions, and at worst, contributed to artificial cost inflation. As such, the decision by both programs to abandon such percentage caps is a positive development; we encourage other PV programs to do the same. Furthermore, the total pre-rebate cost of PV installations in California has tracked, to some degree, the size of the rebate itself. Whether this link is merely representative of the "teething problems" that are typical of new programs,[xi] or should instead be of long-term concern is somewhat unclear. As rebates are reduced over time, however, we expect that the link between incentive levels and pre-rebate installed costs will be severed, as lower rebates require contractors to price systems at cost in order to ensure a sale. Hence, while rich incentives may be required initially to jump-start the market, over time the incentives should decline to a level that can support a functional market infrastructure without providing room for potential price manipulation.

- ***Targeted incentives that account for the relative economics of different system sizes and application types may be appropriate.*** Though there is a significant spread in the data, our analysis shows that installed costs are heavily dependent upon the size and type of installation. We find clear evidence of sizable economies of scale in PV installations. We also find that systems installed in large new home developments are, on average, far more economical than retrofitted systems. These results suggest that a further targeting of incentives to account for the relative economics of different system sizes and application types may be appropriate.

[xi] Such "teething problems" might include initial over-subsidization intended to spur the market, coupled with insufficient supply infrastructure to handle the resulting increase in demand, leading to lackluster competition and artificial price increases until new supply infrastructure enters the market.