

CONDITIONS FOR PV RELEVANCE IN THE GLOBAL ENERGY FUTURE

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ABSTRACT

For the last five years Photovoltaic (PV) module production has been growing at an impressive 35%ⁱ average annual rate. At that rate, annual production doubles every 2.3 years and total cumulative production¹ doubles approximately every 3.3 years. Based upon the industry's 17% learning curve, this translates to a 17% cost reduction every 3.3 years. We show that if the industry can maintain its present growth rate, we can conservatively estimate break-even for utility applications in 13 years. For PV to figure significantly into the world energy picture, it is also necessary to have sufficient production capacity. At last year's photovoltaic (PV) module production rate, the power-producing equivalent of about 1/20th of a nuclear power plant was added to the world generating capacity. However, at the current growth rate, annual production will be equivalent to one nuclear power plant by 2010 and over 20 nuclear power plants per year by 2020. This 40,000% growth in production capacity compares to a net depletion of known reserves in the fossil fuel industry. For example, the world uses about 77 million barrels of oil per day but an average of only 15 million are discovered.ⁱⁱ Industrial engineers have discovered that learning curves are a very reliable predictor of cost reduction. The PV industry's small size offers it significant room for growth. Its growth potential is, for all practical purposes, unlimited² and cost reduction will continue for years to come.

1. INTRODUCTION

Recently Vice-President Cheney stated that the federal government had not received much for its

money in terms of its investment in renewable energy. A hypothetical look at that perspective may provide a foundation for more effective dialog with those who share that view.

One could imagine Mr. Cheney considering the rolling blackouts and terrorist threats and having a very aggressive timeline in mind for regaining energy independence. Perhaps his advisors presented something like the following: "There are 180,000 megawatts (MW) of natural gas fired power plants on order for installation by 2005ⁱⁱⁱ. If we can supply them with gas, we solve the country's electricity shortage for the foreseeable future. We know how to drill, and we know how to deliver the gas where it needs to go. If we relax some of the regulatory barriers, we can resolve this crisis and keep America strong. Gas pollutes far less than coal, so we can move towards a cleaner energy future this way. We looked at solar energy and found the following: Solar Photovoltaics (PV) doesn't pollute at all and the public likes it. Unfortunately, even if we subsidized PV so that it continued its rapid annual growth rate, of about 35%, and we diverted all the world's production to the US, it could only provide about 500 MW (adjusted for capacity factor)³ or about 0.3% of the scheduled capacity additions by 2005. It just isn't ready for *this* crisis." It is unlikely that after hearing that, that the vice president would be interested in discussing hypothetical scenarios that *could* occur over the next 20 years. One can imagine that from where the vice president sits, with the immediate crises at hand, it might not make sense.

¹ Cumulative production refers to the sum total of all PV produced since its invention.

² Limitless in this context means that production can exceed any foreseeable demand. With fossil fuels production capacity is limited and is thought to be less than foreseeable demand.

³ 3400 MWp (MWp = megawatts peak) will be manufactured in this time frame. With a 15% capacity factor, this translates roughly to 500 MW. Gas fired plants have a capacity factor of about 80%, so by the end of 2005 there will be about 144,000 MW capacity added to the US power plant fleet.

**PV Module Experience Curve 1975-2000
Current Dollars, Volume Factory Order
Utilizes Data Courtesy of Paul Maycock**

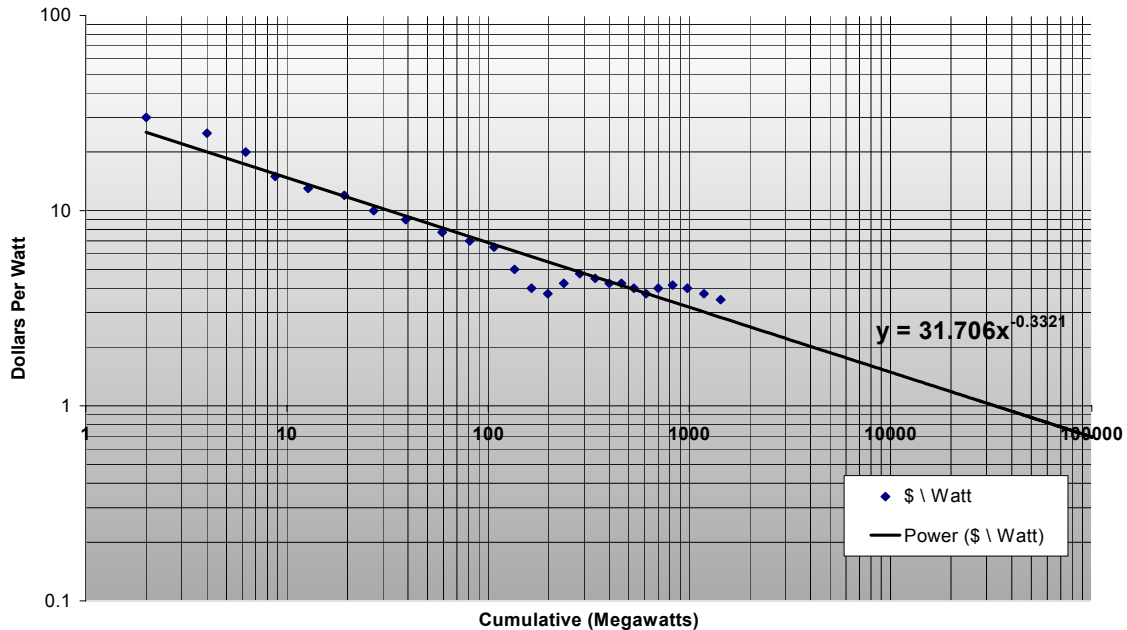


Figure 1. PV industry learning curve plotted on log-log paper.

However, if the current industry growth rate is maintained, then from about 2011 onward, PV will be positioned to make real substantive contributions to the energy mix. At about the same time fossil fuels' decline will become painfully evident. With the added demand on natural gas supplies from construction of new power plants and new homes that heat with gas, it can be inferred that substantial shortages and price spikes will resume sometime between 2005 and 2015.^{iv} In that timeframe and with the implementation of wise energy policy, PV can be ready to play a significant role in the solution to the shortfall.

To get there quickly, the PV industry will need outside funding, probably in the form of subsidies. The solar industry needs to be able to articulate to policy makers and the general public, what the investments of public money will purchase. Exponential growth and simple learning curve theory provide the tools to do this. This paper will focus on two primary points:

1) The PV module industry is on a 17% learning curve. This means that for every doubling of cumulative production, the cost of solar modules decreases by 17%.

2) For the last 5 years the industry has been growing at an average rate of 35%. At this rate, annual production doubles every 2.3 years and cumulative production doubles approximately every 3.3 years. If growth continues at this rate, it will result in an annual production rate of about one Nuclear Plant Equivalent (NPE)⁴ annually by 2010 and roughly 20 NPE annually by 2020.

⁴ Nuclear Power Plant Equivalent (NPE) = The average, capacity factor adjusted, power output of a typical US nuclear power plant which is equal to 830 MW.

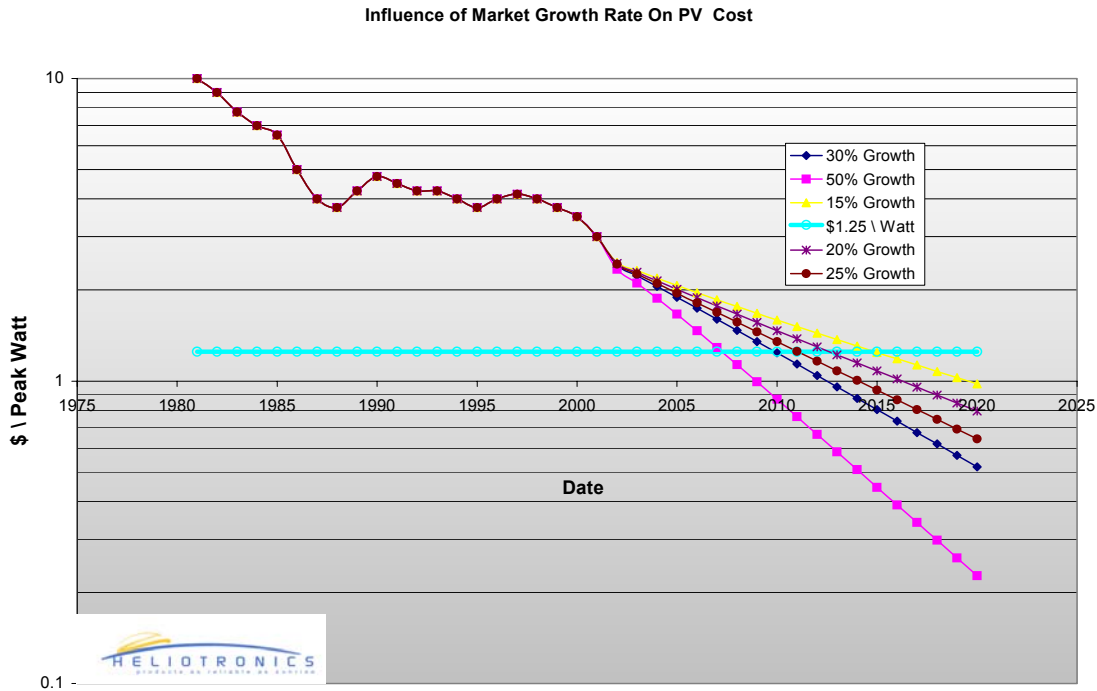


Figure 2. Influence of Market Growth Rate on PV Cost

2. LEARNING CURVES

2.1 Learning Curves Made Easy

Learning curve theory can be applied to the work of an individual in a production line, to an organization producing a product^v or an entire technology category such as photovoltaics^{vi}. Learning curve theory states that for each doubling of cumulative production, the cost drops by a fixed percentage. In Figure 1 we have plotted PV module cost versus cumulative production for the PV module industry^{vii}. Using standard curve fitting techniques, we have found that a 17% learning curve describes cost reduction in the PV industry. In other words, PV module cost is reduced by 17% for every doubling of cumulative production.

2.2 Breakeven Determination

If a constant production growth rate is assumed, then a time dependent module cost function can be generated and plotted. Figure 2 shows the cost curves assuming a variety of growth assumptions.^{viii} Since PV modules are the dominant cost driver for PV systems they serve

as a useful benchmark to which to tie other system costs for cost modeling purposes. It is a common assumption in the industry that when modules hit \$1.25 per watt, PV will become cost effective in a number of areas in the United States. In order to do a somewhat more conservative analysis, we selected a breakeven point of \$1.00 per Watt. If this assumption is accurate and a 35% industry growth rate can be maintained, then PV generated electricity will reach break-even in the utility market around 2013 or in just over 10 years.

2.3 Model Breakdown

A point will be reached at which other costs such as those for raw materials will dominate the overall module cost. This will lead to the breakdown of the learning curve model for this technology. For example, with standard framed modules, it is likely that glass, extruded frames, and possibly silicon will become significant cost components. These are products of mature industries and will not follow the same 17% learning curve even when vast production scales for PV modules are reached. However, some experts contend that the industry is already moving to a new learning curve based upon thin

film technologies^{ix}. This curve is shifted down and thin film is in an early stage of development. Thin film technology offers a variety of less costly cell mounting approaches and it uses less semiconductor material. This promises to extend the learning curve for PV in general beyond the point where it breaks down for framed modules. The conclusions of this paper are based upon the assumption that the above learning curve will provide an upper bound for the PV industry *at least* until PV modules reach \$1.00 per watt.

3. MARKET SIZE AND POTENTIAL

3.1 Industry Growth

For the last 5 years, the PV industry has experienced a hearty 35% average annual growth in MWp production of PV cells. That rate represents a doubling of annual production each 2.3 years and a doubling of *cumulative* production approximately every 3.3 years! In other words a the cost of a PV module is reduced by 17% every 3.3 years. Because the growth is compounded, it is an extremely rapid exponentially increasing function. Cost effective niche markets, such as communications and off-grid power, drive industry growth at an annual rate of about 15%. The remaining 20% has been coming from subsidized grid connected PV, mostly in Japan and Germany.

3.2 The Industry Is Still Very Small

Last year world PV cell production was nearly 400 MWp^x. In terms of where the PV industry has been, that sounds like a lot. However, in the global energy market, it is insignificant. Consider that the United States has a fleet of 103 nuclear power plants that produce about 20% of the nation's electricity. These plants have an average output (adjusted for capacity factor) of about 830 MW^{xi}. So the total United States electricity production is about 515 NPE. For comparison, 400 MWp of PV adjusted for a 15% capacity factor, is equivalent to about one 60 MW power plant. Another way of looking at it is that an average nuclear power plant will generate more energy in a month than the entire world PV production (for the year 2001) will in a year.

3.3 The Interplay of Small Size and Rapid Growth

In Figure 3 we have plotted annual production of PV modules in units of NPE. This provides a qualitative way to see when PV becomes relevant. In Figure 4 we show a similar plot for cumulative production. We have chosen 2011 as the turning point year for PV. That is the year at which annual production reaches one NPE, cumulative production can approximately meet 1% of the United States' electrical needs.

Japan and Germany have made dramatic contributions to the industry by subsidizing the purchase of PV. In spite of dropping costs, sustaining a 35% growth rate will require a substantial commitment by the United States. Reaching break even will require the installation of roughly 33,000 MWp (6 NPE) of PV. To date the total cumulative production is less than 2,000 MWp (~1/3 NPE).

4. CONCLUSION

No mention of wind power has been made in this paper. Wind is nearly cost competitive, with fossil fuels now. However, issues of siting and portfolio diversification make the discussion of solar important and relevant. Wind power's success does not alter the conclusions of this paper.

In the, sometimes contentious, national energy discussion, both sides often miss the jewels that the other offers. Many fossil fuel advocates think that we can drill our way out of our energy problems, seemingly forever. However, use exceeds discoveries. The question is not whether but when. Furthermore, the predictability of "when" is getting more accurate with each passing year. More and more experts are concerned as is evidenced by BP and Shell's work in solar energy.

Renewable energy advocates suggest that renewable energy is ready now. While the technology *is* ready now, the production capacity is not and in most utility applications it is not close to cost competitive. This paper seeks to present a balanced perspective that emphasizes the immensity of the tools that each has at their disposal. The extraction industry offers vast amounts of energy in the near and medium term. However they are in decline. If we do not develop the alternatives now, we will suffer devastating economic consequences in the years to come.

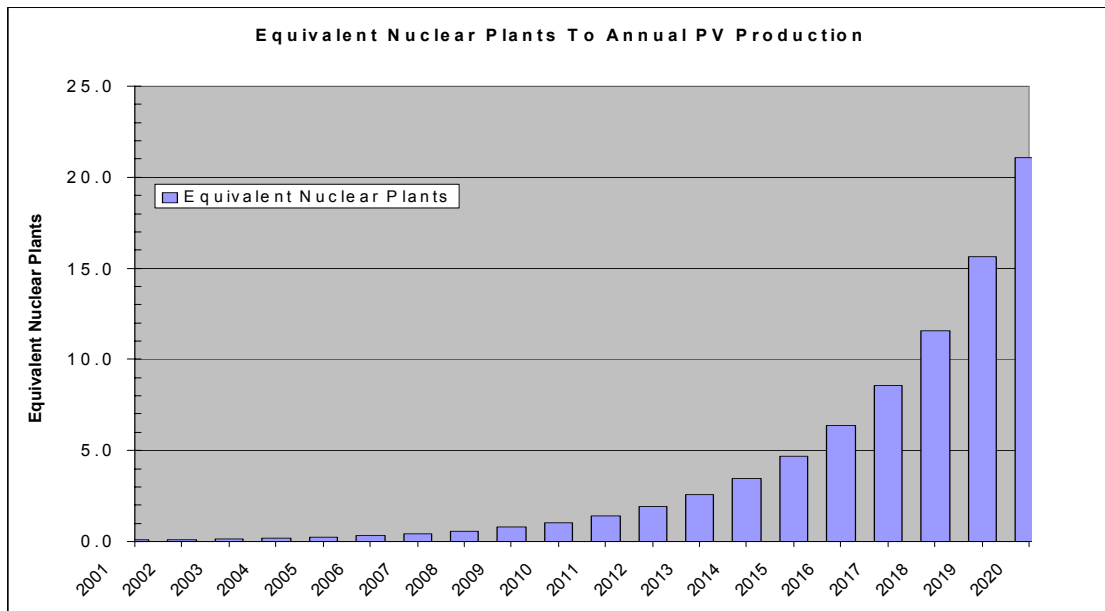


Figure 3. Annual PV production in units of equivalent nuclear power plants (Assumes 35% annual growth in module production).

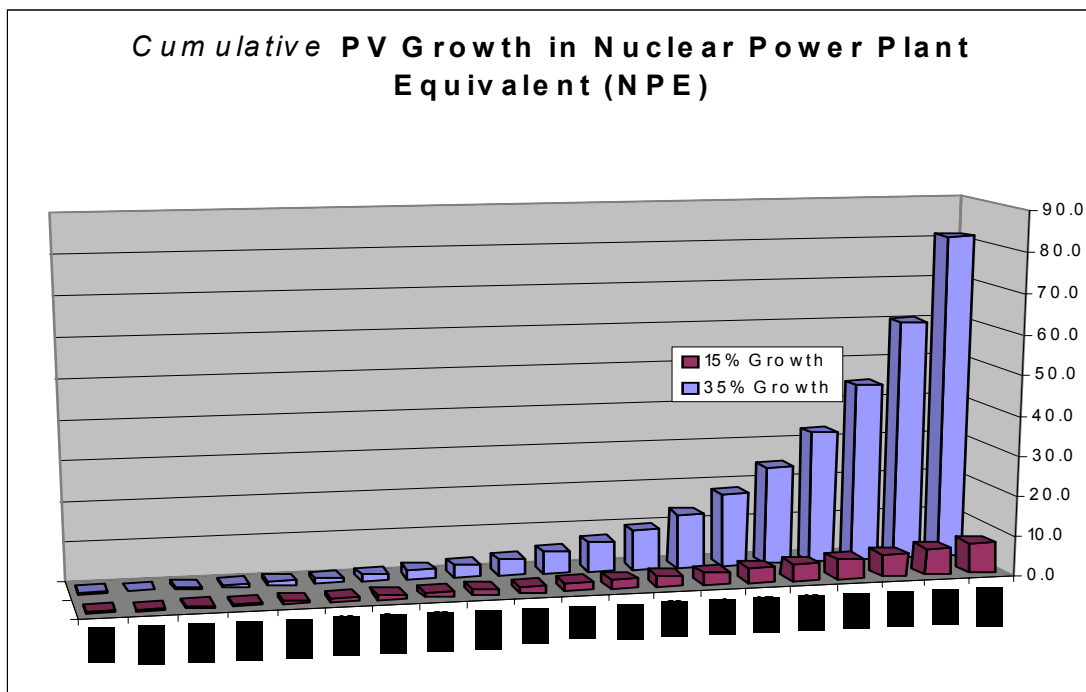


Figure 4. This plot compares the cumulative production (in NPE) resulting from 15% and 35% annual module production growth rates.

Due to the power of exponential growth, PV can play a significant role in the medium and long term. If its current 35% growth rate continues, relentless cost reduction will occur in conformance with widely accepted learning curve theory. However, in any conceivable growth scenario, PV will not be relevant in terms of its contribution to the energy supply for another 10 years.

The very fact that the PV industry is small works to its advantage. A 17% cost reduction occurs every time the cumulative output of the industry doubles. Because it is a small industry, cost reduction (cumulative production doublings) can be purchased for a relatively small amount of money. It is by virtue of the fact that the PV industry is small now, that it can credibly offer the promise of large scale, clean, cost effective electricity generation in the next decade.

ⁱ Paul Maycock, *Photovoltaic News*, Volume 21, No. 3, March 2002, pp. 1.

ⁱⁱ Randy Udall and Steve Andrews, *When Will The Joy Ride End*, CORE web site, http://www.altenergy.org/core/Fossil_Fuels_Futures/Joy_Ride/Joy_Ride_-_Print/joy_ride_-_print.html.

ⁱⁱⁱ Randy Udall and Steve Andrews, "Methane Madness: A Natural Gas Primer," *Solar Today*, July/August 2001, pp. 36 - 39.

^{iv} *ibid.*

^v Walton M. Hancock and Franklin H. Bayha, "The Learning Curve," *Handbook of Industrial Engineering*, ed. Gavriel Salvendy (New York: John Wiley & Sons, 1982), pp. 4.3.1.

^{vi} Arnulf Grubler, Nebojsa Nakicenovic, and David G. Victor, "Modeling Technological Change: Implications for the Global Environment," *Annual Review Energy Environment*, Volume 24, 1999, pp. 545-69.

^{vii} Data courtesy of Paul Maycock, PV Energy Systems, 4539 Old Auburn Rd., Warrenton, VA 20187.

^{viii} Clayton Handleman, "An Experience Curve Based Model for the Projection of PV Module Costs and Its Policy Implications", *Utility Photovoltaic Experience Conference & Exhibition 2001*, 2-4 October 2001, Sacramento, California, U.S.A.

^{ix} Paul Maycock, conversations with author at *Utility Photovoltaic Experience Conference & Exhibition 2001*.

^x Paul Maycock, *Photovoltaic News*, Volume 21, No. 3, March 2002 pp. 1.

^{xi} Nuclear Energy Institute, 1776 I Street N.W., Suite 400, Washington D.C. 20006