PV ENERGY PAYBACK VS PV INPUT ENERGY DUE TO MARKET GROWTH

Andy Black
OnGrid Solar Energy Systems
4175 Renaissance Dr. #4, San Jose, CA 95134, USA
andy@ongrid.net, (408) 428-0808, www.ongrid.net

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ABSTRACT

The energy payback for most photovoltaic systems is between 2 and 4 years. The input energy is much less than the net total energy that will be returned by the system, but is still a significant amount of input energy. Photovoltaic market growth rates average 30% to 40% per year. Such a fast rate of growth will require a large amount of input energy in future manufacturing. Rapid improvements in energy payback will hasten and increase the ramp-up of net new clean energy production. There is a need to accelerate the improvements in manufacturing efficiency with new products and technologies.

1. INTRODUCTION

The question of photovoltaic "Energy Payback" has long been settled with modern modules and systems returning their input energy within just a few years or less. Cell and module efficiency have increased and manufacturing energy has decreased. Compared to the expected lifetime of 30 years or more, it is clear that PV systems will produce far more energy than was required to manufacture and install them. From a net energy balance, this is a necessary result to qualify them as a sustainable energy source.

The solar PV industry has been growing at a rate exceeding 35% per annum both domestically and abroad for the last several years (as reported in Photon and PV News market surveys). And well it should, if PV is ever to contribute a substantial fraction of the world's electrical energy. The International Energy Agency projects that between 2000 and 2030, global energy consumption will increase by 66% (a 1.7% per annum rate), and electricity use could double.[1]

As a proxy, this paper will focus on California's electrical use and PV market. It will assume that all PV installed in California was produced in-state from in-state materials sources. See Figure 1 for an illustration of a 1.7% annual rate of growth in electricity use compared with a 35% annual growth rate (declining over time) in PV production.

The concern is that as the industry grows, it will require ever-larger amounts of input energy to produce the new

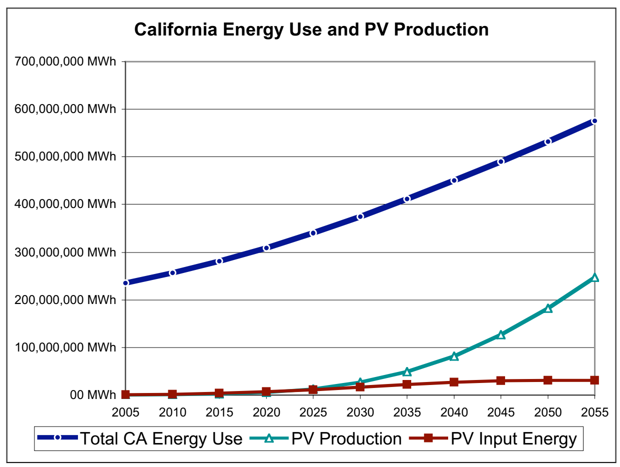

Fig. 1: California Energy Use & PV Production

modules. The growth in input energy requirements of the industry may consume a significant fraction of the energy produced, unless more efficient methods for making PV modules and systems are devised.

This paper will show the necessity to move towards technologies that require less input energy, allowing a high rate of growth while providing significant "net new clean energy." The reasons for this needed shift are both financial and resource efficiency.

2. CURRENT ENERGY PAYBACKS

PV modules and complete systems take a lot of energy to produce. In 1998 Alsema[2] calculated an energy payback of about 4 years for then current multi-crystalline silicon PV systems, including module, framing, mounting hardware and the energy input to the Balance of System (BOS). In 2000 Knapp and Jester[3] studied an actual manufacturing facility and found that, for single-crystal-silicon modules, the energy payback time was 3.3 years. This includes the energy to make the aluminum frames and purify and crystallize the silicon, but does not appear to include the energy input for the BOS components such as inverters, wiring and mounting structures. The additional energy payback time for the BOS is estimated to be about a half a year.

Accounting for the past seven and five years of process and product development since Alsema's and Knapp and Jester's reports, and the lag time of their reports after their data gathering, it is estimated that current systems have an energy payback time of 2.6 years.

3. ENERGY REQUIRED TO SUPPORT GROWTH

Given a stabilized growth rate, and an installed base of PV, if the energy payback time is 4 years, the industry will consume all the energy output of the installed base if it grows at a 25% rate. That is, if there is 100 MW installed, that 100 MW could supply energy for the manufacture and installation of 25 MW of new systems based on the 4-year energy payback rate. The following year, the now 125 MW installed base could support one quarter of 125 MW, or 31.25 MW of new systems, for a net production growth of 25% year-over-year.

This becomes a cycle that could continue indefinitely. An example could be: All the modules made to date produce just enough energy to produce this year's crop of new solar modules. This year's crop, plus all the ones made before will produce just enough energy to make next year's crop, etc.

3.1 Implications in Cost of Manufacture

If the industry is using in its growth as much energy as it is producing from its installed base, and the energy on either side of the equation has a similar retail value in all locations (a hypothetical assumption), it leaves no monetary budget in the manufacturing process for other inputs such as labor and raw materials (assuming the energy needed to produce the raw material is already counted in the PV input energy), and no margin to cover overhead, profit, etc. The cost of manufacturing next year's modules will always be more than this year's panels can be sold for, if they are valued based on the amount of electricity they can produce at retail (ie. without subsidy).

3.2 Implications in Cost and Pollution Shifting

An assumption in the above cost of manufacture is that electrical energy cost and pollution at all locations is similar. This assumption is invalid because some regions electric rates are so high that PV has become economically viable[4], while other areas have very low retail rates.

Because PV manufacturing is energy intensive, pressure will drive manufacturing to lower cost regions, while sales will occur in high cost regions (excluding the effect of subsidies). It becomes clear why Shell has its ingot and wafer facility in Washington state with its 4.36¢/kWh average electricity cost in 2004. Other states such as Wyoming, Utah and Kentucky also have low average electricity cost[5] (see Figure 2.) but much of their electricity comes from coal.

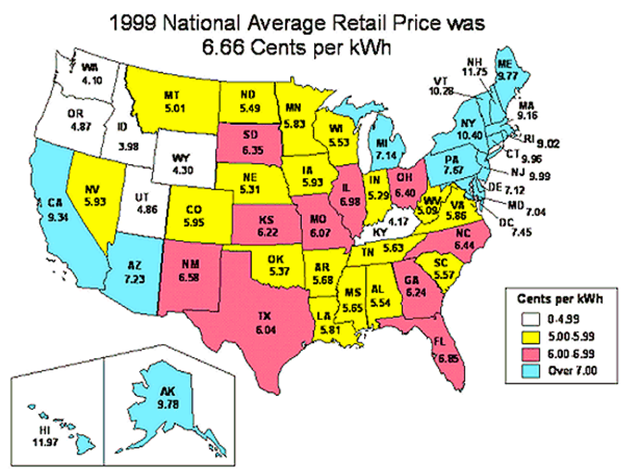

Fig. 2: State average retail electricity costs.

3.3 Variables

Energy Payback Period (in years): A long energy payback means a lower industry growth rate can be supported without requiring additional input energy. See Table 1 for various growth rates that can be supported for corresponding Energy Payback periods. The Energy Payback period as of 2005 is assumed to be 2.6 years for purposes of the initial analysis. This is an estimation based on the Alsema[2] and Knapp and Jester[3] studies, which are 7 and 5 years old, assuming manufacturing has gotten more efficient in that time.

TABLE 1: GROWTH VS. PAYBACK

Energy Payback Period	Self Sustaining, Energy Neutral Growth Rate
5 years	20%
4 years	25%
3 years	33%
2 years	50%
1 year	100%

Industry Initial Growth Rate: 35% in 2005.

Industry Growth Rate Reduction Factor: This is the rate at which the industry is estimated to slow down. Large industries tend to grow more slowly than small ones. As of 2004, the PV industry is still considered very small, so a 35% growth rate, while exceptional, is not unheard of. However, at this rate of growth, the industry will soon be large. One reason the industry's growth must eventually slow is because the input capital requirements will become very large, even by the financial market's measures. Shell[6] has estimated that at an annual growth rate of 25%, in 10 years, the industry will need $200 Billion in working capital and capital finance funds. For purposes of this study, a 3.5% annual growth rate reduction factor will be applied.

PV Energy Payback Reduction Factor: The industry is getting more efficient at producing wafers, cells, modules, and systems, requiring less input energy and producing more output energy, thus shortening energy payback periods. A 6.0% annual energy payback reduction factor is assumed for our initial analysis. The actual rate is unknown at this time and could be higher, or become higher as new technologies emerge that could significantly reduce the input energy requirements.

Other input variables include:

- 93 MW installed PV capacity through 2004 in California[7]
- 26,300 MW average California electrical load[8]
- 1.7% annual growth rate in average electrical load
- 1300 AC kWh PV production per year per DC kW of installed capacity

3.4 Initial Analysis

Figure 3 shows reduction in Energy Payback Period and Industry Growth Rates over 50 years assuming the above rate reduction factors. In 2055, an industry growth rate of 6% when the industry is supplying 43% of California's electricity is rapid, but perhaps not inconceivable.

Figure 4 shows the results of an analysis based on the values of the variables in section 3.3. The results show that PV Production output energy ramps up nicely starting around 2020. However, PV input energy remains significant until about 2025, after which, the industry explodes in terms of production of net new energy as shown in Figure 5.

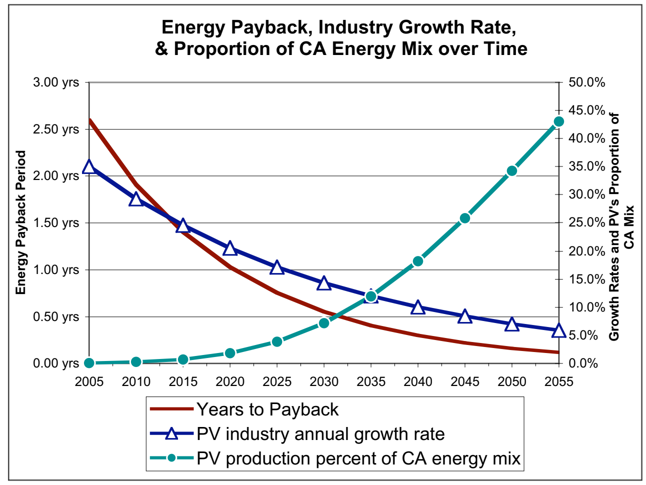

Fig. 3: Energy Payback Period and Industry Growth Rates

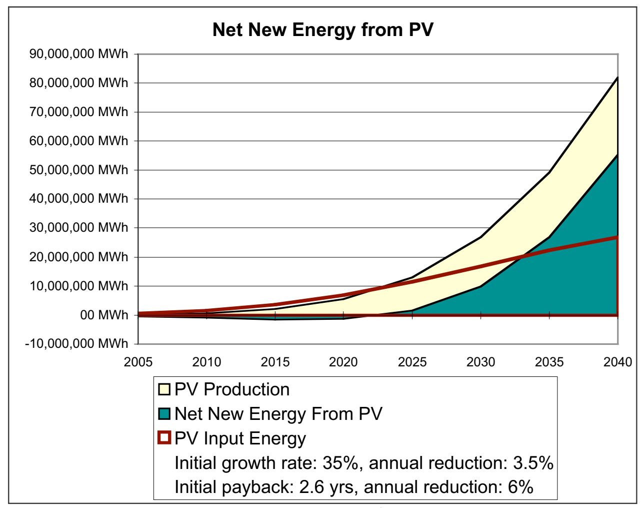

Fig. 4: Net New Energy from PV, 1st scenario.

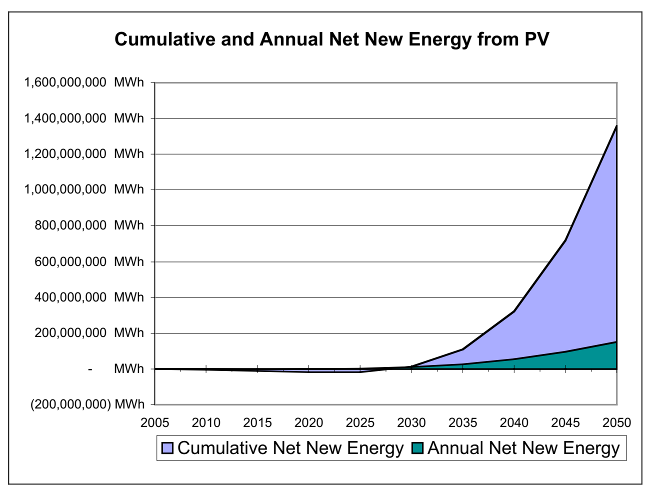

Fig. 5: Cumulative and Net New Energy from PV

3.5 Sensitivity of the Variables

The Industry Initial Growth Rate has a strong affect on the long-term proportion of PV energy in the California energy mix. It does not affect when the ramp-up occurs in the production of net new energy, but it does affect the magnitude of production.

The Industry Growth Rate Reduction Factor has a very strong affect on the long-term proportion of PV energy in the California energy mix. It does not affect when the ramp-up occurs in the production of net new energy, but it does affect the magnitude of production.

Initial Payback period has a major affect on what year the ramp-up occurs. It has a minor affect on annual and cumulative production of net new energy.

The rate at which the industry reduces the payback period has the strongest affect of all factors regarding when the ramp-up occurs. It has a minor affect on annual and cumulative production of net new energy.

3.6 Analysis Assuming Faster Payback

Rerunning the analysis assuming a 2-year initial payback and a faster improvement in production efficiency of 7% per year (faster reduction in energy payback) shows a scenario where the production of net new energy ramps up sooner and faster, starting in 2020. See Figure 6. This scenario might occur if the industry successfully shifts to new, less energy intensive technologies sooner.

CONCLUSION

The next 20 years will serve as an incubation period until the production of net new PV energy begins to explode around 2025. By 2055, the PV industry is capable of producing over 40% of California's electrical energy needs.

Energy payback periods have been steadily improving. The above results can be achieved sooner by more quickly improving energy payback periods.

RECOMMENDATIONS

To make faster progress in supplying a large quantity of net new energy, the industry must improve the energy payback, through technology and manufacturing improvements. An increased focus on energy optimization as part of cost optimization may naturally occur if energy costs continue to rise.

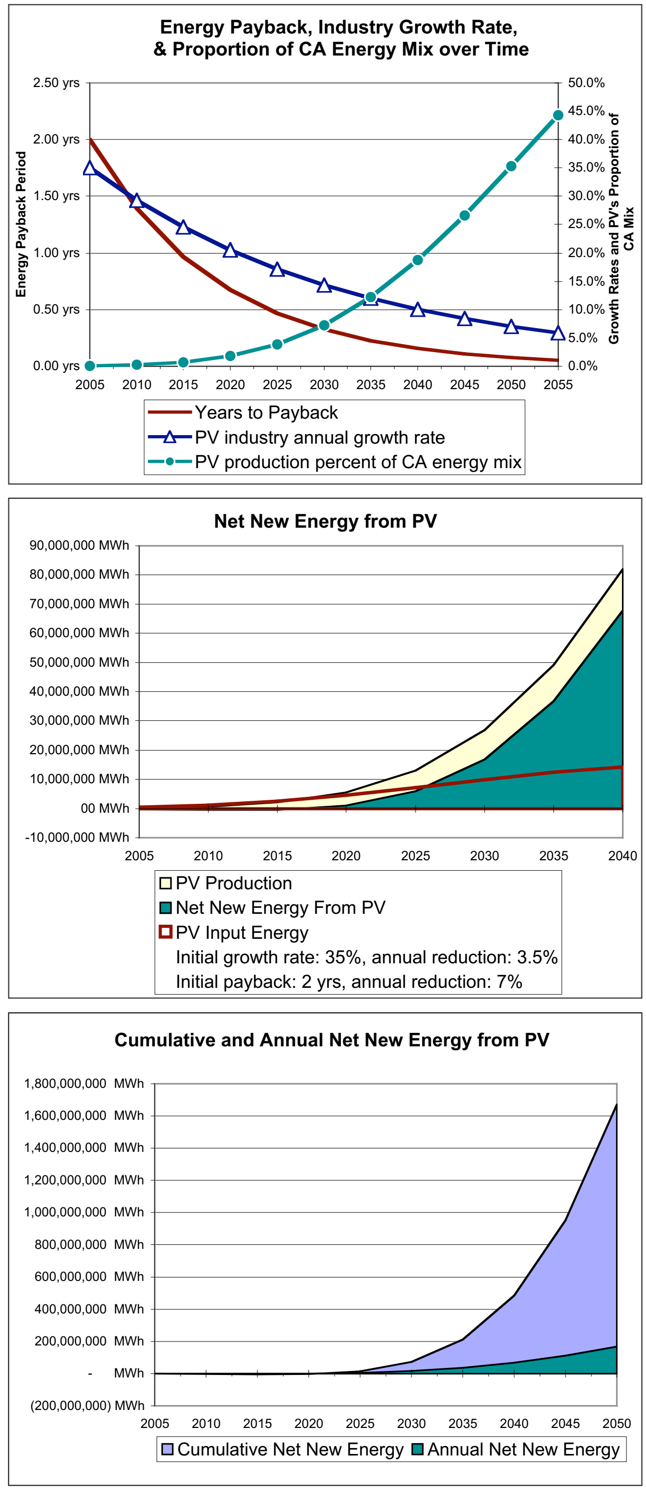

Fig. 6: Faster payback scenario.

Increase funding for research in technologies with high probability of accelerating improvements in energy payback. Thin film technologies hold high promise of using very low energy processes and very small amounts of material. Alsema[2] projects the payback for thin-film PV would drop to just 1 year by 2009. CuInSe2 and CdTe modules are already being sold in the 9%–12% efficiency range, so their energy payback may be less than a year[9]. More research funding will aid this important area.

Favored technologies will have the lowest relative input energy requirements when accounting for the entire system, and will result in manufacturing and production cost advantages in the marketplace. New thin film cells will still need to be encapsulated and mounted, but the cell input energy could be dramatically reduced. The higher the efficiency of these thin films, the less mounting and encapsulation material and energy will be required, further boosting their net results. Eliminating module frames and reducing the use of aluminum in the support structure would be a further improvement[9].

To improve the accuracy of this study, more effort is needed on the projected industry growth rates and projected improvements in energy paybacks, particularly in the novel technologies.

This study has only focused on California, which has a head start along with Germany & Japan. Other parts of the world are further from establishing a major inflow of net new clean energy. However, once they get started, they will benefit from the interim improvements in energy payback.

Initial growth rate: 35%, annual reduction: 3.5%	
Initial payback: 2.6 yrs, annual reduction: 6%	
PV industry 2005 growth rate	35%
PV growth rate reduction factor (% per year)	3.5%
Initial years to PV energy payback	2.6 years
PV energy payback reduction factor (% per year)	6.0%
CA avg electric load in 2003. Source: 2003 CA ISO Market Rep	26,329 MW
CA total electrical energy use growth rate, excluding PV input	1.7%
PV total installed capacity in CA thru 2004. Source: CEC	93 MW
AC kWh PV production per year per DC kW installed capacity	1,300 AC kWh

Year	2004	2005	2010	2015	2020	2025
CA energy use, excluding PV input energy	230,642,040 MWh	234,562,955 MWh	255,190,315 MWh	277,631,636 MWh	302,046,437 MWh	328,608,265 MWh
PV manufacturing & installation input energy	449,821 MWh	567,686 MWh	1,569,701 MWh	3,575,764 MWh	6,884,866 MWh	11,464,711 MWh
Total CA energy use, including PV input energy	231,091,861 MWh	235,130,641 MWh	256,760,016 MWh	281,207,400 MWh	308,931,303 MWh	340,072,975 MWh
PV industry annual growth rate		35.0%	29.3%	24.5%	20.5%	17.2%
Installed PV Capacity	93 MW	126 MW	493 MW	1,588 MW	4,302 MW	10,031 MW
Annual derated PV energy production (=MW*1300)	120,900 MWh	163,215 MWh	641,357 MWh	2,064,979 MWh	5,592,088 MWh	13,039,820 MWh
PV production percent of CA energy mix	0.05%	0.07%	0.25%	0.73%	1.81%	3.83%
Cumulative PV production starting in 2004	120,900 MWh	284,115 MWh	2,309,941 MWh	9,225,604 MWh	28,974,525 MWh	77,270,160 MWh
Years to PV system energy payback	2.76 yrs	2.60 yrs	1.91 yrs	1.40 yrs	1.03 yrs	0.75 yrs
Net new energy from PV (annual)	(328,921) MWh	(404,471) MWh	(928,344) MWh	(1,510,785) MWh	(1,292,778) MWh	1,575,109 MWh
Cumulative net new energy from PV (production minus input)	(328,921) MWh	(733,392) MWh	(4,232,279) MWh	(10,705,126) MWh	(18,216,446) MWh	(17,638,313) MWh

2030	2035	2040	2045	2050	2055	Year
357,505,927 MWh	388,944,837 MWh	423,148,471 MWh	460,359,957 MWh	500,843,804 MWh	544,887,782 MWh	CA energy use, excluding PV input energy
16,850,527 MWh	22,254,980 MWh	26,828,828 MWh	29,925,296 MWh	31,248,780 MWh	30,857,779 MWh	PV manufacturing & installation input energy
374,356,455 MWh	411,199,817 MWh	449,977,299 MWh	490,285,252 MWh	532,092,584 MWh	575,745,561 MWh	Total CA energy use, including PV input energy
14.4%	12.0%	10.1%	8.4%	7.0%	5.9%	PV industry annual growth rate
20,565 MW	37,759 MW	63,093 MW	97,295 MW	140,153 MW	190,559 MW	Installed PV Capacity
26,734,423 MWh	49,086,102 MWh	82,020,445 MWh	126,483,833 MWh	182,199,341 MWh	247,726,739 MWh	Annual derated PV energy production (=MW*1300)
7.14%	11.94%	18.23%	25.80%	34.24%	43.03%	PV production percent of CA energy mix
180,558,136 MWh	377,380,666 MWh	717,106,125 MWh	1,255,950,006 MWh	2,051,225,498 MWh	3,155,291,464 MWh	Cumulative PV production starting in 2004
0.55 yrs	0.41 yrs	0.30 yrs	0.22 yrs	0.16 yrs	0.12 yrs	Years to PV system energy payback
9,883,895 MWh	26,831,122 MWh	55,191,617 MWh	96,558,537 MWh	150,950,560 MWh	216,868,960 MWh	Net new energy from PV (annual)
12,348,994 MWh	108,536,851 MWh	322,781,586 MWh	717,513,841 MWh	1,358,471,459 MWh	2,306,829,538 MWh	Cumulative net new energy from PV (production minus input)

Fig. 7: Raw data from the model.

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