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Subject: LED Lighting vs. PV Arrays

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My recent visit to Sandia triggered the suggestion to compare our LED lighting proposal and its request for government funding with the current government support for the solar cell industry. I was surprised about the magnitude of the difference in economic terms. I was told that the current subsidy going to the PV industry is in the range of 70M$/year. If we would succeed in redirecting this river of green, we would have more money for a breakthrough attempt in SSL than what I am asking for. And, the taxpayer would get a tangible return instead of dropping this money into a black hole.

How often do we find an opportunity to improve the efficiency by 2x to 10x in a significant energy sector consuming 25 Quads/year? This is a chance that comes once in a lifetime. Let's go for it!

RH/pp
Attachment

The Cost to Reduce CO_2 Emission: Energy Savings through Solid-State Lighting vs. Emission Reduction through Photo-Voltaic Generation

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Introduction:

The Agilent/Sandia White Paper on Solid-State Lighting (SSL) concludes that efficiency improvements could reduce global electricity consumption in 2025 by 1100 TWh. If this reduction comes from coal fired power plants, it would correspond to a CO_2 emission reduction of 1800 M tons annually by 2025.

The wide-spread use of SSL comes with a steep price tag: SSL lamps are much more expensive than incandescent light bulbs or fluorescent lamps. White incandescent light bulbs retail for $0.50, SSL lamps are predicted to sell for $100.00/klm in 2002 and dropping to $18.00/klm by 2025. In other words, replacing a 100W incandescent light bulb (1500 lm) with a SSL lamp costs $150.00 in 2002 and $27.00 by 2025. Assuming a 10-year life for SSL lamps results in a cumulative lamp investment by consumers approaching $800B over the 2002-205 period. Does such a huge investment make economic sense?

In the White Paper, we modeled the payback and concluded that energy savings will pay back the high lamp cost in 3-6 years in the 2002-2005 time frame. By 2010, the payback period could drop below one year.

The replacement of inefficient incandescent lamps with SSL lamps has two objectives: (1) Reduce the cost of lighting for the consumer and (2) reduce energy consumption and its by-product, the emission of Greenhouse gases. Since the SSL comes with a high price tag, it is fair to ask: Can we achieve the same objectives through an alternate, emission free process of generating electricity, i.e., through the use of photo-voltaic (PV) arrays?

It is the purpose of this study to compare the macro-economic issues related to emission reduction via efficiency improvements in light generation compared with emission free generation of electricity for PV arrays.

Economic Model:

For the energy savings alternative of using more efficient SSL lamps, the analysis is quite simple:

- The lighting industry commits to an R&D investment in the range of $1B over 10 years.
- The government funds an attempt to make a major breakthrough in SSL lamp efficiency. Estimated cost: $500M over 10 years.
- The consumer makes an investment by buying expensive but more efficient SSL lamps.
- The consumer receives a reward through the reduced consumption of electricity and the subsequent reduction in monthly billings.

- The economy receives a benefit because the global electricity suppliers do not have to provide generating capacity equivalent to the power saved by SSL.

If the economic analysis takes into account a significantly long time frame, i.e., 25 years, then the up-front investment by industry and government is negligible compared with the last three figures: lamp cost, electricity savings, and reduction in generating capacity.

In the upper part of Table 1 labeled SSL, we are computing the reduction in generating capacity (GW) resulting from the energy savings of Table C3 of the White Paper. Next, we list the annual retail cost of SSL lamps and the energy cost savings both from the same Table C3. The annual savings by the utility industry is calculated by multiplying the capacity reduction in GW with the cost of providing base load capacity from coal fired power plants, in this case, $1.20/W. If the energy savings would be used to not build nuclear plants, the multiplier would be higher, i.e, $4.00/W.

The line "Net Annual Cost" contains the annual lamp investment less energy cost savings, less capacity cost savings and represents the cost to the economy. The next line computes the cummulative cost from 2002 on. Positive numbers represent a cost or investment, negative numbers a savings, or return on the investment.

During the period from 2002-2012, the installation of new lamps exceeds the energy savings and we have a cost to the economy. In 2013, we have a break-even situation and a strong return thereafter. By 2025, the savings exceed the lamp investment of nearly $800B by $254B.

Now, let us look at the scenario where the same CO_2 emission reduction is achieved by installing PV arrays. We have to start with a fact of life: The sun does not shine all the time. The output of a PV array peaks when the array is aligned perpendicular to the rays of the sun. If the array cannot be rotated, then the energy collected is approximately equal to 4.8 hours times its peak power. In other words, to produce the same energy as 1W for 24 hours, one needs a PV array generating 5W peak for 4.8 hours.

Next, we have to examine the cost of PV arrays and the associated systems cost. Solar panels are predicted to decrease in cost from $8.00 per peak Watt in 1995 to $1.30 per peak Watt in 2015. The slope corresponds to a cost reduction of 9% per year.

Unfortunately, most people do not need to light their house while the sun shines. This fact brings us to the problem of storing energy. For small users, there are two solutions: battery storage or feeding the power into the utility net and buying it back at a later time. In 1999, commercial systemz using battery storage with a capacity of 1-4kWh per day retail for a cost of $17-21 per peak Watt. Systems using the utility grid for storage are in the $10-13 range. In the financial analysis of Table 1, labeled PV, we use a cost model of $15.00 per peak Watt in 2000 and rolling off 9% per year, the same slope that the PV industry projects for their panel cost. This model favors the PV analysis because we do not believe that the systems cost drop at the same aggressive rate as PV panels. Car battery prices will be flat and control electronics represent a fairly mature segment of the semiconductor market.

Other issues are generating and maintenance cost for the array and the control electronics. We found one data point for O&M cost of a PV array as 0.5 cents/kWh. This number looks low for small systems. For instance, a car battery with a capacity of 80Ah equivalent to 1kWh costs around $80.00. Over its rated life of 4 years, it would store 1.4 MWh, 1KWhr/day. This corresponds to a battery cost of 5.5 cents/kWh. Car batteries do not tolerate frequent discharges. Batteries that can be discharged daily cost about twice as much bringing the cost to 11 cents/kWh, more than buying the electricity from the utility company in the first place.

Using the utility grid for storage opens another can of worms. Peak demand is usually in the early morning and early evening hours, not at noon when the sun shines. During the peak hours demand is met by gas turbine driven generators. The difference in generating cost to the utility industry (gas turbine vs. coal/steam) is approximately 2 cents/kWh. We expect that the utility companies will, at a minimum, charge a 2 cent/kWh differential between the price they pay during the day and the price they charge during peak hours.

For the consumer/investor, the electricity cost will be 2 cents/kWh rather than 10 cents/kWh. So far, his investment in a PV systems, saves 8 cents/kWh. Now, we can repeat the financial analysis for the PV case.

Line 1 of Table 1 shows the required peak power installation, 5x the average power saved by more efficient lamps. Line 2 states the cost per peak Watt of installing a PV system between 2000 and 2025. Line 3 computes the annual investment to add PV capacity. Line 4 computes the savings at 8 cents/kWh for all PV installations, both current year and prior years. Line 5 lists the savings to the economy for not requiring the installations of coal fired capacity at a rate of $1.20/W. The result is shocking: The costs exceed savings all the way to 2023 when we reach a cummulative cost to the global economy of $1366B. In 2024 and 2025, we see a small return. But, the $1317B cost in 2025 is far worse than the cummulative savings of $254B that we have computed for SSL lamps. Between the two investment scenarios, we have a $1.6 trillion delta in favor of developing more efficient lamps!

In this analysis, we have even ignored some first order issues that would have worsened the comparison. The SSL lamp analysis assumes a replacement of all lamps after 10 years. This adds substantially to the lamp investment. In the PV case, we have assumed a much longer operating life, i.e., the arrays installed in the early years are still working in 2025. This is a risky assumption considering that PV arrays are exposed to UV light, rain, snow, ice, wind temperature cycles, etc.

Suppose the SSL lamps do not achieve the efficiency breakthrough of 150-200 lm/W by 2015. In that case, LED based lamps can only reach 50 lm/W and will be unable to penetrate fluorescent lamp applications. In this case, we have the situation of Table C2 of the White paper. LED penetration levels off at 10% of the generated flux by 2020. In Table 2, we are comparing the LED lamp investment and its reduced electricity savings with the corresponding PV system investment. In this case, the lamp investment and the corresponding energy savings are lower. Similarly, the PV investment is lower. The LED investment turns into net savings in 2012, while the PV case turns into savings not before 2022. In 2025, the LED case has saved $285B while the PV case is still in the hole with $540B.

It is somewhat counter-intuitive that the aggressive SSL scenario saves only $254B, while the lower efficiency LED scenario saves $285B by 2025. The answer lies in the fact that in the aggresssive scenario, we are still grabing market share by 2025 and, consequently, are still in a lamp investment mode. In the LED scenario, the penetration levels off around 2020 and we are enjoying the full benefits of energy savings while only replacing the lamps installed 10 years earlier.

Conclusion:

This is not the first time that people have raised doubts about the economic viability of electricity generation with PV arrays. PV arrays are great solutions in situations where small amounts of power are needed in remote location, either currently not served by electricity lines or in locations where the line maintenance is disproportionate to the value of the electricity used. But, PV installations do not make any economic sense to reduce the baseload capacity of power plants. In 2000, it takes $75 of PV installation to provide the energy equivalent of 1W of baseload capacity. A coal fired plant can do this for $1.20/W. Such huge discrepancies of nearly 2 orders of magnitude are difficult to overcome, even over 2-3 decades. An emotionally based brute-force approach to reduce CO_2 emission via large scale PV investments cannot be justified by any economic metric. It is foolhardy economic nonsense!

The above analysis, in conjunction with the White Paper, points to a solution that passes muster in an economic analysis. Energy savings through 2x to 10x improvements in efficiency are hard to find, especially for a large scale application in the range of 25 Quads (1 Quad = 10^{15} Btu). In the White Paper, we have analyzed improvement in lighting technology based on LEDs and other solid-state light sources. A pump primer comparable to today's government subsidies to the nascent PV industry could revolutionize the lighting industry and return a much bigger bang for the taxpayer's buck.