BRINGING SOLAR TO SCALE

California's Opportunity to Create a Thriving, Self-Sustaining Residential Solar Market

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Executive Summary

Developing a thriving, self-sufficient solar power market in California can have huge benefits for the state – reducing air pollution, protecting consumers from volatile electricity prices, and reducing the need for expensive upgrades to electricity transmission and distribution systems.

The best way for California to ensure that the state sees a future expansion in solar power capacity is by committing to long-term market development programs that include financial incentives and new construction design policies. Experience in California and in other countries, especially Japan, has shown that such government programs can lead to increased demand, lowered prices, and ultimately a robust, self-sufficient solar market in which government incentives are no longer necessary. It is unlikely that the goal of Governor Schwarzenegger's Million Solar Roofs Initiative – 3,000 MWp (peak megawatts) of total new solar photovoltaic (PV) capacity and half of all new homes built with PV in the next 10 years – can be achieved without a sustained, guaranteed program that combines incentives for both residential and commercial systems, as well as policies that encourage the inclusion of solar power systems into the construction of new buildings.

The most important factor in reducing costs is the experience gained from increased production.

With the growth in solar PV installations in California and worldwide, the solar industry has learned how to improve production methods, improve the efficiency and life of various components, and operate more efficiently. Some of this is due to economies of scale as the companies themselves get bigger, but much of it is due to the fact that they have done each part of the process many times, and have learned how to do it better. This learning curve – what economists call the "experience curve" and quantify in terms of a "progress ratio" – is true for many products across many industries.

Government incentives can spur increased demand for solar power systems, bringing the industry to cost-competitiveness more quickly.

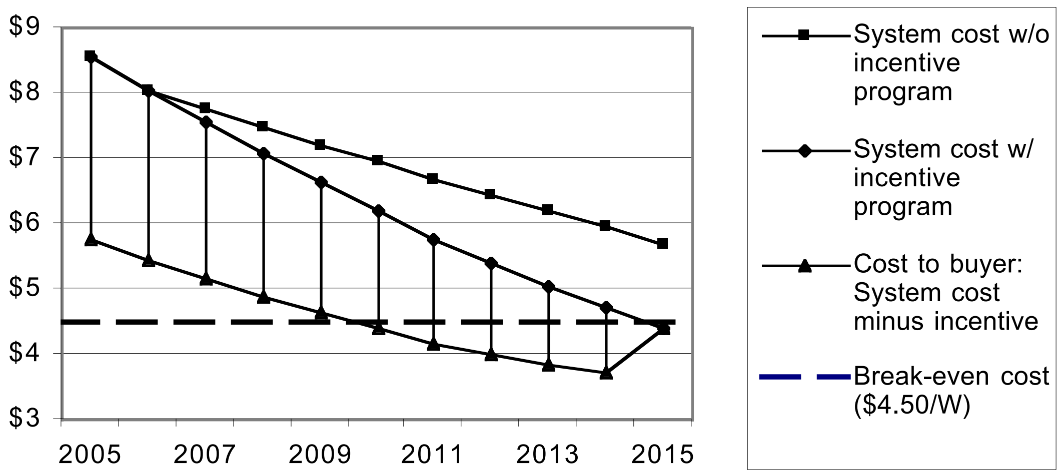
The incentives given under the California Energy Commission's (CEC) Emerging Renewables Program and the Public Utilities Commission's Self-Generation Incentive Program have spurred increased installed PV capacity and decreased price. In fact, the increased production resulting from the CEC's residential incentives has caused the price of retrofitted residential PV systems in California to drop by 36 percent from 1998 to 2004 – from $14.01 per Watt to $8.98 per Watt.[1] (Note: All price figures are in 2004 dollars, and all PV system sizes indicate Watts of alternating current, unless otherwise noted.)

Much of this expense can be recouped by the homeowner over the life of the system, but prices will need to drop further – to within the range of $4.00-$4.50 per Watt – for homeowners to break even on their solar investment without financial incentives.

Using a conservative estimate of the rate at which production increases spur price decreases:

- **With no residential incentive program after 2005:** California would install approximately 53 MW of residential PV systems on new and existing homes by 2015, with the system price in 2015 of $5.69/W – not yet within the range

Figure 1. Impact of a Sustained Solar Incentive Program on the Cost ($/W) of Installing a Residential Solar PV System (Assuming a Progress Ratio of 85 percent)



of being economically self-sufficient for the consumer.

- **With a 10-year incentive program that scales down $0.20/W each year from its current level of $2.80/W**: California would install about 1,278 MW of systems on new and existing homes by 2015, when the system price reaches $4.40/W – a price that would put solar within the range of cost-effectiveness for California homeowners without financial incentives. (See Figure 1.) Getting to this point would require an average annual budget of $180 million for incentives to create the demand for residential installations.

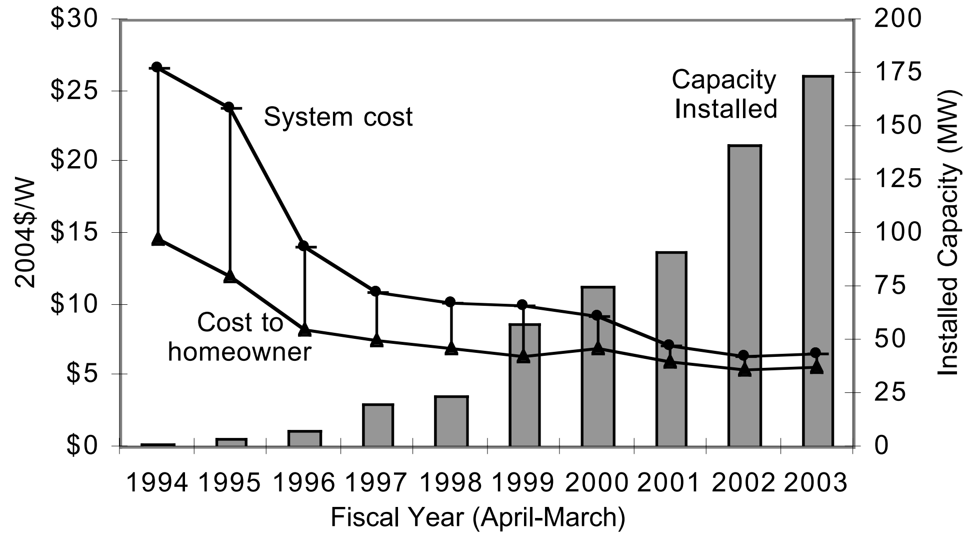
Under a more optimistic estimate of how rapidly price decreases, the residential incentive can be scaled down even more quickly, with residential installation prices reaching the break-even point in 2012 or sooner.

Also, because installation costs are significantly lower when the PV system is incorporated into a new home during construction, system prices in the new home market could hit the break-even point sooner than in the residential retrofit market. This will be an important and growing market in the future, as seen in Japan.

Japanese solar policies over the last decade prove the effectiveness of this approach.

Since the start of Japan's residential incentive program in 1994, the average system cost has fallen by about 75 percent in real (2004) dollars, and the country is approaching the point at which government rebates will no longer be needed. (See Figure 2.) However, much of the cost reduction has occurred in parts of the system price that are specific to Japan (such as balance-of-system components and installation), and therefore has not resulted in equally large price reductions in California and in other markets.[2] By following the example of Japan's incentive program, California

Figure 2. The Success of Japan's Residential PV Incentive Program: 1994-2003[3]



could achieve similar results by allowing designers, installers, and service companies in California's market to develop similar knowledge.

Japan's average annual investment of $115 million over the last 10 years has led to a 35-fold increase in photovoltaic capacity.[4] In fact, Japan has installed almost as much capacity over the last decade as the rest of the world combined.[5] Despite reductions in the size of the incentive from 50 percent of system costs to 10 percent, demand for solar PV has continued to skyrocket. The country achieved its goal of equipping 70,000 homes with solar PV systems by 2000, and it is on track to meeting its goal of installing building-integrated photovoltaic systems on half of all new homes by 2010.[6] In addition, Japan's solar manufacturing industry has surged ahead to become the largest in the world.

A strong commitment to solar PV now can create long-lasting results.

California already has the third-largest PV market in the world, after Japan and Germany, and has great potential for solar generation given its high sunlight exposure. Pursuing the right policies can develop this market and the industries that serve it. The state should:

- **Commit to a sustained incentive program for residential and other small systems.** A new, dedicated solar fund, paid through a surcharge on electric bills, can ensure that residential incentives will continue until the California solar market is self-sustaining. To accomplish the goal, this program must include a guaranteed fund so that companies and investors can plan to meet a growing market that will not suddenly disappear. Equally important, the rebate should be designed to scale down over time, much like the California Energy Commission's current Emerging Renewables Program. Based on projections using conservative assumptions, driving the cost of residential systems down to the point where homeowners can break even over the course of the PV system's lifetime will require at least $180 million per year for 10 years. This amount will allow the program to meet the demand that arises from the reduced cost of PV systems to homeowners.

- **Commit to a sustained incentive program for commercial systems.** Creating a parallel incentive program for commercial installations is critical as well. In conjunction with a residential incentive program, this will further drive down the cost of solar power. The programs should be coordinated, and the size of the incentives should also ramp down over time.
- **Incorporate solar into new home design and construction.** California builds approximately 135,000 new single-family homes each year. Incorporating solar systems into the home during construction is one of the most cost-effective and efficient ways to build California's solar market. Policies targeted specifically at new homes – such as requirements to install solar on an increasing percentage of new homes or offer systems to homebuyers – can develop the most cost-effective, but largely untapped, part of the residential PV market.
- **Raise the net metering cap.** Raising the net metering cap to at least 5 percent of a utility's peak demand will allow more homeowners and businesses to get credit for the electricity they generate – a key component to making solar power cost-effective for homeowners.
- **Continue tax incentives for solar installations.** California should continue the various tax incentives it currently gives for solar PV systems and other renewable energy technologies.

Such residential and commercial programs will create the demand needed to drive down prices in the long term. Funding for these incentives should come through an electricity surcharge because electricity customers benefit directly from increased solar power capacity. By reducing peak demand, solar power reduces the need for expensive new power plants and upgrades to the transmission and distribution system, decreases reliance on imported fuels, and reduces electricity rates – as well as creates cleaner air and more in-state jobs, which benefit everyone.

Photo: Courtesy of Shell Solar

Automated manufacturing of solar cells and panels, possible as demand increases, reduces the cost of PV modules.

INTRODUCTION

California has some of the strongest potential in the world to benefit from solar power, due to high levels of sunlight. We also have some of the greatest need. Much of the state's energy comes from imported fossil fuels, and increasing solar photovoltaic (PV) generation will reduce California's reliance on these out-of-state energy sources, as well as benefit the environment by reducing our dependence on fossil fuels and nuclear power. Solar PV systems can also reduce strain on the electric grid by generating electricity where it is used, and hedge against rate spikes by generating the most electricity when demand is the highest, on hot summer afternoons when air conditioners are running.

Solar PV has moved rapidly from serving off-grid niche markets like remote locations, emergency signs and calculators to becoming a mainstream electricity source. This has been accompanied by a boom in grid-connected distributed uses like residential and commercial systems, from 5 percent of the U.S. market for PV in 1994 to 31 percent in 2003, while the overall U.S. market for PV grew from 26 MW to 103 MW.[7] The largest potential market – installations on homes – is blossoming worldwide, especially in Japan.

The cost of a home or commercial PV system in California has not fallen to the level where it makes long-term financial sense for a homeowner or business to install a system without government incentives. The installation costs are still high enough that they outweigh the savings on a homeowner's electricity bill – though these savings do not reflect all of the economic benefits of a residential PV system, like lessening the need for transmission capacity upgrades and new power plants.

It has often been said that it is not a question of if, but when solar power becomes cost-competitive with traditional electricity sources. By adopting the right programs and policies today, California can have a great deal of control over the future cost of solar power and how rapidly it becomes cost-competitive. By getting in on the ground floor of this new market, California can also benefit economically.

The experience over the last 10 years shows that if we invest now in creating the demand, the solar industry will meet it and, in doing so, will be able to manufacture and install solar PV systems more cheaply. And as the industry learns how to build solar PV systems more cheaply, demand will increase, creating a "virtuous cycle" that will give solar power a tremendous boost in becoming a major source of California's power.

While government incentives can certainly increase California's installed solar capacity, an even better reason for them is that they can push down the cost of solar in the long run, to the point where incentives are no longer needed. To achieve this goal, any new incentive program needs to include both commercial and residential PV markets, be sustained over a long period of time, include cost reduction controls such as mandatory incentive declines each year, and encourage efficient design and installation.

The residential incentive program that has been run by the California Energy Commission (CEC) since 1998 has been a major driver of California's strong market for residential solar photovoltaics. Continuing to pursue this and other policies that increase demand is California's best option for bolstering residential solar to cost-competitiveness.

California is already experiencing booming solar demand, but this needs to increase even further before the industry will be able to take off. By committing to a dedicated and aggressive incentive program like the CEC's Emerging Renewables Program in the long term and coupling these funds with complimentary system and building design standards, the state can help guarantee future demand. This will give companies reason to make the investments needed to improve their products and services.

In contrast, allowing the incentives to end would deal a blow to the state's industry, cutting back both the rate of installations and the rate at which the price has been falling. Further, by continuing the historic pattern of "fits and starts" in the availability of state funding, California would weaken the future development of the state's solar market. Both of these mistakes could set back the clock on solar becoming a mainstream source of electricity by several years.

Identifying the "Break-Even" Point

The cost of a home solar PV system has been dropping steadily. However, in the absence of government incentives, the cost is still higher than the value of the home's electricity demand that it offsets.

A homeowner can already recoup much of the installed cost of solar PV over the lifetime of the system. In a year, a typical 2.5 kW system will generate electricity worth approximately $540 at current California electricity rates. Over the system's lifetime, it will generate about $13,300 worth of electricity, and even more if electricity rates increase in the long term. California, like many other states, helps to ensure that the homeowner gets the financial benefit of this generation through net-metering regulations. (See box on net metering below.)

Net Metering

When a PV system generates more electricity than the residence is consuming at any given time, the extra electricity is fed back onto the grid and goes to other utility customers. In California and in many other states, the homeowner gets credit for that power at the same rate that the utility charges for the electricity it supplies. This is known as net metering: because the home's electric meter can be set up to run backwards, it measures only the net electricity drawn from the grid.

If a consumer generates more electricity over the course of the month than he or she consumes, the credit can be rolled forward to the next month for up to a year.[8] California customers who pay electricity rates that vary over the course of the day (known as time-of-use billing) are entitled to deliver electricity at the same rates that they pay for power; this means that the credit they get for the electricity they supply to the grid is closer to what that electricity is worth. Unfortunately, not all utility companies in California allow time-of-use pricing, and total enrollment in net metering is currently capped at 0.5 percent of a utility's peak demand.

As more Californians install residential solar power, raising the net-metering cap and expanding time-of-use billing will be necessary to ensure that solar is cost-effective for all homeowners.

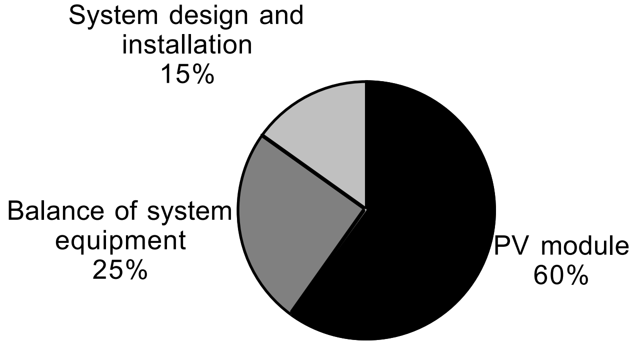
However, in 2004, residential-sized PV systems (under 10 kW) installed on existing homes under the CEC's Emerging Renewables Program cost an average of $8.98/W – or about $22,400 for a typical 2.5 kW system – prior to incentives. Given conservative projections of future electricity rates, the cost of residential PV systems will have to come down to about $4.00-$4.50/W in order for a homeowner to break even. (See methodology for details.)

The initial costs of installing a solar PV system can be broken into three categories: the PV modules, the balance-of-system components, and the installation costs. (See Figure 3.) Installation costs are significantly lower when the system is incorporated into a new home, because the home can be designed with the PV system in mind and all of the installation can be done as part of the home's construction. However, because this has been a much smaller segment of the residential solar market to date, we focus our analysis in this report on residential retrofits, for which ample data is available. In the future, the new home market can be expected to grow dramatically.

Solar power is different from most traditional power sources in that the fuel (sunlight) is free. This means that the cost of a solar PV system is primarily upfront capital costs, and any future costs are fairly predictable. The modules generally have lifetimes of 20 to 30 years, and a 20-year performance warranty is typical, though complete systems are usually warrantied for only five years.[10]

Inverters, which convert the direct current generated by PV modules into the alternating current used in households, have lifetimes of about seven to nine years – although the industry has set a short-term goal of improving the average life-span to 10 years or more.[11] The owner of a residential PV system can expect to replace the inverter at least once, and perhaps twice, during the system's lifetime. In 2004, inverter prices averaged $0.831 per continuous Watt, or about $2,080 for an inverter serving a 2.5 kW system; however, a recent study has estimated that it is technically possible to reduce the cost of inverters by half.[12]

Figure 3. Breakdown of Residential PV System Costs[9]



Note on Units

PV modules are generally rated in terms of peak output, their maximum direct current (DC) output when fully illuminated. This is measured in peak kilowatts (kWp). However, because the DC output must be converted to alternating current (AC) for use in a home, residential PV systems are frequently rated in terms of AC output; we designate this output as kW. A system's AC output (kW) will always be less than the total rated DC output (kWp) of the modules; a typical conversion ratio is 94 percent.[13] Residential PV system costs given as "$/W" indicate dollars per Watt-AC. Where it is more convenient, we use MW (1 MW = 1,000 kW) and MWp (1 MWp = 1,000 kWp).

All dollar figures, both past and future, are given in 2004 dollars unless otherwise noted.

Getting to "Breakeven": How Increasing Production Lowers Costs

The most important factor in lowering the cost of residential PV systems is not time, but the learning that comes from doing. If the solar industry installs 100 MW of PV capacity next year, it will learn how to do it better and for less money than if it installs 50 MW during the same time period. Conversely, no matter how much time passes, if the industry does not install any more systems then very little progress will be made toward reducing costs.

Economists have long noted that, for many products across many industries, per unit costs decline in relation to cumulative production.[14] This has led to the study of what economic theory calls *experience curves*, which are based on the basic idea that the cost of producing an object goes down as production levels increase due to the accumulated knowledge that comes from experience. This encompasses cost reductions that result from a wide range of factors including production improvements, product development, and decreases in the costs of inputs (like parts and materials).

Based on various studies that have comprehensively applied experience curve theory to solar photovoltaics development in Japan and Europe, every doubling of cumulative production reduces the price to between 75 and 85 percent of what it was before.[15] This percentage is known as the *progress ratio*. A higher progress ratio means that cost reduction occurs more slowly. Experience curves can be used to project how future cost will change as cumulative production increases, because progress ratios usually remain constant over many doublings of cumulative production. This opens possibilities for policy handles that decrease the cost of solar power by increasing demand for new solar generating capacity.

The CEC Residential Incentive Program: Driving Down Solar Costs

Giving rebates to homeowners who install solar PV systems can help induce the demand necessary to create long-term cost reductions. Such a "demand-pull" approach allows the industry to sort through the best way to supply the market, so the companies will pursue the most promising technologies, structure themselves in optimal ways, and compete for market share. This, in turn, leads to cost reductions, making the incentives less necessary and leaving solar power in a stronger position in California.

The California Energy Commission's (CEC) Emerging Renewables Program has been based on this idea, and its success has shown how effective this approach can be. The incentives given under the program, in the form of rebates, have been a major factor in bringing down the dollar per Watt cost to homeowners for residential retrofits, leading to an increase in demand.[16] (See Figure 4.) Annual demand for the program's incentives has risen steadily since the program began, even though 2001 was the only year during which the incentive was increased (from $3.00/W to $4.50/W, in nominal dollars). Since then, the CEC has periodically reduced the rebate, and it is currently $2.80/W.

Figure 4. Residential Retrofit PV Cost and Demand in CEC's Emerging Renewables Program[17]

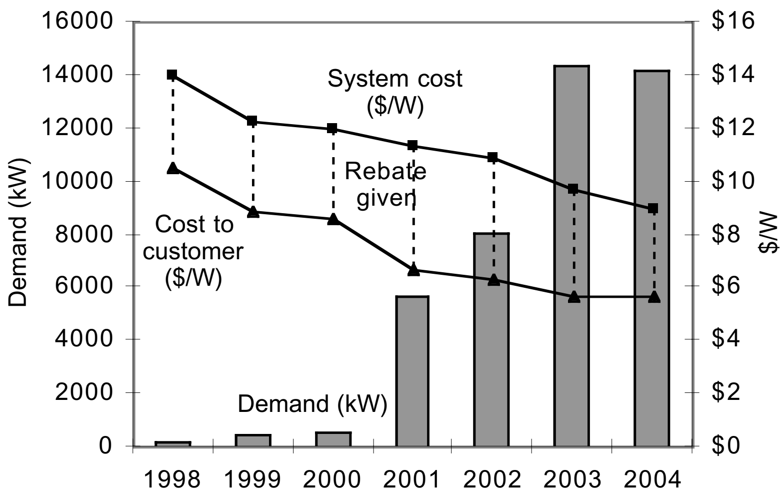
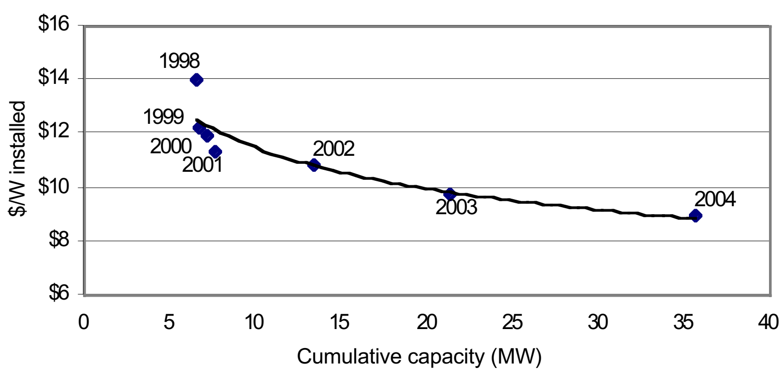


Figure 5. Decreasing Installed Cost ($/W) of Solar PV as Cumulative Residential Retrofit Capacity Increased in California[18]



The growing demand has been boosted by the incentives, but it is due much more to the cycle that they have kicked off: incentives reduced the cost to homeowners, which increased demand, which led to increased production, which further decreased costs. This increase in demand has also been fueled by rising electricity rates, which make solar power more economical, and public concern resulting from the rolling blackouts in 2001.

Furthermore, the history of California's residential PV market confirms the idea of experience curves and a progress ratio: that price reductions accompany increasing cumulative installations at a steady rate. (See Figure 5.) However, the experience that has led to these price reductions has been due not only to installations in California, but also to PV modules and inverters manufactured to meet global demand. To fully understand how installations in California can affect prices, one must apply two experience curves to two separate groups of solar products – those components of the system that are commodities supplied globally and those components and services that are primarily local. California demand is significant because the state is already the world's third-largest market for solar installations (after Japan and Germany), and because giving incentives in California can have an especially large impact on cost reductions in aspects of PV systems that are more specific to California, such as installation costs. (See Figures 6 and 7, next section.)

The Case for Continued Residential Incentives in California

The difference between how residential solar PV will develop in California with a strong government incentive program versus without one is significant. As discussed above, the rate at which increased demand drives down the cost depends on the progress ratio, which is generally constant over time. However, because sufficient historical data does not exist to calculate a precise progress ratio, we use two scenarios with two different progress ratios (80 percent and 85 percent) in projecting the difference that having a government incentive program makes. We also focus our projections on the residential retrofit market; incentives given for systems on new homes and for commercial systems will increase demand in a way that will drive down prices, but we do not have sufficient historical data to project how these would develop, so we assume that demand outside of the residential retrofit market will continue on the same path that it is on. (See methodology for more detail.)

The major factor in bringing down the cost of solar is the production supported by the increased demand. With either progress ratio, the cost of a residential retrofit system gets within the break-even range – about $4.50/W – several years sooner with an incentive program than without one. (All prices are in 2004 dollars.)

- **Progress ratio = 85 percent:** With a government incentive that scales down $0.20/W each year from the 2005 level of $2.80/W, the installed cost of a residential solar PV system would be $4.40/W in 2015 – about the level at which California homeowners would find it cost-effective to install solar power on their homes without financial incentives. (See Figure 6.) To meet the resulting demand, the average annual amount spent on incentives would be $180.8 million. (See Table 1.) In the meantime, California would have added 1,278 MW of new PV capacity on homes. Without an incentive program, the installation cost in 2015 would be approximately $5.69/W, and new residential capacity would be 53 MW.
- **Progress ratio = 80 percent:** With a government incentive that scales down $0.40/W each year from the 2005 level of $2.80/W, the installed cost of a retrofitted residential system would be $4.53/W in 2012, when the incentive disappears entirely. (See Figure 7.) To meet the resulting demand, the average annual amount spent on incentives would be $63.8 million. (See Table 2.) In the meantime, California would have added 364 MW of residential capacity; in the following years, installed capacity would skyrocket as the cost of a system drops well below the break-even cost. Without an incentive program, the installation cost in 2012 would be $5.51/W, and total new residential capacity would be 49 MW.

Figure 6. Impact of a Sustained Solar Incentive Program on the Cost ($/W) of Installing a Residential Solar PV System (Assuming a Progress Ratio of 85 percent)

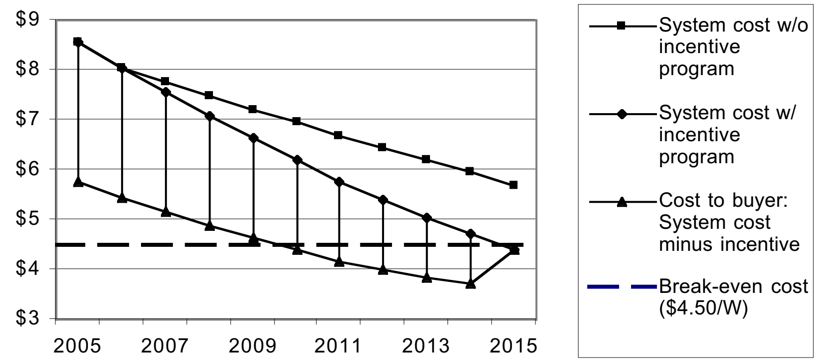


Table 1. Residential PV Program Incentive Size, Resulting Demand, and Budget Needed (Progress Ratio = 85 percent)

Year	Incentive (2004$/W)	Resulting Demand (MW)	Budget Needed (million 2004$)
2005	$2.80	13.9	$38.80
2006	$2.60	20.3	$52.80
2007	$2.40	30.2	$72.50
2008	$2.20	45.2	$99.50
2009	$2.00	67.8	$135.60
2010	$1.80	100.9	$181.60
2011	$1.60	147.1	$235.40
2012	$1.40	207.9	$291.10
2013	$1.20	281.7	$338.10
2014	$1.00	362.7	$362.70
		Total: 1,277.80	$1,808.10
		Annual average:	**$180.80**

Figure 7. Impact of a Sustained Solar Incentive Program on the Cost ($/W) of Installing a Residential Solar PV System (Assuming a Progress Ratio of 80 percent)

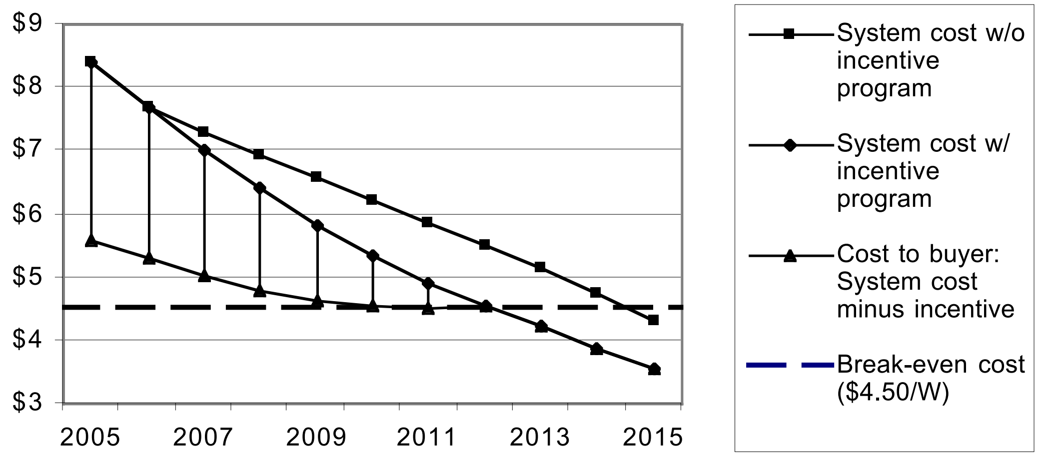


Table 2. Residential PV Program Incentive Size, Resulting Demand, and Budget Needed (Progress Ratio = 80 percent)

Year	Incentive (2004$/W)	Resulting Demand (MW)	Budget Needed (million 2004$)
2005	$2.80	17.0	$47.60
2006	$2.40	25.5	$61.30
2007	$2.00	37.5	$75.00
2008	$1.60	52.4	$83.80
2009	$1.20	67.8	$81.40
2010	$0.80	79.6	$63.70
2011	$0.40	84.0	$33.60
		Total: 363.9	$446.40
		Annual average:	**$63.80**

Although the two scenarios require different annual budgets for the incentives given, there are few policy options for improving on the progress ratio beyond investments in research and development, so the state should plan for the future of an incentive program based on the more conservative progress ratio of 85 percent. Over the next 10 years, this will mean an average annual budget of $180.8 million, in 2004 dollars. If residential electricity demand in California were to stay at 2003 levels, this budget could be satisfied with an annual average surcharge of $0.00224 per kWh.[19] Given that the average California household uses about 6,800 kWh of electricity each year, this translates to about $15.25 per household per year.[20] This investment could eventually be reflected in lower electricity rates, because increased solar generation will reduce the need for fossil fuel purchases, costly power plant construction, and transmission and distribution upgrades.

Once the price of retrofitted solar PV systems reaches the break-even point, the rate of installations will take off as vastly more homeowners decide to invest, and the price of solar will be driven down further. The money California invests in incentives early on will have enormous benefits in the long term by bringing the cost of solar down to where the incentives are no longer needed. This will create a dramatic boost in renewable electricity generation in California, reducing demand for fossil fuels and the accompanying pollution.

How Incentives Helped Build the Solar Industry in Japan

Japan provides a prime example of how demand-pull incentives can build an industry and bring solar PV to the point of cost-competitiveness for consumers. Japan currently enjoys a predominant position in both producing electricity from solar energy, and in supplying the growing worldwide market for photovoltaic technology. With 47.5 percent of the world's installed photovoltaic capacity in 2003, Japan converts more solar energy into electricity than any other country in the world.[21] This far surpasses the second and third largest solar countries: Germany has 22.7 percent of global photovoltaic capacity and the United States has 15.2 percent. Japan also leads the way in terms of installed capacity per capita.[22] The government policies that put Japan in this position provide good lessons on how to build a photovoltaic market in any country or state.

Most of this capacity has been installed through a national residential incentive program.[23] Since the inception of this program 10 years ago, Japan has increased its photovoltaic capacity over 35-fold (compared to an 18-fold increase in California's capacity over the same period).[24] Japan's strong domestic demand has led to significant growth in its photovoltaics industry, creating thousands of new jobs. Today, shipments from Japan supply 50 percent of the world photovoltaics market, up from 21 percent in 1995.[25]

Industry growth has reduced the price of residential PV systems, with the installed cost of an average system falling from $26.54/W in FY 1994, to $6.50/W in FY 2003.[26] During this time, the residential incentive program has gradually decreased the maximum per-household incentive, with no slacking off in demand. This program is expected to be completely phased out by the 2006 fiscal year.[27]

Why the Japanese Committed to Solar

The dual desires of decreasing energy-import dependence and preventing global warming are at the root of Japan's support for solar energy. Both of these are issues of concern for California as well.

Table 3. The Success of Japan's Residential PV Program

	Japan's PV Capacity at Year's Start[28]	Cost of an Average System (2004$/W)[29]	Average Incentive (2004$/W)[30]
FY 1994	24.3 MWp	$26.54	$11.94
FY 2003	859.6 MWp	$6.50	$0.85
Change	35-fold increase	76 percent decrease	93 percent decrease
Average Annual Program Budget (2004$)		$115 million	

Photo: Courtesy of Shell Solar

A utility scale installation of solar panels.

In 1994, the Japanese Ministry of Economy, Trade and Industry (METI) recognized the need to decrease the country's dependence on petroleum and other energy imports.[31] Japan depends on imports for about 80 percent of its energy needs, and half of its total energy supply is from imported oil.[32] Faced with minimal domestic energy reserves and increasing global demands for oil, developing new sources of energy is critical for Japan.

California also relies heavily on energy imports. In 2003, the state imported 58 percent of its oil and 84 percent of its natural gas.[33] Natural gas is the source of about half of the electricity generated in California, though 22 percent of the state's electricity must be imported from outside the state.

The second reason Japan supports the development of solar energy is the country's belief in the importance of preventing global warming. As an island nation, Japan is particularly concerned about the rise in sea level that could result from global warming. Even before signing the Kyoto Protocol in 1998, the country saw photovoltaic energy as an important way to reduce global warming pollution that results from burning fossil fuels.[34]

Although California's 840 miles of coastline is a fraction of Japan's 18,000 miles, changes in sea level could still have disastrous impacts on some of California's unique ecosystems, not to mention its coastal real estate and tourism businesses.

Planning for Industry Development

From the beginning, the Japanese government recognized that the best way to make solar power cost-effective was by stimulating demand and developing the industry. In the early 1990s, Japan set a target of installing, across all applications, 400 MW of solar capacity by 2000 and 5,000 MW by 2010.[35]

The primary vehicle for achieving these targets was the residential PV incentive program, implemented in 1994.[36] Unlike other government-sponsored programs, which only focus on industry development, this program builds the industry while increasing total installed capacity; in this way, it has operated much like the California Energy Commission's (CEC) Emerging Renewables Program. The program's three components – a national incentive program, local programs, and net-metering regulations – were primarily designed to reduce the high upfront costs that have historically been a stumbling block to residential PV. As increasing numbers of homeowners began installing PV systems, a market-based stimulus emerged for the PV manufacturing industry. Because the Japanese government made clear its intention to continue supporting the residential PV incentives program for the next decade, Japanese manufacturers felt confident that demand for rooftop solar applications would not diminish. This confidence led them to invest in research and improved manufacturing processes. These investments, in turn, have helped bring down the cost of manufacturing residential solar systems.

The second way Japan helped develop the solar industry was through a series of smaller programs promoting industrial research and development. The primary objective of these programs was to further advancements in PV production and cost reductions of PV systems.[37] Nationally funded research and development projects have helped develop a series of PV applications, including power supplies for unattended lights and signs, desalination plants on marine vessels, and solar cars.[38] While significant technological advances have been made as a result of these research programs, growth of Japan's photovoltaic capacity is primarily due to an increase in the residential photovoltaic market.[39] In Japan, demand for residential PV systems accounts for more than 80 percent of the total demand for photovoltaic power generation.[40]

Japan's National Incentive Program

The core policy for stimulating demand was METI's national incentive program. This program defrayed the costs of PV modules, balance-of-system components, and installation work.[41] At the onset, this program paid 50 percent of the installation costs of residential PV systems. Each year, the national contribution has incrementally decreased. In 2003, the incentive was approximately 10 percent of installation costs.[42] From 1994 to 2003, the program had an average annual budget of $115 million.[43] The CEC's program, by comparison, has given an annual average of $22 million to residential PV retrofits over its seven years.

At first this national program was only open to individuals installing systems on their own homes. Later it was expanded to housing developers and local public organizations.[44] This program expansion was designed to encourage mass installation of PV systems, but the average installed system size has remained close to 3.5 kW.[45]

Local Programs

In addition to the national incentive program, more than 300 local/regional governments provide additional funds to help offset the cost of installing residential PV units.[46] These local programs provide a mixture of direct financial incentives and low-interest loans. Depending on the area, direct financial incentives range from less than one-twelfth of total system price (for participants in the national incentive program) to half of the total installation cost (for non-participants in the national incentive program).[47] Naturally, regions that provide additional incentives have significantly more PV installations than others.[48]

Historically, local governments that implement incentive programs have been eligible to apply to METI for additional funding.[49] After the national residential incentive program ends, it is expected that the promotion of residential solar systems will be fully managed by the local governments.[50] Although many local governments appear ready to continue modest incentive programs after the national program is phased out, it is unlikely that the amount of resources they dedicate to these programs will be comparable to the amount of resources currently allocated by METI.

Net Metering

An important component of Japan's PV incentive program is net metering, by which homeowners can sell excess electricity back to their utility company at the same per-kilowatt-hour price as the utility supplies it. (See "Net Metering," page 9.) Moreover, homeowners in Japan can get power supply contracts with rates that vary over the course of the day (with higher rates usually charged during the peak demand hours).[51] This "time-of-use" billing is only sporadically available in California. In Japan, time-of-use billing has helped make net metering one of the driving forces for Japanese homeowners to install PV systems.[52]

This has also resulted in the introduction of an entire line of "zero-cost-electricity" pre-fabricated homes. These homes are "zero-cost-electricity" because they sell surplus electricity produced during the daytime, and then buy back electricity at night, at a third of the daytime charge, from the utility company.[53] Although pre-fabricated homes form a larger share of the new homes market in Japan than in California, a new home where a family never has to pay an electric bill would certainly appeal to California homebuyers.

Success of Japan's PV Incentive Program

In the past 10 years, total solar capacity in Japan has increased exponentially. During this same time the cost of installing a residential photovoltaic system has dramatically fallen, and Japanese PV module manufacturing has grown 22-fold. This growth in installed PV capacity and in the PV industry is primarily a result of Japan's residential incentive program.

Increasing Capacity

In 1993, before launching the residential incentives program, Japan had 24.3 MWp of installed PV capacity.[54] By 2003, Japan had added 835 MWp of PV – roughly equal to the new capacity added during this time period in every other country in the world, combined. (See Figure 8.) Since 1993, Germany has increased installed PV capacity by 401 MWp, the United States has increased installed PV capacity by 225 MWp, and the rest of the world has increased its combined capacity by 211 MWp.

Figure 8. Japan Has Surpassed the Rest of the World in Installed PV Capacity (MWp)[55]

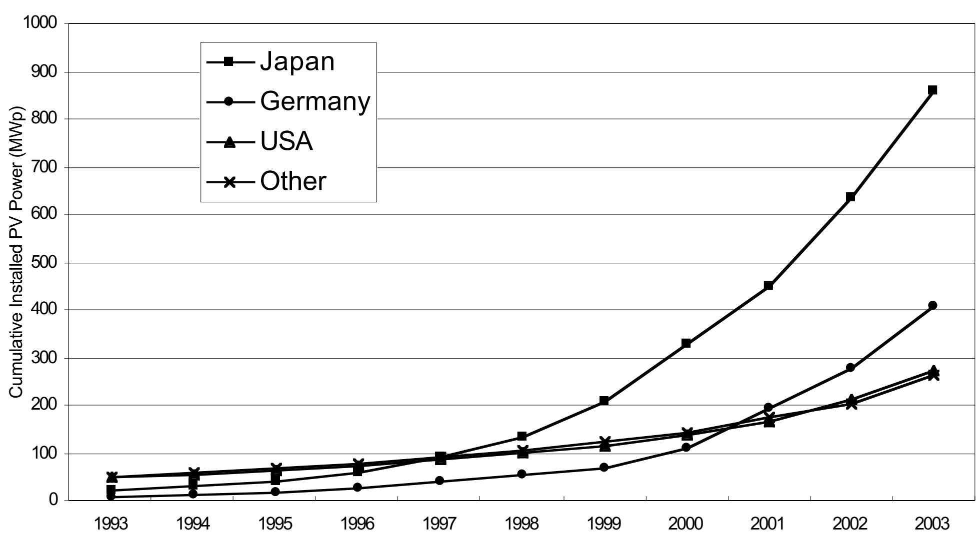
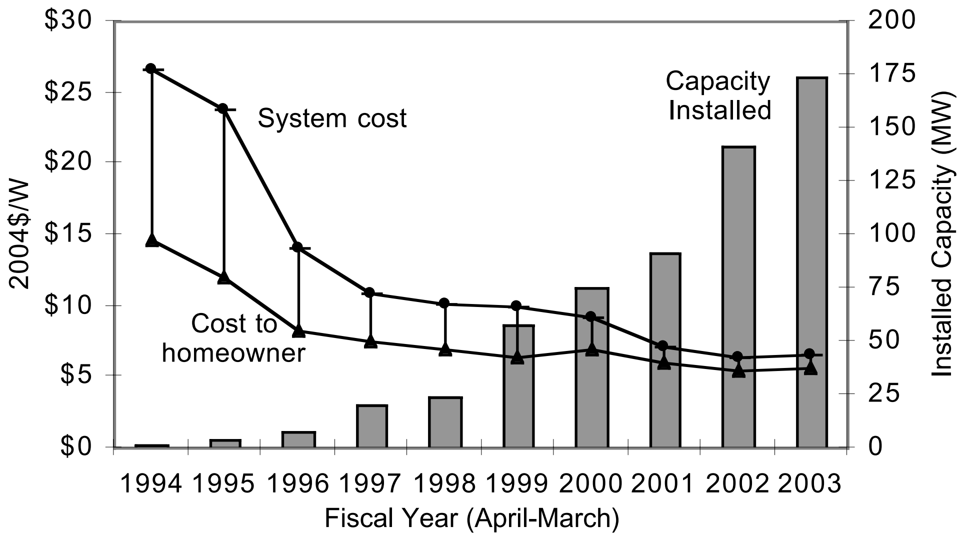


Figure 9. The Success of Japan's Residential PV Incentive Program: 1994-2003[63]



The original goal was to equip 70,000 homes with 3 kWp systems by 2000 and to install building-integrated photovoltaic systems on half of new homes by 2010.[56] The first target was hit with only one year's delay and the present development of production capabilities and market growth indicates that the target for 2010 can be met as well.[57]

Growth in installed PV capacity in Japan is strongly correlated to the residential incentives program.[58] Every year since the program was first introduced annual installed capacity has increased. In FY 1994, 539 residential PV units were installed, compared to 46,760 residential units installed in FY 2003.[59] Through March 2004 (the end of FY 2003), this program has resulted in the addition of 595 MWp of new residential PV capacity.[60] This accounts for over 70 percent of the increase in PV capacity in Japan during the last decade.[61] Although money for promotion for the installation of residential PV systems has been significantly scaled back since 2001, participation in the program has continued to rise rapidly. This suggests that promotion and demand are becoming independent of one another and that Japan is on course to a self-supporting solar market.[62]

Decreasing Cost

The cost of installing residential PV systems has fallen dramatically in Japan since the residential incentive program began: from $26.54/W in FY 1994 to $6.50/W in FY 2003. (See Figure 9.) As rising demand drove industry expansion, the experience gained and economies of scale resulted in cost savings, driving down the cost of electricity from solar cells.

Decreasing costs of installing residential PV systems allowed Japan to decrease the maximum incentive provided to homeowners while simultaneously increasing the amount of solar capacity installed annually.[64] The average governmental contribution dropped from $11.94/W in FY 1994 to $0.85/W in FY 2003.[65]

Not only has the total incentive per household decreased during this period, but the incentive as a fraction of the total installation costs has also decreased. From 1994 to 2003, the maximum incentive per system shrunk from 50 percent to 10 percent of installation costs.[66] This is a sign of the residential PV incentive program's success: the industry is rapidly approaching the point where the cost of installing a system is low enough that government incentives are no longer necessary.

However, the cost reductions resulting from the Japanese market expansion have not translated into equal cost reductions in California or other markets. Reduced cost of balance-of-system components and installation have been a significant portion of the price reductions in Japan, but these components tend to be more regional in nature, specific to the type of house and the companies themselves.[67] This means that system costs in California will respond most to increased demand in California. Also, because electricity rates and household electricity consumption vary between California and Japan, the system price may need to be lower for a California homeowner to break even.

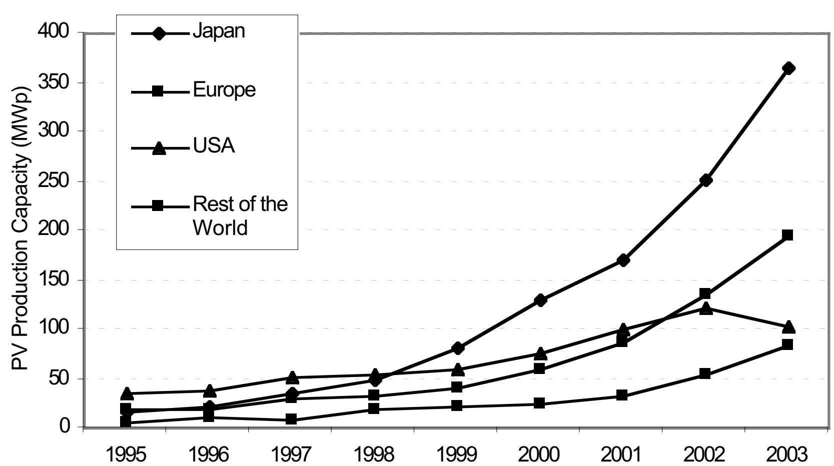
Growing an Industry

Strong domestic demand, coupled with a national commitment to developing a self-sustaining market, has led to significant growth in Japan's photovoltaics industry. Over the course of the past decade, Japan has passed the United States as the world's leading manufacturer of PV modules. (See Figure 10.)

In 1995, Japanese-based manufacturing capacity accounted for 21 percent of world production. Today, production in Japan supplies 50 percent of the global photovoltaics market. From 1995 to 2005, Japan's photovoltaics manufacturing capacity increased from 16.40 MWp to 363.91 MWp. Industry experts believe that the increase in Japanese global market share is due primarily to growth of the building-integrated photovoltaic market, which directly benefits from residential PV incentives and net-metering regulations.[69]

This industry growth has brought thousands of jobs with it. Industry analysts indicate that approximately 20 year-long jobs are created per megawatt of production capacity during manufacturing; 30 jobs are created per megawatt of capacity during the process of installa-

Figure 10. World PV Module Manufacturing Capacity (MWp): 1995-2003[68]



tion, retailing and provision of other local services; and one maintenance job is created per installed megawatt.[70] Thus, in 2003, the photovoltaics industry in Japan provided approximately 15,000 new jobs (7,300 new manufacturing jobs, 6,700 installation jobs, and 900 maintenance jobs).[71]

In addition to helping the industry grow, the residential PV incentive program also changed the structure of the solar industry, especially with regard to new homes. In 1997, 1.5 percent of new single-family homes came with pre-installed PV systems. By 2002, nearly 10 percent of the 350,000 single-family home new construction starts in Japan had PV.[72] Currently the residential PV market in Japan is half retrofit and half new construction.[73] Part of this increase is linked to the fact that prefabricated manufactured housing is prevalent throughout Japan. Recognizing that this type of construction lends itself well to incorporation of PV systems, many solar manufacturing companies have formed strategic alliances with developers of new homes. This type of vertical integration of the industry has played a critical role in bringing down costs of owning a solar home in Japan.

Future Prospects

In addition to being committed to increasing installed PV capacity, the Japanese government firmly believes that this can only be achieved by developing a strong and self-sustaining PV market. Future solar energy policy will continue to be market-based and designed to meet both of these objectives.

Japan's residential PV incentive program was initially scheduled to finish at the end of the 2002 fiscal year. However, the program was extended three more years until FY 2005, with sharp cuts in both the budget and the size of the maximum incentive per household. At the time the Japanese PV community worried about the impact these cuts would have on the domestic market. However, since the end of FY 2002 there have been more applications for PV systems then ever before.[74]

Although the residential incentive program has played an important role in developing the PV market, in an attempt to boost industry competition, the government is looking towards eliminating its residential PV incentives. Starting in FY 2006 it is expected that the role of promoting residential solar system installations will be transferred fully to local municipalities.[75]

Looking forward, the Japanese New Energy and Industrial Technology Development Organization (NEDO) believes it is possible to have a total installed PV capacity in the range of 100,000 MWp by 2030, at which time PV power generation would supply approximately 50 percent of residential electricity consumption and approximately 10 percent of total electricity consumption in Japan. In order to achieve this goal, NEDO has set the following targets: 1) PV electricity costs equivalent to the standard charge for residential use by 2010; 2) PV electricity costs equivalent to that of business use by 2020; 2) PV electricity costs equivalent to that for industrial use by 2030.[76] Based on the experience with its residential program, Japan appears to be well on its way to achieving these goals.

Policy Recommendations

Policies targeted at increasing demand for solar power installations are the best way to simultaneously increase California's solar generating capacity and pull down the cost of PV in the long-term. This will increase the amount of electricity generated from clean, distributed sources, build the strength of California's solar industry, and pave the way for further growth in generation from clean solar power in the decades ahead. Governor Schwarzenegger set a goal of 3,000 MWp of total new solar PV capacity and half of all new homes built with solar power over the next 10 years, and meeting that goal will require bringing down the cost. The strongest policies to get us there combine market-based mechanisms with design standards for new construction.

Dedicate Funds for a Solar Incentive Program

California needs a secure, statewide and dedicated fund for residential and commercial solar power incentives, with a flexible but capped rebate that declines over time. A guaranteed fund will assure companies involved in the solar industry that the capital investments they make to meet the rising demand will be well spent. The California Energy Commission's Emerging Renewables Program and Japan's residential incentives program have proven the strength of this approach.

We suggest a new, dedicated residential solar incentive fund of an estimated $180 million per year, funded through a surcharge on electricity bills. Given conservative assumptions about the rate at which prices decline (see "The Case for Continued Residential Incentives in California," page 12), this amount will bring the cost of retrofitted systems down to the break-even level in 10 years, while also leading to the installation of 1,278 MW of new residential retrofit systems. The incentives should also be available for systems on new homes, which are generally cheaper than retrofitted systems and therefore would result in even more installations given that the funds could be used more economically.

A similar incentive fund should also be established for commercial installations. This will increase overall solar generating capacity, and will further bring down the costs of residential systems because much of the technology development will spill over.

Integrate Solar PV into New Home Design and Construction

Incorporating solar photovoltaic systems into new housing design and construction has been key to Japan's success at creating a robust, self-sufficient solar market. California should do the same by establishing policies that ensure Governor Schwarzenegger's goal of building half of all new homes with solar power is reached. Such policies will maximize ratepayer and taxpayer investments by driving prices down and increasing installation efficiencies.

Encourage Solar through Utility Billing Practices

Other important policies can help ensure that homeowners who install solar PV systems maximize the return on their investment.

- **Raise the net metering cap.** Currently, utilities allow net metering up to one-half of one percent of their peak demand. This should be raised to at least 5 percent. Allowing more homeowners to get credit for the electricity they generate is critical to making PV a viable widespread power source.

- **Make time-of-use billing an option for all electric power customers.** With this form of billing, the credit given to net-metered electricity from a residential PV system is closer to its actual worth.

Continue Tax Incentives

California should continue the various tax incentives it currently gives for solar PV systems and other renewable energy technologies – such as exemption from property taxes, a personal tax deduction on the interest paid on loans used to purchase PV systems, and income tax credits for the purchase and installation of PV systems. Several of these tax incentives will expire over the next year if not renewed.

Establish Manufacturing and Installation Standards

As new suppliers enter the market, the state should ensure safety and installation standards, minimum warranties on systems, and adequate training for installers and developers.

Research and Development

The state should also continue policies that can help improve the progress ratio – the rate at which prices decrease in relation to production increases. Programs that support improvements in the various photovoltaic conversion technologies, inverter engineering, factory production, and other technical aspects can develop knowledge that can then disseminate through the industry to help companies make better decisions about how to reduce costs as they meet increasing demand.

METHODOLOGY

The projections made in this report are based on modeling experience and demand curves for residential PV systems. All dollar figures are given in 2004 dollars, unless otherwise noted. Residential system sizes are given as kilowatts (kW), and describe the AC output of the system; likewise, residential system prices given in dollars per Watt are alternating current. When discussing modules or total installed capacity, it frequently makes more sense to talk of the peak DC output; in such cases, we use peak kilowatts (kWp) or peak Megawatts (MWp).

The Break-Even Point and General Assumptions

Financial benefits to homeowners consist of displaced electricity costs over the lifetime of the system. Costs consist of initial installation, plus inverter replacement costs. We make the following assumptions:

- Typical residential system size is 2.5 kW, based on the most common system size given a rebate by the California Energy Commission's Emerging Renewables Program. (See CEC, *Data Showing Approved and Completed Systems* (spreadsheet), downloaded from www.energy.ca.gov/renewables/emerging_renewables.html, 9 January 2005.)
- PV panels operate at 20 percent capacity, meaning that a 2.5 kW system generates 4,380 kWh in a year (2.5 kW x 8,760 hours/year x 20% = 4,380 kWh/year). This is based on average daily solar radiation at locations in California, which ranges from 4.4 to 6.6 kWh/meter-squared – equivalent to full sunlight for 18 to 28 percent of the day (Renewable Resource Data Center, Department of Energy, *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, downloaded from rredc.nrel.gov/solar/pubs/redbook, 22 January 2005).
- Future electricity rates through 2013 are based on CEC, *California State-Wide Weighted Average Retail Electricity Prices by Sector*, downloaded from www.energy.ca.gov/electricity/statewide_weightavg_sector.html, 8 January 2005. For years beyond 2013, we use the average of the prior 10 years.
- Normal PV module lifetime is 25 years.
- We assume that a homeowner will need to replace the system's inverter twice over the lifetime of the system, with a replacement cost of $1,000 each time. Current inverters' life-spans are seven to nine years, but the industry expects to improve average life-spans to ten years or more. (See Sigifredo Gonzales, Chris Beauchamp, Ward Bower, Jerry Ginn, Mark Ralph, "PV Inverter Testing, Modeling and New Initiatives," *National Center for Photovoltaics and Solar Program Review Meeting Proceedings 2003*, sponsored by U.S. Department of Energy.) Current inverter costs are also approximately $2,000; however, a recent study has estimated that it is technically possible to reduce the cost by half. (See Gerrit Jan Schaeffer, et al, *Learning from the Sun: Analysis of the Use of Experience Curves for Energy Policy Purposes: The Case of Photovoltaic Power. Final Report of the Photex Project*, August 2004.)
- Break-even cost of solar installations is based on the price at which installation cost plus future inverter-replacement costs are equal to the value of displaced electricity over the system lifetime. Although there may be other

maintenance costs incurred, these are relatively minor compared to the upfront and inverter replacement costs.

In a previous analysis, we concluded that residential grid-connected PV systems in the United States would reach $6 per peak Watt (DC) by 2006. (See Tony Dutzik and Bernadette Del Chiaro, Environment California Research & Policy Center, *The Economics of Solar Homes in California*, December 2004.) Because this report projects the relationship between future cost reductions and demand, we make more conservative assumptions for the projections. We also project forward from more detailed, California-specific data (see below), rather than the nationwide price data used in the previous report.

Historical Data

Historical installation and cost data for the California retrofit market are from the California Energy Commission's Emerging Renewables Program. (See CEC, *Data Showing Approved and Completed Systems* (spreadsheet), downloaded from www.energy.ca.gov/renewables/emerging_renewables.html, 9 January 2005.) Todd Lieberg of the CEC assisted us in determining the size of the rebate given each system and therefore the cost to the homeowner. We removed all records greater than 10 kW, which are not likely to be residential, and counted projects during the year in which their rebate was approved. We also focused our analysis on retrofitted systems and removed records of systems on new homes; these make up a small portion of the residential PV market, and there have been too few of them to supply sufficient data. Because there were PV systems in California before the CEC's program started, we assumed an initial cumulative installed capacity of 6,494 kW, based on the cumulative grid-connected PV at the end of 1997. (See CEC, *Amount (MW) of Grid-Connected Solar Photovoltaics (PV) in California, 1981 to Present* (spreadsheet), downloaded from www.energy.ca.gov/renewables/emerging_renewables.html, 9 January 2005.)

Projection of Future Costs and Demand

Projecting the future cycle of increasing demand and decreasing price requires projecting a demand curve and an experience curve. For a more detailed discussion of the application of experience curves and progress ratios to energy technologies, see Richard Duke and Daniel Kammen, "The Economics of Energy Market Transformation Programs," *The Energy Journal*, 20(4), 1999.

In order to account for the price reductions resulting from worldwide demand for PV, we split the future dollar per Watt price of a system in California into two parts:

- A "global" component, which starts at the 2004 average market price for a PV module ($5.31/W), and
- An "in-state" component, which starts at the difference between the 2004 average price of a residential system in California ($8.98/W) and the 2004 average market price for a module ($5.31/W).

We project two scenarios: one in which we use a progress ratio of 80 percent for both components of the system price, and one in which we use a progress ratio of 85 percent for both components.

Global Component of Price

The global component is projected forward from the 2004 average market price for a PV module, as given by the Solarbuzz price survey. (See Solarbuzz, *Solar Module Price Environment*, downloaded from www.solarbuzz.com/moduleprices.htm, 28 January 2005.) We assume that the price falls to the level of the progress ratio (either 80 percent or 85 percent in our scenarios) when cumulative production doubles, with the projected module price for any given year based on the cumulative international PV production at the end of the previous year. We assume that global cumulative installed PV capacity will continue to grow along the same exponential path of the recent past. (See International Energy Agency, Photovoltaic Power Systems Programme, *Total Photovoltaic Power Installed In IEA PVPS Countries*, downloaded from www.oja-services.nl/iea-pvps/isr/22.htm, 28 January 2005.)

In-state Component of Price

The in-state component is projected forward from the difference between the 2004 average price of a residential system in California (from the CEC data) and the 2004 average market price for a module (see above). We assume that the price falls to the level of the progress ratio (either 80 percent or 85 percent in our scenarios) when cumulative installations double; the projected price for any given year is based on the cumulative installed residential PV in California at the end of the previous year.

Predicting the amount of residential PV installed in California each year requires a demand curve, with the demand in any given year based on the price to homeowners (the installation price minus any assumed incentive given). We use the historical CEC data to establish a demand curve for the California market. Residential PV is a unique product, and insofar as it has financial paybacks, it is essentially like any other investment. This demand curve would not likely hold true in the cost range below $4.00/W, where solar PV pays off so well that it makes little sense not to invest, but we are only interested up to the point where homeowners can break even.

Note on Progress Ratios

As mentioned in the text, calculating a progress ratio specifically for residential PV systems in California presents difficulties. PV modules and other parts of a residential system are part of a global learning curve, because they are essentially the same worldwide, and are often manufactured for many purposes other than residential power by companies operating internationally. Furthermore, the California data that is available is only from the start of the CEC's Emerging Renewables Program in 1998, when the California market was undeveloped. Calculating an experience curve from this historical data yields a progress ratio of 87 percent, +/- 10 percent. This large margin of error reflects the wide variance of system prices in the market during the early years of the CEC program.

Therefore, we project future costs and demand based on two scenarios, with progress ratios equal to 80 percent and 85 percent, in line with the results of studies that have analyzed comprehensive data from Japan and Europe. (See Christopher Harmon, International Institute for Applied Systems Analysis, *Experience Curves of Photovoltaic Technology*, 30 March 2000. Also, Gerrit Jan Schaeffer, et al, *Learning from the Sun: Analysis of the Use of Experience Curves for Energy Policy Purposes: The Case of Photovoltaic Power. Final Report of the Photex Project*, August 2004.)

Endnotes

1. Historical installation and cost data for the California market are from the California Energy Commission's Emerging Renewables Program. (See CEC, *Data Showing Approved and Completed Systems* (spreadsheet), downloaded from www.energy.ca.gov/renewables/emerging_renewables.html, 9 January 2005.) Todd Lieberg of the CEC assisted us in determining the size of the rebate given each system and therefore the cost to the homeowner. We removed all records greater than 10 kW, which are not likely to be residential, and counted projects during the year in which their rebate was approved.

2. Reduced cost of various components in Japanese market: Richard D. Duke, *Clean Energy Technology Buydowns: Economic Theory, Analytic Tools, and the Photovoltaics Case*, November 2002.

3. Data provided by Junko Movellan, Kyocera Corporation, personal communication, 8 March 2005; also available in Japanese at www.solar.nef.or.jp/josei/zissi.htm. Japanese fiscal years start in April (e.g. FY 1994 ran from April 1994 to March 1995). Figures were converted from yen to dollars using Federal Reserve Board annual exchange rates (Federal Reserve Board, *Annual Foreign Exchange Rates (G.5A)*, 3 January 2005) and the Bureau of Labor Statistics's inflation calculator (www.bls.gov/bls/inflation.htm); because month-to-month data is unavailable, we assumed that exchange and inflation rates apply to the calendar year closest to the fiscal year.

4. Average annual investment: Data provided by Junko Movellan, Kyocera Corporation, personal communication, 8 March 2005; also available in Japanese at www.solar.nef.or.jp/josei/zissi.htm. Japanese fiscal years start in April (e.g. FY 1994 ran from April 1994 to March 1995). Figures were converted from yen to dollars using Federal Reserve Board annual exchange rates (Federal Reserve Board, *Annual Foreign Exchange Rates (G.5A)*, 3 January 2005) and the Bureau of Labor Statistics's inflation calculator (www.bls.gov/bls/inflation.htm); because month-to-month data is unavailable, we assumed that exchange and inflation rates apply to the calendar year closest to the fiscal year. 35-fold increase: International Energy Agency Photovoltaic Power Systems Programme, *Trends in Photovoltaic Applications: Survey Report of Selected IEA Countries Between 1992 and 2003*, September 2004.

5. International Energy Agency Photovoltaic Power Systems Programme, *Trends in Photovoltaic Applications: Survey Report of Selected IEA Countries Between 1992 and 2003*, September 2004.

6. Arnulf Jager-Waldau, European Commission Joint Research Centre, *PV Status Report 2003: Research, Solar Cell Production and Market Implementation in Japan, USA and the European Union*, September 2003; Peter Holihan, "Technology, Manufacturing, and Market Trends in the U.S. and International Photovoltaics Industry," *Renewable Energy 2002: Issues and Trends*, February 2001.

7. Paul Maycock, "PV Market Update," *Renewable Energy World*, Vol. 7 (4), July-August 2004.

8. Database of State Incentives for Renewable Energy, *California Incentives for Renewable Energy: Net Metering*, downloaded from www.dsireusa.org, 10 January 2005.

9. Public Renewables Partnership, *Solar PV Cost Factors*, downloaded from www.repartners.org/solar/pvcost.htm, 9 January 2005.

10. California Solar Center, *PV Project Gallery: Grid-Tie Applications*, downloaded from www.californiasolarcenter.org/pvgallery1.html, 10 January 2005.

11. Seven to nine years: Sigifredo Gonzales, Sandia National Laboratories, personal communication, 22 November 2004. Industry goal: Sigifredo Gonzales, Chris Beauchamp, Ward Bower, Jerry Ginn, Mark Ralph, "PV Inverter Testing, Modeling and New Initiatives," *National Center for Photovoltaics and Solar Program Review Meeting Proceedings 2003*, sponsored by U.S. Department of Energy.

12. $0.831: Solarbuzz, *Inverter Price Environment*, downloaded from www.solarbuzz.com/Inverterprices.htm, 12 January 2005. Reducing cost of inverters by half: Gerrit Jan Schaeffer, et al, *Learning from the Sun: Analysis of the Use of Experience Curves for Energy Policy Purposes: The Case of Photovoltaic Power. Final Report of the Photex Project*, August 2004.

13. Go Solar Company, *Solar Module Performance Summary*, downloaded from www.solarexpert.com/grid-tie/system-performance-factors.html, 7 February 2005.

14. For a more detailed discussion of the application of experience curves and progress ratios to energy technologies, see: Richard Duke and Daniel Kammen, "The Economics of Energy Market Transformation Programs," *The Energy Journal*, 20(4), 1999.

15. See, for example: Richard Duke and Daniel Kammen, "The Economics of Energy Market Transformation Programs," *The Energy Journal*, 20(4), 1999; Christopher Harmon, International Institute for Applied Systems Analysis, *Experience Curves of Photovoltaic Technology*, 30 March 2000; Gerrit Jan Schaeffer, et al, *Learning from the Sun: Analysis of the Use of Experience Curves for Energy Policy Purposes: The Case of Photovoltaic Power. Final Report of the Photex Project*, August 2004.

16. See note 1.

17. Ibid.

18. Ibid. Because there were PV systems in California before the CEC's program started, we assumed an initial cumulative installed capacity of 6,494 kW, based on the cumulative grid-connected PV at the end of 1997. (See CEC, *Amount (MW) of Grid-Connected Solar Photovoltaics (PV) in California, 1981 to Present* (spreadsheet), downloaded from www.energy.ca.gov/renewables/emerging_renewables.html, 9 January 2005.)

19. 2003 residential electricity demand: U.S. Department of Energy, Energy Information Administration, *Current and Historical Monthly Retail Sales, Revenues, and Average Revenue per Kilowatthour by State and by Sector* (spreadsheet), downloaded from www.eia.doe.gov/cneaf/electricity/page/data.html, 21 February 2005.

20. Average California household electricity consumption calculated from 2003 residential electricity demand in California (U.S. Department of Energy, Energy Information Administration, *Current and Historical Monthly Retail Sales, Revenues, and Average Revenue per Kilowatthour by State and by Sector* (spreadsheet), downloaded from www.eia.doe.gov/cneaf/electricity/page/data.html, 21 February 2005) and occupied housing units in California (U.S. Census Bureau, *2003 American Community Survey Summary Tables: California*, downloaded from factfinder.census.gov, 22 February 2005).

21. See note 5.

22. Ibid.

23. Mark Bolinger and Ryan Wiser, Berkeley Lab and the Clean Energy Group, *Case Studies of State Support for Renewable Energy: Support for PV in Japan and Germany,* September 2002.

24. See note 5.

25. See note 7.

26. See note 3.

27. Arnulf Jager-Waldau, European Commission Joint Research Centre, *PV Status Report 2003: Research, Solar Cell Production and Market Implementation in Japan, USA and the European Union*, September 2003.

28. See note 5.

29. See note 3.

30. Ibid.

31. See note 27.

32. International Energy Agency, *Energy Balances of OECD Countries 1999/2000,* 2002. (Cited in New Energy Foundation, *New and Renewable Energy in Japan*, downloaded from www.nef.or.jp/english/new/, 21 February 2005.)

33. California Energy Commission, *California's Major Sources of Energy*, downloaded from www.energy.ca.gov/html/energysources.html, 6 February 2005.

34. See note 27.

35. Peter Holihan, "Technology, Manufacturing, and Market Trends in the U.S. and International Photovoltaics Industry," *Renewable Energy 2002: Issues and Trend,* February 2001.

36. The residential photovoltaic incentive program has gone by many different names and slight variations in the past 10 years. Some of these names include: The Ten Thousand Roofs Program, the 70,000 Roofs Program, the New Sunshine Program, the Building Integrated Photovoltaic Program (the BIPV Program), the Subsidy Program for Residential Applications, the Residential PV Systems Dissemination Program, and the Residential PV System Monitoring Program. These programs have consistently been supported by the Japanese Ministry of Economy, Trade and Industry (METI). However, prior to 2000 METI was named the Ministry of International Trade and Industry (MITI). METI works in close alliance with the New Energy and Industrial Technology Development Organization (NEDO) to supervise development of the solar power in Japan.

37. See note 27.

38. The New Energy Foundation, *Present State of New Energy Introduction in Japan and Its Outlook,* downloaded from www.nef.or.jp/english/new/present.html, 12 December 2004.

39. See note 35.

40. Osamu Ikki and Yukao Tanaka, International Energy Agency Co-Operative Program on Photovoltaic Power Systems, *National Survey Report of PV Power Applications in Japan 2003*, May 2004.

41. The New Energy Foundation, *Subsidy Program for Residential PV Systems,* downloaded from www.nef.or.jp/english/moniter/moni1.htm, 6 January 2004.

42. See note 7.

43. Arnulf Jager-Waldau, European Commission Joint Research Centre, *PV Status Report 2003: Research, Solar Cell Production and Market Implementation in Japan, USA and the European Union*, September 2003. (Figures converted from yen to dollars using annual Federal Reserve Board annual exchange rates: Federal Reserve Board, *Annual Foreign Exchange Rates (G.5A)*, 3 January 2005.)

44. See note 41.

45. See note 27.

46. Junko Movellan, Kyocera Corporation, personal communication, 25 February 2005.

47. See note 38.

48. See note 27.

49. See note 41.

50. See note 27.

51. See note 38.

52. See note 27.

53. Yuji Utsunomiya, "Sekisui Chemical Touts Energy-Efficient Homes," *Japan Times*, 16 April 2003.

54. See note 5.

55. Ibid.

56. See note 35.

57. See note 27.

58. See note 40.

59. See note 3.

60. Data provided by Junko Movellan, Kyocera Corporation, personal communication, 8 March 2005; also available in Japanese at www.solar.nef.or.jp/josei/zissi.htm. Japanese fiscal years start in April (e.g. FY1994 ran from April 1994 to March 1995).

61. See note 7.

62. Oliver Ristau, The Solarserver Forum for Solar Energy, *The Photovoltaic Market in Japan: Unquestioned Leadership of World Markets*, September 2001.

63. See note 3.

64. Mark Bolinger and Ryan Wiser, Berkeley Lab and the Clean Energy Group, *Case Studies of State Support for Renewable Energy: Support for PV in Japan and Germany,* September 2002.

65. See note 3.

66. See note 7.

67. Reduced cost of various components in Japanese market: Richard D. Duke, *Clean Energy Technology Buydowns: Economic Theory, Analytic Tools, and the Photovoltaics Case*, November 2002.

68. See note 7.

69. See note 35.

70. Murray Cameron, et al, "'Solar Generation': A Blueprint for Growing the PV Market," *Renewable Energy World*, Vol. 4 (5), September-October 2001.

71. Manufacturing jobs: calculated from PV manufacturing capacity in Japan in 2003 (Paul Maycock, "PV Market Update," *Renewable Energy World*, Vol. 7 (4), July-August 2004). Installation jobs: calculated from increase in installed PV capacity in Japan from 2002-2003 (International Energy Agency Photovoltaic Power Systems Programme, *Trends in Photovoltaic Applications: Survey Report of Selected IEA Countries Between 1992 and 2003*, September 2004). Maintenance jobs: calculated from total installed PV capacity in Japan in 2003 (International Energy Agency Photovoltaic Power Systems Programme, *Trends in Photovoltaic Applications: Survey Report of Selected IEA Countries Between 1992 and 2003*, September 2004).

72. California Energy Commission, *Accelerated Renewable Energy Development*, 30 July 2004.

73. Ibid.

74. Michael Schmela, "High Demand for PV in Japan: A Dramatic Cut in Subsidies Does Not Stop Japanese Citizens From Investing in Solar," *Photon Magazine*, June 2004.

75. See note 27.

76. New Energy and Industrial Technology Development Organization, *Overview of "PV Roadmap Toward 2030,"* June 2004.