THE ECONOMICS OF SOLAR HOMES IN CALIFORNIA

How Residential Photovoltaic Incentives Can Pay Off for Homeowners and the Public

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Executive Summary

Developing clean, abundant solar power resources in California can benefit all those who live and work in the state – reducing air pollution, protecting consumers from volatile electricity prices, and reducing the need for expensive upgrades to electric transmission and distribution systems. By providing incentives in the near term for installing solar photovoltaic systems on residences, the state can reap these public benefits while helping the bottom line of solar homeowners.

Including solar photovoltaic (PV) systems in new housing in California can result in significant public benefits.

Societal benefits of solar power development – in the form of reduced electric system costs, mitigation against price volatility, environmental benefits and encouragement of new business opportunities – rarely are assigned an economic value. Nevertheless, studies suggest that the value of this power to Californians is significant:

- **Reduced electric system costs:** To meet rising demand for electricity in California, utilities (and in turn, ratepayers) will either need to invest in expensive transmission upgrades, improve energy efficiency, or develop local resources. Solar PV delivers power during peak demand times when it is most needed. Studies have shown that it is cost effective for utilities to invest as much as $2,200 to $4,500 for every kilowatt of solar power developed in lieu of other capital investments.
- **Mitigation against price volatility:** California now depends on natural gas to supply nearly half of the state's electricity needs. This dependence on natural gas leaves Californians vulnerable to volatile prices and steadily increasing fuel costs – natural gas prices have doubled between 1995 and the present. Increased use of solar PV can reduce future demand for natural gas and provide a hedge against future price fluctuations.
- **Environmental benefits:** PV systems reduce air pollution emissions that result from fossil fuel power generation – particularly global warming gases (carbon dioxide) and smog-forming emissions (nitrogen oxides). A study conducted for the Sacramento Municipal Utility District found the benefits of averting these emissions could range from $38 to $1,048 per kilowatt of capacity.

Installing solar PV systems on new housing has the potential to maximize these benefits by reducing the costs of solar PV installations. Builders of new homes are often able to achieve bulk discounts for PV module purchases while saving on installation costs.

A buy-down grant of $2,800 per kilowatt of installed solar capacity in 2006 would enable solar PV to generate economic benefits for many buyers of new homes in California while compensating homebuyers for the societal benefits resulting from their decision.

Based on outputs from an economic model developed for the National Renewable Energy Laboratory, the installation of a 2.5 kW DC (2.14 kW AC) solar PV system priced at $6.00 per Watt can be expected to generate net eco-

Table ES-1. Economic Benefits of 2.5 kW DC Solar PV System on a New Home With $2,800/kW Buydown Grant

	Monthly Electric Bill Savings	Net Monthly Loan Payment (after tax, year 1)	Year 1 Savings	Cumulative Cash Flow (30 yrs.)	Net Present Value
San Jose	$57	$44	$152	$7,662	$2,722
Bakersfield	$53	$44	$100	$5,718	$1,989
San Diego	$54	$44	$122	$6,534	$2,296
Murrieta	$47	$44	$32	$3,144	$1,018
Fontana	$46	$44	$20	$2,702	$851
Rancho Cucamonga	$46	$44	$20	$2,702	$851
Irvine	$49	$44	$58	$4,116	$1,384
Long Beach	$49	$44	$58	$4,116	$1,384
Chula Vista	$49	$44	$52	$3,910	$1,307

nomic benefits for new homebuyers in nine of California's fastest-growing municipalities with a buydown grant of $2,800 per kW (AC). (See Table ES-1.)

- On average, residents of one of the nine communities listed above could expect to save $4,500 over the lifetime of their solar investment, with savings of $68 in the first year (if the system is financed as part of a 30-year mortgage). The net present value of that investment (which measures the benefits of the project versus the costs, both discounted back to the present) would average approximately $1,500.
- The amount of benefits a homeowner can expect from solar PV varies from place to place based on several factors – most importantly, the price of electricity. In cities such as San Jose, where utility rate structures are favorable to PV, solar PV could potentially be cost effective with incentives as low as $1,300 per kW, assuming savings from installing the systems during home construction.

These results – coupled with published estimates of the societal benefits of solar power – suggest that an aggressive state solar PV buydown program coupled with other incentives and standards for the inclusion of solar power in new homes, could benefit residential homebuyers, utility ratepayers and the state as a whole.

INTRODUCTION

California has much to gain from developing its solar power resources. Solar photovoltaic (PV) systems reliably harness free energy from the sun. They generate electricity when California needs it most – during peak demand times such as the hot, sunny summer days when air conditioners are running and the power grid is being stretched to its capacity. Moreover, solar PV systems create electricity without creating health-threatening smog pollution or global warming pollution associated with conventional fossil fuel power production.

In addition, solar PV is rapidly becoming a commercially self-sustaining industry. In fact, if California positions itself as a leader in solar manufacturing over the next few years, it is likely to realize significant revenues from exporting solar technology throughout the United States and the world. Developing state solar resources leads to direct benefits to the local economy, particularly when manufacturing, distribution, and installation are all local. In contrast, dependence on fossil fuels such as natural gas, coal, and oil results in large sums of money leaving the state.

As Californians, we all benefit from increased reliability, protection from fuel price volatility, a cleaner environment and a more vigorous local energy economy when a significant portion of the electric grid is supplied by "homegrown" solar power. But solar power faces a number of hurdles that have prevented it from becoming more widespread. Homeowners considering "going solar" often contend with high upfront costs, information barriers, and difficult interactions with utilities that deter many consumers from going forward.

Incorporating solar PV into new homes can alleviate many of these barriers by allowing builders to integrate solar into their building designs from the very start. But would an individual solar homebuyer benefit economically from the installation of solar panels on a new home without government support, or must a person purchasing a solar home simply subsidize the benefits for the rest of us?

The answer depends on a number of factors explored in this document: the cost of solar photovoltaic cells, the future costs of electricity, the amount of solar power that can be generated in a given location and the financing options available. It also depends on the government incentives that are available to help defray the initial capital investment involved with incorporating solar panels into a home – incentives that recognize the public benefits resulting from an individual's solar investment and help accelerate the point in time when a new industry with new jobs will generate tax revenues for the state.

Given realistic assumptions about most new homes that will be built in California over the decades to come, however, the answer is simple: California can develop tools to ensure that solar homebuyers in the Golden State contribute renewable energy to the benefit of all, without making a personal financial sacrifice.

Solar Power in California: An Abundant Resource

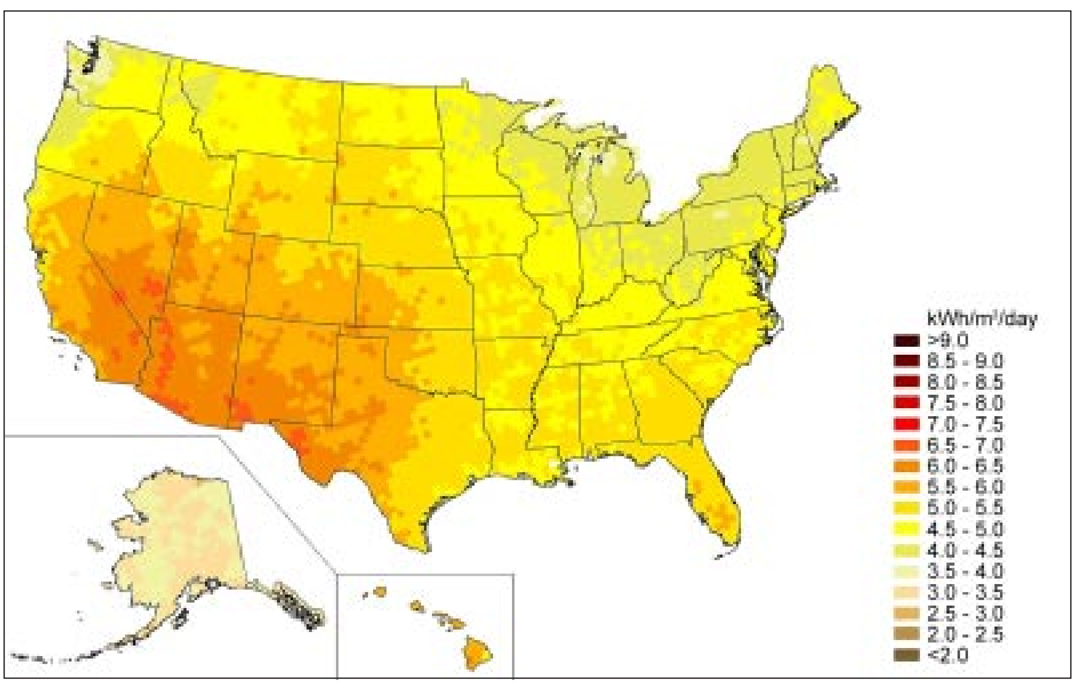
Each day, the sun provides enough energy to meet the world's energy needs thousands of times over. In contrast, other energy sources are becoming increasingly scarce. While governments and energy companies continue to seek out the remaining reserves of fossil fuels, attention is increasingly turning to developing cost-effective technologies for harnessing the energy of the sun.

California's Solar Resource

California is blessed by an abundant solar resource – nearly the entire state receives an average of more than 5 kilowatt-hours (kWh) of solar energy per square meter per day. Much of the state receives 5.5 to 6.5 kWh of solar energy daily.[1] The average California household consumes an average of about 16 kWh of electricity per day, meaning that the solar energy reaching a four square meter (about 43 square foot) plot could theoretically generate more than enough energy to supply the home, *if* the energy could be captured and used with no loss of energy and then be stored and used when needed.[2]

Unfortunately, electricity generated from solar PV typically cannot be cost-effectively stored. (Battery storage is available, usually at significant cost. However, future developments in hydrogen and fuel cell technologies hold the potential eventually to solve the storage dilemma.) In addition, solar PV systems do not generate electricity during the evening when residential customers are likely to need it for lighting, heating or cooling.

Figure 1. Annual Average Solar Radiation per Square Meter per Day[3]



However, solar panels do generate electricity when it is in greatest demand in California in the aggregate – during the daytime and particularly during hot, sunny weather in which air conditioning demand is great.

Because of these factors, the most efficient setup for most owners of solar photovoltaic (PV) systems is to remain connected to the electric grid – drawing power from the grid when needed and supplying power to the grid when they are generating more than they can use. Net metering, in which power flowing into and out of the house is monitored, allows consumers to be compensated for the extra power they supply to the grid. Net metering policies can have a large impact on the degree to which solar PV is cost-competitive for individual consumers.

Not all homes, new or existing, are equally able to take advantage of California's solar resource. For solar homes to operate most effectively, the solar PV system needs to be in the sunlight for most or all of the day. Since the sun is always in the southern half of the sky in California, south-facing roofs are generally preferable, though east or west-facing roofs may also work. Solar PV panels can also lie flat on a roof, but are optimized if they are tilted at an angle toward the south, increasing the amount of time that the full panel is exposed to the sun's rays.

Untapped Potential

Despite California's extraordinary potential to generate electricity from the sun, the state's abundant solar resource remains largely untapped. California is by far the national leader in solar electricity, generating 542 million kilowatt-hours (kWh) of electricity in 2001 – although this figure includes power generated from large-scale utility solar thermal installations, not just PV.[4] Solar power, however, contributes only a small portion of the electricity consumed in California's homes, businesses and factories – approximately 0.2 percent.[5]

While government has made some efforts to promote the use of solar PV, a number of hurdles remain. The up-front cost of solar PV, limits to net metering, problems with utility interconnection and rate policies, poor building design, and lack of knowledge about solar all contribute to the small role solar energy has played in California's energy supply to date.

Building Solar Panels into New Homes

Integrating solar PV systems into new home construction is an effective way to surmount many of the hurdles to greater PV penetration.

- First, by including PV in initial plans, builders can choose home and site layouts that can take maximum advantage of the solar resource – for example, by preserving southern exposure or by integrating PV into plans for high energy efficiency homes.
- Second, including PV in initial plans may reduce the cost of the system in a variety of ways. For example, builders may gain experience with PV installations and/or be able to achieve discounts on bulk orders of PV systems, while the building's electrical systems can be specifically designed to take advantage of PV.

Policies that encourage the development of "solar homes" have the capacity to ease the way for California to take better advantage of its solar resource, while reducing the costs of dependence on fossil fuels and nuclear power.

The installation of solar panels on homes in California has benefits for a broad range of California residents. Solar homes can reduce the cost of generating and delivering electricity, protect consumers from price volatility, reduce air pollution and enhance California's energy security and independence.

Reduced Electric System Costs and Price Volatility

Every solar panel installed on a rooftop in California provides economic benefits for all consumers of electricity by reducing the overall cost of producing and delivering electricity. Solar PV contributes to electricity cost savings by reducing the need for additional resources, such as upgrades to transmission lines or new power plants, to respond to peak demand, providing power locally, and reducing consumers' exposure to volatile fossil fuel prices.

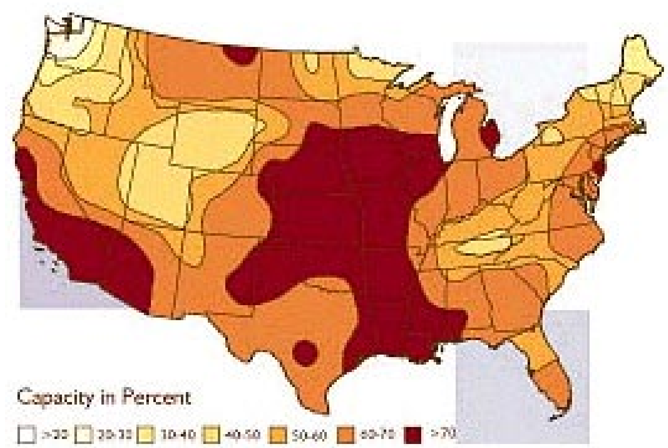
Smoothing System "Peaks"

The electric system must be designed to accommodate peak demand for electricity – even if such peak conditions occur for only a few hours each year. Smoothing the peaks in electricity consumption, therefore, can reduce the costs of operating the electric system, even if the overall amount of electricity consumed does not change.

Solar photovoltaics are perfectly situated to smooth peak demand. Solar PV generates power at times when power is needed most, such as when air conditioning is in heavy use. As a result it can displace the need for expensive (and often inefficient) peaking generation resources. It can also reduce the need for investments in transmission and distribution facilities needed to serve peak demand.

This is particularly true in California. Researchers with the National Renewable Energy Laboratory have matched the availability of the solar resource nationwide with utility load patterns. The study found that, in most of California, the effective load-carrying capacity (ELCC) of solar power – which measures the ability of solar to contribute to a utility's capacity at times when it is most needed – is very high, meaning that solar power can effectively reduce the amount of generating capacity utilities must keep on hand to respond to peak conditions. (See Figure 2.)

Figure 2. PV Effective Load-Carrying Capacity[6]



Smoothing system peaks also reduces the opportunities for individuals or groups to manipulate power markets to generate excessive profits. Such opportunities multiply when the power system is near its capacity. Under those conditions, individual generators can demand – and receive – extremely high prices for power. The California energy crisis of 2000-01 was just such an example, with energy companies taking advantage of artificial conditions of scarcity (caused by the unplanned shutdown of power plants) to demand unreasonable prices for power. The energy crisis is estimated to have cost California consumers $40 billion.[7] Avoiding another such crisis, by reducing demand for scarce power under peak conditions, should be a top priority.

Generating Power Locally

Solar PV panels generate power at, or close to, the point of use – reducing the need for an elaborate and costly electric infrastructure to deliver power from far-away central station power plants.

The electric industry and government officials in the West and nationwide are considering massive investments to improve the transmission grid to accommodate the greater long-distance transfers of power set loose by the restructuring of the electric industry. Nationally, the cost of these investments has been estimated at approximately $50 billion, much of which would be paid for by electric ratepayers.[8] A 2003 study by regional transmission organizations in the West estimated the cost of transmission investments in the region at $2.6 billion to $16.7 billion over the next decade.[9]

Generating power locally also improves energy efficiency. A significant amount of electricity – up to 7 percent – is "lost" in the transmission and distribution of power from central-station power plants to homes.[10] Solar PV and other forms of local distributed generation avoid these losses, thus improving the efficiency of the entire system.

Protecting Against Price Volatility

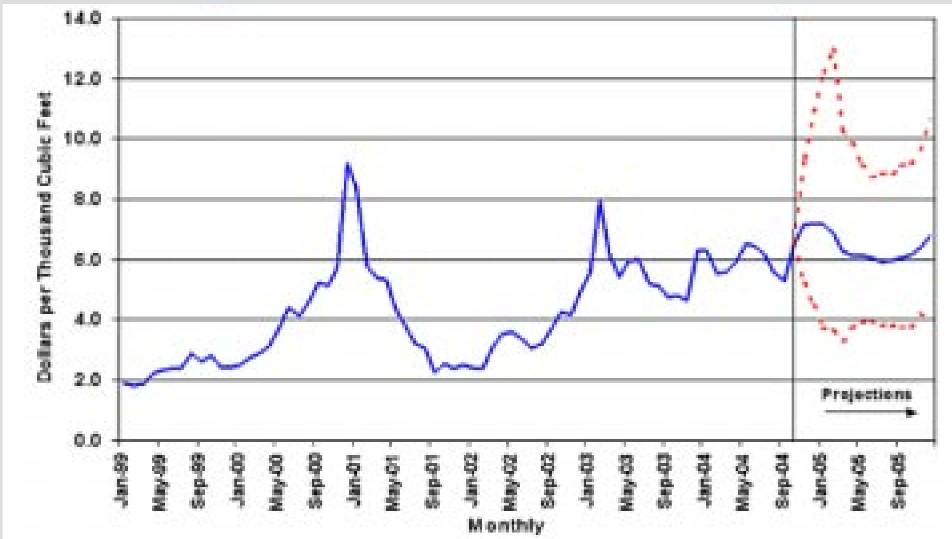
Volatility in electricity prices has significant economic consequences. Companies or individuals facing unpredictable energy costs must keep extra cash on hand, or restrict spending in other areas, in order to ensure that they are able to pay their energy bills.

As mentioned above, solar PV insulates California consumers against price volatility in part by reducing peak demand. PV also can protect consumers by reducing the demand for highly volatile natural gas.

California's electric system has become heavily reliant on natural gas, the bulk of which is imported from out of state, for both baseload and peak demand. Over the past decade, California's demand for natural gas to generate electricity has increased significantly. In 1993, natural gas-fired generation provided 43 percent of the power generated in California; by 2002, it provided 48 percent.[11] Natural gas prices have been extremely volatile in recent years, having doubled between 1995 and the present.[12] The U.S. Department of Energy projects that prices will remain high at least through the end of 2005. (See Figure 3, next page.) By reducing demand for power, solar PV can reduce demand for volatile natural gas, thus reducing California consumers' exposure to price volatility.

Historically, the value of solar power has been underestimated, since price predictions rarely consider the possibility of short-term spikes in electricity prices. For example, the actual value of

Figure 3. U.S. Natural Gas Spot Prices (Base Case and 95 Percent Confidence Interval)[13]



solar power generation in the Sacramento Municipal Utility District in one month during the energy crisis (May 2001) exceeded the predicted value of that solar generating capacity for the whole year.[14]

Quantifying Electric System Benefits

Investments in solar PV, therefore, provide direct cost savings and other benefits to utilities and, by extension, consumers. An exhaustive survey of research quantifying these benefits is beyond the scope of this report, but a few examples are illustrative of the degree of savings that can be achieved.

One recent study estimated the potential savings to four different utilities across the nation from PV installations. The study found that the value to utilities ranged from $2,200 to $4,500 per kilowatt, meaning that the utility could invest that amount in PV at no gain or loss compared to capital investments in the grid.[15]

A 2002 study conducted for the Sacramento Municipal Utility District (SMUD) estimated that direct, electric system-related benefits of PV installations could range from about $1,300 to $1,600 per kilowatt. The study also noted that, because of the high density of energy consumption and relatively low level of transmission and distribution infrastructure required in SMUD, other utilities could experience greater savings in these areas.[16]

An analysis of Mid-Atlantic electricity markets estimated that load reduction (including self-generation through solar PV) has a value to society of more than twice the market price of power during most hours of the year and three to eight times the market price of power during the 10 percent of hours closest to peak consumption.[17] In the case of one PV installation in the Philadelphia area in 2000, the study estimated its value at approximately 10 cents/kWh – well above the cost of baseload generation and enough to provide economic justification for significant subsidies to solar power.

Finally, a study by the Rocky Mountain Institute estimated the economic value of another form of distributed generation technology: fuel cells. RMI estimated that the use of distributed fuel cells could reduce system costs by $150 to $575 per kilowatt of capacity per year.[18] (See Table 1.) The operational characteristics of solar PV are significantly different from those of fuel cells, but should PV provide even a fraction of the avoided costs, the benefits to consumers would be significant.

While not a complete look at the literature, these studies suggest that the tangible economic benefits of solar PV to electricity customers are significant. Utility rate structures and government policies should not hesitate to compensate consumers that install PV for a portion of the benefits they bring to all consumers.

Reduced Air Pollution

Solar power eliminates air pollution that threatens public health and the environment, here in California and globally, by offsetting the burning of fossil fuels.

Each kW of solar power that replaces fossil fuel power in San Diego, for example, is estimated to avert a ton of carbon dioxide emissions.[20] Experts anticipate that emissions of greenhouse gases (such as carbon dioxide) must be curbed significantly for efforts to stop global warming to be successful. In addition, solar power reduces emissions of smog-forming nitrogen oxides and other health-threatening pollutants.

Reducing air pollution can have economic benefits as well, particularly if tighter limits on nitrogen oxide emissions are imposed or if the state is eventually required to reduce carbon dioxide emissions to limit its contribution to glo-

Table 1. System Benefits of Distributed Fuel Cells[19]

Item	Description	Estimated Value ($/kW-year)
Option Value	Value of the option of rapidly building small amounts of electric generating capacity.	$50-200
Deferral Value	Value of deferring infrastructure investments such as transmission and distribution upgrades.	$50-200
Engineering Cost Savings	Value of reducing operations and maintenance costs of transmission and distribution system. Includes reduced losses, voltage support, balancing reactive power, extending equipment life.	$50-175

bal warming. By avoiding the need for additional pollution controls on fossil fuel power plants – or the need to obtain carbon dioxide reductions elsewhere in the economy – solar PV can reduce the cost of complying with these limits. In addition, reducing pollution from the generation of electricity also reduces public health costs attributable to the treatment of air pollution-related illnesses such as asthma. The study conducted for SMUD estimated the environmental benefits of solar at $38 to $1,048 per kilowatt of capacity.[21]

Local Economic Benefits

California is a net importer of natural gas, meaning that much of the money spent in California for gas winds up outside the state. On the contrary, investments in solar PV create jobs and retain wealth in California. Solar PV creates approximately two to three times as many construction jobs per megawatt of developed capacity as natural gas.[22] There are approximately 500 solar PV-related companies in California, including 70 manufacturers of solar panels and modules.[23] Investing in solar PV will create a market for these home-grown businesses, as well as the assorted other businesses that install and maintain solar panels.

Energy Independence

Solar power also contributes to California's – and the nation's – energy independence, reducing consumers' exposure to events overseas. While the natural gas currently used to fire much of California's electric generating capacity generally comes from North America, increasing strain in domestic supplies has led some, including Federal Reserve Board Chairman Alan Greenspan, to call for increased imports of liquefied natural gas (LNG) from overseas.[24] These imports may open up a new source of supply to meet growing demand from electric generators and other sources, but new LNG facilities will be expensive to construct and LNG imports may lead the United States to greater dependence on other nations as suppliers of natural gas, replicating many the problems caused by the nation's dependence on foreign oil.

Consumer Benefits and Costs of Solar Homes

The benefits of solar to society are significant, and argue for government intervention to ensure that solar PV purchasers are compensated for those benefits. But what about the direct costs and benefits to consumers? Will the installation of solar panels on the average new home result in a net benefit or cost to individual consumers?

The answer depends on the assumptions one makes about the cost of the solar PV system, the future of electricity prices, the availability of government incentives, future trends in inflation and interest rates, and numerous other factors. To estimate the costs and/or benefits of installing a solar system, we used the online "Clean Power Estimator" developed for the National Renewable Energy Laboratory (NREL). The model includes assumptions as to the efficiency of solar panels in various locations, the availability of net metering programs under various utility rate structures and other factors in the economics of solar power.

Assumptions to the Analysis

Key assumptions included:

- **Size of the system**: We assumed that the solar systems to be installed would be 2.5 kilowatts DC, 2.14 kW AC. (Direct current – or "DC" power – is produced by solar panels. The current must then be converted to the alternating current – "AC" – that is commonly used in homes.)
- **Electricity costs**: We assumed that electricity costs would escalate at an annual rate of 1.5 percent.
- **Mortgage interest rates:** We assumed an average mortgage rate of 7.25 percent, based on the average 30-year mortgage rate over the past decade, per the Federal Home Loan Mortgage Corporation.[25]
- **Annual electricity consumption:** We assumed that the average new home will consume an average of 730 kWh of electricity per month, based on projections provided by the California Energy Commission.[26]
- **Cost per kW:** We assumed that in 2006 the average cost of a PV system per kW will be $5,500, and included a 9 percent builder markup, increasing this to $6,000. (For more detail on this assumption, see next section.)
- **Electricity costs:** Electricity costs in 2006 were based on projections of rates at the state's three main investor-owned utilities made by the California Energy Commission, multiplied by estimated monthly consumption as described above, then rounded up to the next increment available in the Clean Power Estimator.[27] Based on the consumption estimates above, these rates translate to an annual $1,200 electric bill for customers of San Diego Gas and Electric, $1,050 for customers of Southern California Edison and $1,000 for customers of Pacific Gas and Electric.

Other inputs for the model were household income (assumed to be $110,000), tax filing method (married, filing jointly), and the slope and direction of the PV system (30 degrees, south-facing).[28]

Further discussion of the assumptions of this analysis can be found in the "Assumptions and Methodology" section at the conclusion of the report. Two assumptions, however, have such a strong influence on the economics of solar power that they deserve discussion at length here: the cost of the solar PV systems themselves and the availability of government incentives.

Solar PV System Costs

Solar PV is at the cusp of becoming cost-competitive with fossil fuel power generation, and policies that promote large-scale manufacturing of PV cells and associated system parts can help achieve this target – it not a question of if, but when. Solar energy prices have declined 4 percent annually over the past 15 years. Over the same time period, global demand for solar PV has skyrocketed – increasing by 25 percent annually. The decline in prices is expected to continue into the future as a result of increasingly efficient solar modules, economies of scale as solar PV manufacturing expands, and other technological developments.[29]

Actual data for installed systems costs over the past two decades show a trajectory toward achieving $6/W prices by 2006. (See Figure 4.) According to analysts in the solar industry, this price has already been achieved in Japan, where 51,000 new homes have been built with systems averaging $6 per Watt. With volume installation of solar systems in California in 2006, system prices could be expected to fall to $5.50 per Watt, before any markup in price is passed on to the consumer by the builder.[30] The cost would continue to decline in future years. As a result, the installed cost of $6 per Watt assumed in this analysis for 2006 appears to be readily achievable.

The cost of a solar PV system can be broken down into three areas: the cost of the solar panels (or modules) themselves, the cost of other components (inverters, etc.), and installation costs. Currently, the average price of modules is around $5 per peak Watt (Wp) DC when purchased in single units. However, a number of solar modules are available for as low as $3.50/Wp individually, and can be purchased in very large volumes appropriate to the builder market for $3/Wp or less.[32]

The cost of other components and installation costs represent about 40 to 50 percent of the cost of an installed

Figure 4. Trend in Price in Residential Grid-Connected PV Systems[31] (1992-2003 actual, 2004-2008 projected)

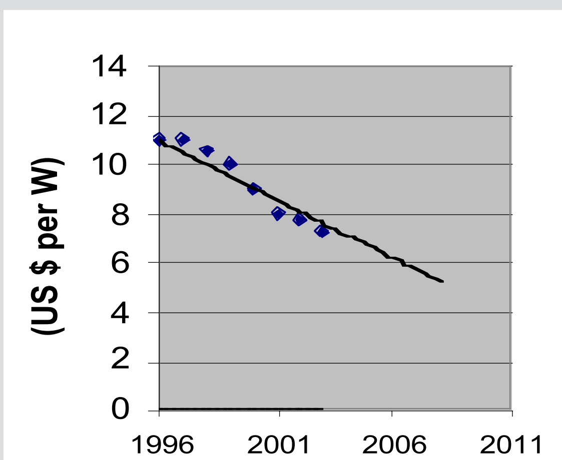


Table 2. Breakdown of Solar System Costs[33]

Cost component	% of Total
PV module	60%
Balance of system (equipment only)	25%
System design and installation	15%

Table 3. Projected Cost of Solar Modules (per Wp)

Year	If module price declines by 5% annually	If industry goal is met
2005	$3.33	$2.96
2006	$3.16	$2.67
2007	$3.00	$2.38
2008	$2.85	$2.08
2009	$2.71	$1.79
2010	$2.57	$1.50

solar PV system. (See Table 2.) This percentage breakdown can be expected to shift over time as the costs of various aspects of PV systems decline at different rates.

Estimating the *future* cost of solar PV systems and installation is challenging. Over the past 20 years, the price of PV modules, alone, has plummeted – from over $20/Wp in the 1980s to as low as $3.50/Wp today.[34] Should module prices decline at a rate of 5 percent per year (assuming $3.50/Wp in 2004), module prices could reach just over $2.50/Wp by 2010. Industry manufacturers have targeted a more aggressive goal of achieving $1.50/Wp by 2010, without subsidies.[35] Table 3 shows projected prices per peak Watt for solar modules through 2010.

Installation and component costs could also be expected to decline over time as installers gain experience with installing PV systems and component manufacturers achieve greater economies of scale.

Government Incentives

A variety of government programs exist that can subsidize the installation of solar PV systems. Tax credits for purchasers or manufacturers of PV systems, electric rate incentives and net metering, and "buy-down" programs (or grants) are among those possible incentives. Buy-down programs are among the most effective policies to promote solar development and provide for straightforward assessment of their impact on solar purchases.

There are two possible ways to set the optimal level of a buy-down grant. The first is to establish the level of the grant that is necessary to bring solar installations to the "break even" point for the consumer. An effective buy-down program must include at least this level of subsidy to encourage consumers to install the system.

A second way to assess the optimal level of a buy-down program is to consider and quantify the societal benefits that would accrue from the installation of the system. As noted above, we have not attempted definitively to quantify the societal benefits of residential PV installations in California. However, the analyses cited above suggest that societal benefits – in the form of reduced electric system costs, mitigation against price volatility, environmental benefits and encouragement of new business opportunities – could be as high as $4,000 per kilowatt.

In this analysis, we used the first method – attempting to estimate the level of buy-down grant that would assure net economic benefit for consumers installing solar panels in the scenarios modeled. We assumed no continuation of the California Solar Energy System Tax Credit currently scheduled to sunset on January 1, 2006.[36]

The Influence of Location

Location has a significant influence on the economic merits of solar PV. This influence manifests itself in two ways. First, the degree to which a California home outfitted with PV can take advantage of solar energy depends partially on the availability of the solar resource. While California generally has access to a strong solar resource, the quality of the resource does vary from place to place within the state. Fortunately, many of the areas experiencing the most development are also the areas with the best solar resources.

A second and more important influence is the impact of varying electricity rates and utility rate structures across the state. Consumers with higher electric rates benefit more greatly from solar power because each kilowatt-hour of power that is generated from their PV system is a kilowatt-hour that does not have to be purchased from a utility.

In addition, some California utilities allow consumers to choose time-of-use pricing (in which consumers are charged lower rates during offpeak hours than peak hours) and/or have "tiered" rate structures (in which consumers pay lower rates below a certain level of usage and substantially higher rates for every unit of power consumed above that threshold). When combined with net metering, these rate policies can make solar PV more advantageous for certain types of consumers – for example, those who consume little power during peak daytime periods or those who have high monthly electricity consumption and must thus purchase power at higher rate tiers.

Costs and Benefits to Consumers

To estimate the economic impact of solar PV installation for new home buyers, we chose to analyze those communities in which the most new homes are likely to be built. We identified nine of the top 12 areas in the state with the highest total population growth between 2003 and 2004 for this analysis.[37] (See Table 4, next page.) Because we opted to focus on areas served by investor-owned utilities, the three cities on this list served by publicly owned utilities (Los Angeles, Sacramento and Elk Grove) were excluded.

For each of the nine communities studied, the financial characteristics of the solar PV investment were the same: the 2.5 kW DC (2.14 kW AC) system was estimated to cost $15,000, with a buy-down grant of $5,985 ($2,800/kW AC) reducing the net cost of the system to $9,015. As noted above, it was assumed that the cost of the solar PV system was incorporated into the total cost of the home, financed through a 30-year mortgage.

Table 4. Top Ranking California Cities for Population Change: 2003 to 2004

Rank	City	County	1/2003 Total Population	1/2004 Total Population	Numeric Change
1	Los Angeles	Los Angeles	3,859,400	3,912,200	52,800
2	Elk Grove	Sacramento	85,900	109,100	23,200
3	San Diego	San Diego	1,281,400	1,294,000	12,600
4	Bakersfield	Kern	268,900	279,700	10,800
5	Murrieta	Riverside	68,200	77,700	9,500
6	Chula Vista	San Diego	200,700	209,100	8,400
7	Fontana	San Bernardino	146,500	154,800	8,300
8	Sacramento	Sacramento	433,400	441,000	7,600
9	Rancho Cucamonga	San Bernardino	147,400	154,800	7,400
10	Irvine	Orange	164,800	171,800	7,000
11	Long Beach	Los Angeles	480,400	487,100	6,700
12	San Jose	Santa Clara	919,600	926,200	6,600

The Clean Power Estimator, run with the input assumptions described above, estimates that consumers in all nine communities would achieve a net economic benefit from their solar investment (as shown in Table 5, next page). The average benefit in terms of cumulative cash flow (total number of dollars saved over the 30-year period) in the nine communities is approximately $4,500. Using the concept of "net present value," which compares the discounted benefits of a project over time with its initial costs, the economic benefit over the period averages approximately $1,500.

While a $2,800/kW incentive would be sufficient to put buyers of new homes in the black for their solar PV investment, it would not likely generate a substantial windfall for consumers, especially if the cost of inverters (which likely would have to be replaced at least once during the lifetime of the PV system) does not decline significantly in the coming years. The net discounted return on investment on a solar PV system in the nine communities after 30 years ranges from 5 percent to 17 percent, less than could be recovered from a low-interest savings account. Nevertheless, these results suggest that, for consumers who want to power their homes with solar, cost would not be a factor with a $2,800/kW incentive.

Other measures traditionally used to evaluate solar investments, such as "simple payback" (the time it takes for an investment to "pay for itself") are less applicable for investments in solar in new homes, which are integrated into the original construction. For the nine communities studied, simple payback times varied from 10 to 12 years.

It is also important to remember that the benefits estimated by the Clean Power Estimator include only economic benefits *to the end user*. As noted above, many Californians benefit whenever an individual installs solar power on his or her home. Just because a $2,800/kW incentive would be sufficient for consumers in these communities to "break even" does not mean that a larger incentive (or other policy adjustments that reallocate benefits to the solar home owner) might not be justifiable on the basis of the societal benefits of installing solar PV.

Assessing the Break-Even Point

If a $2,800/kW buy-down is likely, based on the assumptions made here, to yield a mild economic benefit for consumers, what is the minimum level of buy-down that will cause consumers to "break even"? In the two communities studied that achieve the least economic benefit from PV (Rancho Cucamonga and Fontana), the tipping point appears to be at approximately $2,400/kW. In other words, this is the point at which consumers in all nine communities would still break even on their solar investment (excluding operation and maintenance costs, see below). It thus appears to be the minimum level of incentive *currently* required to provide adequate support for solar installations. As solar prices decline, the break-even point should decline as well.

Other Important Influences on the Economics of Solar Investments

Future Electricity Rates

The future path of electricity rates is of critical importance for determining the financial viability of solar power. Unfortunately, it is very difficult to estimate what electricity prices are likely to be in 30 years, making any assessment of the economic benefits of a new solar PV system fundamentally uncertain.

The California Energy Commission has projected that rates at two of the state's three largest investor-owned utili-

Table 5. Estimated Economic Benefits of 2.5kW (DC) Solar System for Purchaser of New Home in 2006

	Monthly Electric Bill Savings	Net Monthly Loan Payment (after tax, year 1)	Year 1 Savings	Cumulative Cash Flow (30 yrs.)	Net Present Value
San Jose	$57	$44	$152	$7,662	$2,722
Bakersfield	$53	$44	$100	$5,718	$1,989
San Diego	$54	$44	$122	$6,534	$2,296
Murrieta	$47	$44	$32	$3,144	$1,018
Fontana	$46	$44	$20	$2,702	$851
Rancho Cucamonga	$46	$44	$20	$2,702	$851
Irvine	$49	$44	$58	$4,116	$1,384
Long Beach	$49	$44	$58	$4,116	$1,384
Chula Vista	$49	$44	$52	$3,910	$1,307

Table 6. Projected Near-Term Electricity Rates at Three California IOUs[41]

	(Nominal cents, 2002)		Projected Change Annual Percent	Relative % of New Homes in Service Area
	2006	**2013**		
PGE	11.2	11.2	0	49%
Edison	11.9	11.7	-0.2%	39%
SDGE	13.3	11.9	-1.6%	11%

ties are likely to remain roughly stable until 2013, resulting in a decrease in rates when inflation is taken into account.[38] (Rates for San Diego Gas and Electric customers are estimated to decline significantly over the period. See Table 6.) Longer-term trends, however, are more difficult to ascertain. The U.S. Energy Information Administration, in its *Annual Energy Outlook 2004*, estimates that real (inflation-adjusted) electricity prices in the Pacific region (which includes California) will decline by an average of 0.8 percent annually between 2006 and 2025.[39] Assuming this same annual rate of decrease, and combining it with the average annual change in the consumer price index in the United States over the past decade (2.46 percent between 1994 through 2003), yields an estimated annual increase in rates of 1.66 percent, which is rounded down to the 1.5 percent used in this analysis.[40]

Making different assumptions about the future course of electric rates changes the financial picture for consumers dramatically. Were one to assume no change in nominal electricity rates over the next 30 years, consumers in only five of the nine communities would achieve a positive net present value for their investment. By contrast, if rates are assumed to increase by 2.5 percent per year – in other words, roughly in line with the average 2.46 percent increase in the consumer price index over the last decade – consumers in the nine communities would see their cumulative cash flow increase from an average of $4,500 to an average of $8,300, and the average net present value of their investment increases from $1,450 to $2,470. (See Table 7.) In addition, temporary spikes in electricity prices – driven by volatility in prices of natural gas or other factors – could lead to significant short-term benefits for consumers who install solar.

Table 7. Average Value of Solar PV Systems Over 30 Years at Various Rates of Electricity Cost Inflation[42]

Annual Increase in Electricity Costs	Cumulative Cash Flow	Net Present Value
0%	$2	$367
1.5%	$4,512	$1,534
2.5%	$8,319	$2,472

System Lifetime

The above analysis assumes that solar PV systems and all their components last for the life of the loan used to finance them: 30 years. For PV modules, this assumption appears warranted; most modules come with a 20-year warranty for power production and can be expected to continue to produce power reliably beyond the expiration of the warranty.[43] Warranties of 25 years for crystalline silicon PV modules are not uncommon.[44]

The same long life-spans are not shared by all elements of the PV system. Inverters (which convert the direct current generated by PV modules into alternating current used in households) have been plagued by short lifetimes and the need for frequent replacement. The industry has set a short-term goal of improving the average lifespan of inverters to ten years or more.[45] Lifespans of at least 7 to 9 years appear reasonable for the current generation of inverters, and recent advances in inverters and the arrival of new imports from Europe (where there is more experience with small solar systems) suggest that further advances can be expected in the years to come.[46] Even so, however, PV system owners can expect to replace the inverter at least once, and perhaps twice, during the 30-year lifespan of their system.

The Clean Power Estimator does not allow for factoring in the lifespan of individual elements of the PV system. Because of this – and the difficulty of estimating the cost and lifespan of future inverters – the cost of inverter replacement is not included in the above cash flow estimates. To take the expense of inverter replacement into account, the cumulative cash flow figures cited above should be reduced by the cost of replacing an inverter somewhere around year 10 (acknowledging the potential for further improvement in reliability between now and 2016, the tenth year of a solar system installed in 2006).

Currently, inverter prices average $0.831 per continuous Watt – translating to about $2,000 for an inverter serving the 2.5 kW DC system modeled above.[47] By around 2016, when inverters would need to be replaced, inverter prices can be expected to have declined significantly. A European study has estimated that it is technically possible to reduce the cost of inverters by roughly half.[48] Should that cost-reduction target be achieved by 2016, the cost of a replacement inverter would reduce cumulative cash flow for the consumer by somewhat more than $1,000 in today's dollars. The impact of inverter replacement expense could also be reduced if lifetimes are extended beyond 10-15 years, if technological improvements bring about a breakthrough in inverter costs, or if future inverters run at higher efficiency than today's models.

Non-Quantifiable Benefits

In addition to the direct costs or savings to consumers from the installation of PV systems, consumers also achieve economic benefits from their ability to hedge against future increases in electricity prices and price volatility. A Californian who buys a solar home is effectively able to lock in his or her rates for the long term – the energy generated from the solar panel will not get more expensive than the initial investment. A rate spike such as that which occurred in San Diego at the outset of the energy crisis of 2000-2001, for example, would yield significant relative benefits for PV owners in very short order. At a time of increased uncertainty over the future of fossil fuel supplies, as well as the competitiveness and efficiency of the electric power system overall, this protection against uncertainty would likely have significant value for consumers.

PVs also have other benefits that are harder to quantify, including reduced need for operation and maintenance expenditures by the homeowner due to the simplicity of the design of PV systems.

Special Financing Opportunities

Finally, PV homes may qualify for special financing available for energy-efficient and clean energy homes. Because the upfront investment in a solar home results in lower electricity bills down the line, a number of lenders will grant mortgages that take into account the positive cash flow that homeowners will experience over the life of the system.[49] Major lenders such as Fannie Mae and Freddie Mac, as well as a host of specialized firms, grant energy-efficient mortgages or clean energy mortgages. If the solar PV investment is structured (through buy-downs and other incentives) to result in consumer savings, banks may allow the homeowner to have a larger mortgage and monthly mortgage payment than would normally be allowed for his or her income level, increasing the size of mortgages available to Californians purchasing energy-efficient homes.

Most banks do not aggressively market clean energy mortgages, but they are potentially significant tools available to help new homeowners maximize the value of their solar PV systems. A more in-depth discussion of solar financing options, "Residential Solar Financing: Homeowners Save, Banks Profit," can be found at www.millionsolarroofs.com.[50]

Conclusion

The installation of solar PV in new California homes has the potential to yield positive economic benefits for consumers – if the societal benefits generated by PV are reflected fairly in utility rate structures and in government policy.

In the near term, a modest buy-down grant of $2,800 per kilowatt would appear to make solar PV cost competitive for homebuyers in most of California's fastest-growing cities. It is likely that the societal benefits California would experience in reduced electric system costs, reduced air pollution, greater energy independence and stimulus to local economies would be well worth the cost of such an investment.

However, additional barriers to the adoption of solar power mean that an aggressive buy-down program alone may not be sufficient to spur widespread installation. In particular, encouraging builders and utility companies to install PV on new homes could alleviate many of the barriers – including informational barriers, high up-front costs, utility interconnection issues and others – that deter consumers from having to install PV as a retrofit on an existing home. Encouraging the use of PV in new residences could also bring down the cost of PV by allowing builders to negotiate bulk discounts and gain experience in PV installations.

Similarly, our analysis shows the important role played by utility rate structures in determining the economic competitiveness of PV. Utilities should consider the adoption of tiered rate structures that increase the per-kilowatt-hour cost for heavy users and should offer time-of-use pricing options that reflect the true cost of delivered utility power and take full advantage of solar power's ability to add capacity to the system during peak demand conditions. And utilities should continue to offer net metering programs that allow solar home owners to receive credit on their electric bill for their excess energy generated.

METHODOLOGY

To estimate the consumer value of solar PV in residential homes, we used economic evaluation software for customer-owned clean energy systems developed by Clean Power Research for the National Renewable Energy Labs, available at www.cleanpower.com/nrelpv/incentives/incentives.asp. The model was run on November 17 and November 22, 2004.

The program takes into account the characteristics of the PV system being purchased, the customer's location, the electric rate structure in that location, and other information such as the customer's income and how incentives interact with each other.

This model allows the user to modify or create incentive structures to determine how they affect the consumer economics of the system. We made two changes to the incentives built into the model. First, we eliminated a California state tax incentive for solar power scheduled to be phased out in 2006 (in the model, titled "CA Tax Credit, Res."). We also modified the "CEC PV buydown" incentive, changing its value in period zero, the first year analyzed, to $2,800 per kW.

Most of the assumptions input in the model are discussed in the text of this report (including the major assumptions related to system cost, net metering, interest rate, electricity consumption and prices, household income, and future electricity cost trends). For each location, the user can choose from different utility rate structures currently offered by the utility. The table below lists the rate structures chosen for each location. When available, we chose time-of-use pricing and net metering, which in general will lead to higher value for the solar power based on the average consumer's load profile built into the clean energy model. When time-of-use rates were not available, we opted for simple net metered residential rates. We did not choose rates specially available for all-electric houses.

The Clean Power Estimator only allows for the evaluation of solar installations in the current year. Because this analysis attempts to estimate the economics of solar installations in 2006, we provided inputs to the model that approximate anticipated conditions in 2006. The discount rate used to calculate net present value is embedded in the Clean Power Estimator and is based on the 7.25 percent interest rate assumed in the modeling run.

Table A1. Rate Schedules Used in Calculating Value of Solar Power

Location	Utility Rate Schedule
San Jose, Santa Clara	Pacific Gas and Electric Company (PG&E), Net Metered Residential Time-of-Use (Rate E7 Area X)
Bakersfield, Kern	Pacific Gas and Electric Company (PG&E), Net Metered Residential Time-of-Use (Rate E7 Area W)
San Diego	San Diego Gas & Electric (SDG&E), Net Metered Residential Service (Rate DR Zone 1)
Murrieta, Riverside	Southern California Edison (SCE), Net Metered Basic Residential Service (Rate D Region 17)
Fontana, San Bernardino	Southern California Edison (SCE), Net Metered Basic Residential Service (Rate D Region 16)
Rancho Cucamonga, San Bernardino	Southern California Edison (SCE), Net Metered Basic Residential Service (Rate D Region 17)
Irvine, Orange	Southern California Edison (SCE), Net Metered Basic Residential Service (Rate D Region 10)
Long Beach, Los Angeles	Southern California Edison (SCE), Net Metered Basic Residential Service (Rate D Region 10)
Chula Vista, San Diego	San Diego Gas & Electric (SDG&E), Net Metered Residential Service (Rate DR Zone 1)

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