Response to Critiques of "The Market Value and Cost of Solar Photovoltaic Electricity Production"

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Since the release of my paper, "The Market Value and Cost of Solar Photovoltaic Electricity Production",[2] in January 2008 — and especially since the media started covering it in late February 2008 — there have been a large number of critiques circulated in industry newsletters, by email, on websites, and in blogs. Many of them are *ad hominem* attacks or nonsensical diatribes, but a few appear to offer serious criticisms that deserve to be addressed. In this note, I respond in detail to the two most widely circulated critiques, one by Bill Powers[3] and another by Tom Beach and Patrick McGuire[4], and in the process also address a few other criticisms that have appeared. I find that a couple of the criticisms have real merit and require some recalculation of my cost/benefit analysis. Unfortunately, I do not find that they change the finding in my paper that has evoked such a harsh response from many in the solar PV industry: that the current cost of solar PV, as it is being installed in California and the rest of the U.S. today, is extremely high not just compared to fossil fuel generation, but also compared to generation from wind, central station solar thermal, geothermal and other renewable resources.

I feel compelled to begin by addressing the assertion of bias that has been made by many critics of my paper.[5] The paper was in fact my attempt to do an unbiased, economically-grounded analysis of solar PV power. Unlike nearly all of the vocal critics of the paper, I have no financial stake in the success or failure of any energy technology. My research

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[2] Available at http://www.ucei.berkeley.edu/PDF/csemwp176.pdf .

[3] Available at http://www.renewableenergyworld.com/rea/news/reinsider/story?id=51782 .

[4] Available at http://votesolar.org/linked-docs/borenstein_response.pdf .

[5] Including the assertion by Mr. Powers in an email he circulated widely in late February that "Severin makes one other error of omission. He and Dan Kammen of Berkeley are major players in British Petroleum's new $500 million Energy Biosciences Institute (EBI) at Berkeley. Severin may think such disclosure is unnecessary in a paper asserting that the economic justification for higher PV tariffs is weak. I think it is significant and relevant that a significant stream of his funding is coming from one of the world's largest oil companies." This statement by Mr. Powers is a complete fabrication. I have had no involvement with the EBI and none of my funding comes from an oil company. Mr. Powers had no basis for his statement at the time he made it and he has never publicly apologized for it, though he did acknowledge his error in a personal e-mail to me and said "You will not see the BP implication from me in future comments on your evaluation of the cost viability of PV." While I appreciate Mr. Powers' willingness to admit his error privately to me, that still leaves the fabrication out there in public with no retraction.

is funded by the University of California and the California Energy Commission, not by any energy companies.[6] I will admit up front that the analysis in the paper is imperfect, but I will also point out that some of the errors and omissions in the paper tend towards undervaluing solar PV, while others tend towards overvaluing it. Interestingly, the critiques from solar PV advocates have only pointed out the former. Some of those criticisms have merit, though their impact on the analysis does not change the basic conclusion. Still, one would think that a critique aimed at getting at the whole truth would at least note some of the issues that would not tend to favor PV. None does.

Also, I need to point out what is made clear in the paper, but overlooked by many critics, as well as journalists seeking a good story: The paper is an economic analysis of the *current* solar PV technology that is being installed in homes and small commercial establishments today. It is not an analysis of the what might happen 3, 5 or 20 years from now. Since I am not an engineer — a fact Bill Powers takes pains to point out[7] — I do not attempt to forecast where technology will be in the near-term or long-term, though I do comment on the economics of the learning-by-doing claims that are frequently used to justify solar PV subsidies. I hope the many claims that solar PV costs are poised to drop substantially will come true. I would like nothing more than to be able to write an analysis that says PV is a cost-effective option. Besides the good news that would be for the fight against climate change, it would also greatly reduce the number of vitriolic emails and phone calls I get from solar PV advocates.

Responses to Bill Powers' "Estimates, Guesstimates, Obsolete and Just Plain Wrong".

I'll divide my responses according to the nine flaws Mr. Powers claims to have uncovered in my paper:

"1. ESTIMATE: Peaking PV prices are much lower than peaking turbine costs". Mr. Powers compares my mid-range calculation of the levelized cost of solar PV, \$408/MWh, to the levelized cost of power from a peaking plant, for which he cites a figure of \$508/MWh.

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[6] To address a bit further the claims that I am an anti-environmental tool of big oil or other energy companies: I have for years been a strong advocate of high carbon taxes or tight caps in a tradable permit system, as well as major increases in government funding for R&D on renewable energy. I have argued that tax breaks for oil and gas exploration in the U.S. should be eliminated. I co-authored work prior to the California electricity crisis warning of the threat of extreme market power in those markets and co-authored work during and after the crisis showing that most of the price runups during 2000 were due to market power not real scarcity. Both studies were published in major peer-reviewed journals.

[7] Interestingly, after noting in his paper that "Professor Borenstein has not overseen or managed deployments of solar PV or other energy systems," Mr. Powers testified in a CPUC hearing in April that the only PV system he has overseen is the 2 kW system on his house.

He suggests that this shows that solar PV is cost effective, contrary to my claims. This sort of sloppy ad hoc comparison is exactly what my analysis is attempting to remedy. It would be a fine comparison to make if all of the power from a solar panel replaced power from a peaking turbine. But real solar PV produces power at all times of the year and on cloudy days as well as the hottest. That's a good thing, but it means that one has to value solar PV at the cost of the resource it is replacing. Most of the production from solar PV replaces a much lower cost resource than a peaking plant, which is why valuation at the market price is a better measure. The market price represents the marginal cost of the marginal production unit, which is what solar PV is crowding out. The simulated prices are set so as to at some times include a scarcity rent above even the highest cost unit. In aggregate over time, those scarcity rents cover the capital costs of generation, which is how the market prices reflect the full cost of the alternative to solar PV generation.[8]

Mr Powers also criticizes my use of $8/watt as the installed cost of solar PV. He argues that a much lower number would be appropriate because thin-film PV can be "as low as" $5/watt. His number is based on a solar PV "farm" in Germany that is currently being built. A few things to note: First the German project is a remote central station production plant, not an end-user facility, so it does not have the transmission and line loss advantages of end-user solar PV. A proper analysis of such a facility would not attribute the line loss and transmission congestion savings that I have attributed to distributed solar PV. Second, this is a relatively new technology and the facility, which says it will be the largest PV installation in the world, has not been completed. The reality is that while it may end up being incredibly successful, that is not the technology, nor the configuration, that is being used for the vast majority of solar PV being installed today in California or the rest of the U.S. My analysis is based on the database of *actual* costs of installing the solar PV systems in California, not a projection of what might be possible in the future.[9,10]

"2. GUESSTIMATE: Ignoring actual PV pricing for hypothetic analysis". Mr. Powers

[8] The critics have *not* pointed out that since solar PV disproportionately produces at peak — for which I have shown it should be more highly valued — the load that remains to be served by conventional generation becomes less peaky and the remaining conventional capacity has a higher utilization rate. As a result, as more solar PV is added, it is replacing incrementally lower average cost generation, so the value of the incremental solar PV would decline. This is not a major effect at the current scale of solar PV in California, but it would reduce the value of incremental solar PV additions if solar became a non-trivial share of generation.

[9] There is some irony to Mr. Powers offering to help revise my paper based on "real" costs when his suggested costs basis is taken from a pilot project in Germany and mine are taken from the actual costs of installation in California. By the way, Harris and Moynahan (2007) argue that the price of solar PV in California is higher than the cost I use and is not likely to decline much at all in the near future. Harris is one of the leading solar PV consultants and advocates, until recently a consultant to CalSEIA, now president of PV Powered.

[10] Also, Mr. Powers use of "as low as", a term usually heard in late-night television ads, misses the point of the analysis. My goal was to use a real representative cost, not "as low as".

cites the peak summer retail TOU price for electricity as the price utilities are “willing to pay” for solar PV. Three problems here: First is the same as in issue 1, the majority of solar power is not produced on summer afternoons. My paper attempts to do a comprehensive analysis, not cherry pick high or low cost hours. Second, end-use solar PV has many real cost savings, but it does not eliminate sunk costs such as from the California electricity crisis or costly contracts from the past, which are part of the retail prices charged today. Retail prices do not accurately reflect the avoided costs from reduced end-use demand going forward. Third, Even if one did value solar PV at the full residential electricity price, the weighted average residential price among Caifornia IOUs is about 17¢/kWh well under half the cost of solar.[11]

“3. OBSOLETE: Working from a 10 kW residential PV system ignores market realities.”. Mr. Powers criticizes my paper for analyzing a 10 kW capacity system, arguing that the installed cost of most PV is much lower because most installed systems are much larger. He is correct that most capacity has been installed in larger capacities in commerical buildings. My paper states that is doesn’t attempt to analyze those directly. The figure in the analysis would be for a very large residential or small commercial installation, but the approach could easily be applied for other size systems. Looking at the largest systems that have filed for incentive payments under the California Solar Initiative — the 75 recent projects with nameplate capacity at or above 1MW that reported installed costs[12] — the average cost is around $6.70/watt, a significant savings, but still the equivalent of about $335/MWh using the mid-range interest rate in my paper. I’m told that such large projects in California now can be had for just under $6/watt, but that wouldn’t change the basic policy conclusions. Nonetheless, if one is analyzing residential and small commercial installations, $8/watt is a fair, if not generous, cost figure to use.

“4. OBSOLETE: Basing analysis and comparisons of PV with obsolete combustion turbine costs”. Mr. Powers gets this one partially right. He correctly points out that the figures I used to simulate wholesale electricity prices in my paper are too low for today. I used 2004 numbers, but increases in steel and transportation costs have driven up capacity costs since then and energy prices have increased as well. Incorporating the increases will raise the simulated long-run market prices. My preliminary runs suggest that the adjustment will be in the range of $30-$40 per MWh. It is worth noting that the increased steel and transportation costs will also affect delivered solar panel costs, something Mr. Powers does

[11] Even if you added a 20% premium to the retail price for the favorable timing of solar PV it is about half the cost of my mid-range estimate of solar PV cost. And that significantly overstates the market value of solar PV.

[12] Of the 94 such projects since the beginning of 2007 that are in the April 2, 2008 database update, available at https://csi.powerclerk.com/Default.aspx, 19 do not report an installation cost.

not mention.[13]

Mr. Powers finishes this paragraph by citing a CEC projection that solar PV costs will decline by 50% by 2020. Great! I very much hope that happens. But my analysis is of what solar PV costs now. Mr. Powers, or at least many of his brethren, will claim that the decline will only happen if California installs a lot of solar panels. I address the fact that there isn't evidence to support significant learning-by-doing cost declines from California's CSI. Interestingly, Harris and Moynahan (2007) agree with me: "...every MW helps, but even California's hoped for few hundred MWs of projects each year will not drive solar costs down significantly. Considering the rapidly growing worldwide multi-gigawatt market, it is much more likely that California will instead benefit from other country's investment in solar." If solar PV is actually going to decline rapidly independent of California programs — due, for instance, to technology improvements or learning-by-doing in other parts of the world — that is an argument for waiting and not installing the soon-to-be-obsolete existing technology.

"5. JUST PLAIN WRONG: Dismissing the value of PV in avoiding billions in new peaking turbine or transmission line build-out" Far from dismissing the value of avoiding new peaking turbines, that is exactly what I am incorporating by analyzing PV power at time-varying value. But I have done it in an economically-grounded way — time-varying prices that peak high enough to cover the costs of a peaking turbine — not an ad hoc comparison to a peaker plant.

The transmission comment that Mr. Powers makes has more content, or at least one interpretation of his comment does. The point, however, is made much more clearly by Beach & McGuire. I address it in my response to B&M section F below.

"6. JUST PLAIN WRONG: Dismissing current and future utility-scale PV deployments to avoid criss-crossing California with more transmission lines". This point is partially redundant to point 5, but in discussing transmission congestion and PV location issues, Mr. Powers does add "The fact that PV has not been focused on transmission constrained areas in the past does not prevent PV from being focused on those areas now." True enough, but I am analyzing the way PV is *actually* being installed, not an idealized implementation. Furthermore, Figure 4 of my paper and the embedded table suggest that with the exception of San Diego, the locational variation in annual value of the power a PV panel will produce is not very large. The San Diego area PV power value is about 18% above the state average, but no one is suggesting focusing all solar PV incentives on San Diego-area customers.[14]

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[13] Harris and Moynahan (2007) point to material and transportation costs as two primary reasons solar PV prices will remain high.

[14] Also, if there were very substainal PV construction in San Diego, that would likely narrow the locational

"7. GUESSTIMATE: Ignoring real-world non-energy capacity payments in revenue requirements of peaking turbines". In fact, the paper is very careful in discussing capacity payments. The basic model I use is for an "energy only" electricity market, such as is currently used in Texas, in which there are no capacity payments. The point of capacity payments is to provide the "missing money" that results when wholesale electricity prices are not allowed to rise to the level necessary to clear a very tight market by rationing down demand. The elimination of such price spikes, through price caps or system operator behavior, is what justifies the creation of a capacity market. In my simulated prices, those extreme price spikes do occur and, by construction, are sufficient to permit recovery of capacity costs. Those price spikes at times of high demand are the basis for the higher valuation of solar PV power that I report. I also analyze an alternative scenario in which prices are not allowed to rise above the marginal cost of the highest cost generator. In that scenario, generators recover capacity costs through a constant per-kWh payment. Prices in that scenario are much less volatile to the detriment of solar PV valuation.

"8. JUST PLAIN WRONG: Ignoring direct and indirect subsidies for gas-fire peaking turbines defining the technology as a "pure market" player". Mr. Powers argues that the favorable tax treatment for oil and gas producers subsidizes the production of natural gas, so natural gas generation is not a "pure market" player. As I pointed out in footnote 32, the real question is whether these subsidies actually lower the market price of the fuel. In economic terms, that is a question of the incidence of the subsidy; does it lower the price to the buyer or raise the profit of the seller? In the worldwide oil market, it is quite clear that subsidies for production in the United States has no effect on price. The answer is less obvious for natural gas, but most observers of the industry agree that the current runup in gas prices is due to a very tight supply, that is, a very inelastic supply curve. That is likely to persist in the short to medium run. In that circumstance, the subsidy will not lower prices substantially, but rather just benefit sellers. That reinforces the argument for eliminating such subsidies, but does not suggest that natural gas generators, the consumers of natural gas, have an unfair advantage in the marketplace due to favorable tax treatment of natural gas production.[15]

"9. JUST PLAIN WRONG: Dismissing oil and natural gas production subsidies on market prices". At first, this point simply repeats point 8, but then Mr. Powers veers off into outrage about how much money the government has given away to oil and gas firms in the past and how helpful it would have been if that money had gone to solar PV. I agree completely about the unjustified giveaways to oil and gas companies, but that really is

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price difference as well.

[15] In the longer run, imports of LNG, a new gas pipeline from Alaska, or new discoveries of natural gas could make the supply curve much more elastic, but it would also substantially lower the price of natural gas and reduce the value of solar PV power.

not relevant to this analysis here, as I have discussed in the previous paragraph and in footnote 32 of the paper. I also agree with Mr. Powers if he is suggesting that in the past more money should have gone to, and still should go to, R&D on solar and other renewable technologies. I do not agree if he is suggesting that the giveaways to oil and gas companies are somehow a reason that we should favor solar PV over other renewable energy technologies. Renewable energy credits that apply equally to all renewable energy technologies — or have real, economically-justified adjustments for timing of production, reduction of line losses, reduced transmission needs, environmental impacts, etc. — are a fine idea. My analysis suggests that putting all renewables on such a level playing field would not be good news for the current solar PV technologies.

Responses to Beach & McGuire's "Response to Dr. Severin Borensteins January 2008 Paper on the Economics of Photovoltaics in California.

Beach & McGuire say up front that they focus "solely on the technical aspects" of my paper. I'm not exactly sure what they mean by that, especially since by the end of their critique they have wandered off into discussing job creation effects of renewable energy in general and impacts on the price of natural gas. They do raise a few worthwhile issues in the cost-benefit analysis of solar PV, though in the end a balanced analysis of their concerns does not raise the value of solar PV by enough to alter the basic conclusion about its cost effectiveness.

It is worth pointing out that nothing in their paper disagrees with my analysis of the cost of solar PV. Rather, they argue that the benefits are larger than I have estimated. That may be true, but their critique certainly does not make that case very well and tilts at every opportunity towards overstating the value.

"A. PV Systems Serve Retail, not Wholesale, Loads".

B & M draw what they seem to think is a clear distinction between wholesale and retail value of electricity. In my paper, I tried to address this issue in a more thoughtful way by doing a careful parsing of the value that solar PV creates. Everyone would agree that it is worth more than the simple wholesale grid price and no serious analysis would claim that its market value is accurately represented by the retail price, at least in California where that price includes payment for substantial sunk costs and does not vary by time of day for many retail consumers. But setting aside their overstatement of the distinction, we clearly agree in practice that the value of solar PV should be built up from its component values in wholesale power, reduced transmission investment, reduced line losses, and other factors.

B & M's first critique points out the omission of avoided transmission costs by avoiding growth in system load. They correctly pointed out that my analysis omitted valuation of the reduced future transmission infrastructure needs. This is the same point that they make in section F, so I will address it there.

"B. Distorted Wholesale Price Data from 2000-2003".

B&M spend much of their critique arguing that the real-time CAISO prices in my paper are out of date and unrepresentative. They point out, as I do in my paper, that prices during this period were distorted by unusual events, the California electricity crisis and then the very low prices that followed in 2002-2003.[16] They then go on to say that I could have easily used more recent data. Interestingly, they don't do the most basic analysis of these recent data. If they had, they would have found that the average price in the CAISO real-time market during 2004-2007 was nearly the same as in the period I used and volatility was much lower. Had I used the more recent period, they no doubt would have complained that 2004-2007 is also not representative of future prices. And I would have agreed with them on that as well. That is why I focused my analysis primarily on the simulated prices.

B&M also suggest that one could use the market price referent (MPR) for my analysis. While the MPR might be a useful index for the price of power from a CCGT, using it for this analysis would miss the point in two significant ways. First, a major focus of the paper is the time-varying value of solar PV production, which could not be calculated from the levelized MPR. Second, and closely related, the power produced by a solar PV panel is not always replacing power from a CCGT. To get a true valuation of that power, one has to know the marginal cost of power at the time that the solar PV panel is producing. That is the point of using a time-varying market price.

"C. Use of a Price Series with Abnormally High Winter Prices".

In this section and the accompanying figure 1, B&M continued to make the point that use of actual prices can lead to idiosyncratic results due to the unusual circumstances in the market. Again, I completely agree with this general point, and have discussed it in this paper and numerous other papers. But the example that B&M point to as a problem

[16] They then quote another paper of mine to support their contention, in what appears to be a suggestion of inconsistency between my studies. In fact, my paper they are citiqueing here has much the same caveat on page 9, "While a price series from actual market operation has the obvious advantage of credibility, it may also have a number of disadvantages compared to simulated prices. Most important is the fact that investment in generating capacity might not be in long-run equilibrium during the period in which the prices are observed. If there is excess capacity, then peak prices are likely to be damped relative to the long-run equilibrium price distribution, penalizing technologies that produce more at peak times, such as solar PV. Of course, if there is a capacity shortage during the observed time, the opposite could be true. In addition, wholesale prices may be restrained by regulation, such as a price cap. This was the case in California where a wholesale price cap was binding in many hours during the period I examine."

that might undervalue solar PV is simply misleading. Their figure 1 does not exactly correspond to my data since they are not using real-time prices, but the point is similar in the real-time data: December and January exhibit very high prices on average during this period, due almost exclusively to the California electricity crisis in late 2000 and early 2001. But if one compares the summer prices during 2000-2003 to the summer prices during 2004-2007, the result is that they are very close on average. What was unusual about 2000-2003, compared to the more recent period is not that the summer prices were significantly lower, but that the winter prices were significantly higher. They're concluding sentence in this section claiming that my data from the earlier period "... may undervalue the summer output of PV systems" is not supported by a more careful analysis of the data.

"D. Use of CAISO Real-time Prices".

B&M then claim that my use of actual documented CAISO prices is inferior to using data from surveys of bilateral day-ahead trades. Each source has its own problems. B&M speculate about why the real-time prices would be too low.[17] There is plenty of experience from the California electricity crisis and other periods in which prices collected by surveying bilateral traders are not representative of real transactions.

"E. Use of Simulated Prices with Based on Outdated Generation Costs".

B&M are correct that the data I used for generation costs were outdated. I am in the process of rerunning the analysis with more current data. It appears this will raise the average market price by about $30-$40/MWh, which is consistent with the revised wholesale power prices that B&M use in their critique.

"F. Congestion Costs".

B&M agree with my conclusion that solar PV has not created much value in relieving transmission congestion because it has not been targeted at load pockets. They then go on to argue that potential savings from transmission infrastructure investments will occur even if they do not relieve current congestion that manifests as higher average locational prices in some areas than in others.

The argument is not really correct as it is stated by B&M. Assuming that the nodal

[17] In the process they repeat the claim that is occasionally trotted out that the low real-time prices "may result from the requirements that... force generators to bid their generation into the real-time market." At best, this is idle speculation. Since firms have wide latitude on the price at which they can bid their generation, it is not at all clear what bias there would be. In particular, firms that definitely want to run their generation because they have a bilateral contract can bid zero and firms that do not want to run their generation can bid the price cap. That would leave the market price being set by the actual real-time supply and demand.

prices that the CAISO calculates are correct, differences between nodal prices represent the true shadow value of transmission capacity. As such, for the time period in which they are applicable, they capture the full value of solar PV in reducing transmission congestion constraints. The calculation that I did in the paper took account of hourly price differences, so it did appropriately account for the value of transmission capacity at peak times.

B&M seem to be appealing to the notion that investment in PV will reduce the need for future transmission upgrades. That is no doubt true. The calculation that I did refers only to the current transmission system and load pattern. As load grows, the need for transmission capacity will also grow, which will be reflected in higher shadow values of transmission, that is, larger price differences between nodes. Thus, the calculation that I did does accurately capture the value of reduced transmission congestion for the period examined (2003-2004), but it would fail to capture an increase in this value as demand grew. Over time, one would want to use a long-run cost of scaling up transmission capacity as demand grows. B&M put the value of $30-$50/MWh on the marginal T&D costs. I am not going to relitigate past CPUC rate cases, but I will point out two ways in which this number overstates the value. First, they are partially double counting by adding that figure to my solar PV cost estimate since both include the value of avoided line losses. Second, my calculations of the current value given the current transmission congestion suggest that the value in the short run is substantially less than this. While the increased solar PV capacity would reduce future transmission infrastructure costs, this would not occur right away, so those future expenditures need to be discounted back to the present.

This leads to a more general response about the future savings from installing solar PV today. The savings might indeed be substantial, and the claims would then have some merit if installing solar PV today were a now-or-never proposition. But it isn't. It is quite possible, even likely, that the net value of installing solar PV in order to obtain these future benefits would be greater if the installation were done not now, but in a few years. That would lead to substantial savings both because of the time value of money and, more importantly, because the cost of solar PV will decline. That is not to say that it will be cost effective in a few years (though I very much hope that it will be), but that it will be more cost effective to make the investment in a few years than to make it today.[18]

"G. Overall Value of PV".

I fully agree with B&M that the cost-effectiveness of solar PV should be assessed from a long-run perspective, but that does not mean that one should simply look at the total assumed benefits of a stream of investments over a long period of time and conclude from that analysis that all of these investments are a good idea or all of them are a bad idea.

[18] Some critics will no doubt respond to this argument by once again claiming that installations in California will create large learning-by-doing effects. I address that argument in the paper beginning on page 22.

When examined carefully, the long-run assessments that have concluded that a solar PV investment plan will yield positive benefits nearly always imply negative returns on the investments made in the near term and positive returns on investments made in the later years. Two things to note about this: first, the returns would be even higher if one delayed the investment until the forecasted cost declines actually occurred and, second, those cost declines are uncertain. They could be greater or less than assumed. It is well understood in financial analysis that such variance increases the option value of waiting to make the investment.

The arguments B&M make for "market transformation" are made frequently in the case of solar PV, but, as is the case with B&M, they are vague claims that are not supported by research. The specific research that exists on learning-by-doing in the solar PV industry does not support a significant effect, as I discussed in my paper. Instead, one should be thinking carefully about the optimal time to make investments and be wary of making investments in technologies that may become economic in the future, but are not economic today. That is unfortunately the case with solar PV today.

Accounting for the current high capacity and fuel costs of fossil fuel generation and giving a generous addition of \$30-\$50/MWh for long-run investment in transmission and distribution, B&M conclude that the value of PV is \$160-\$200 per MWh. Once again here B&M take the most favorable possible approach, using a 30%-50% premium for the value of solar PV from my paper. This is simply cherry picking my results to bolster the position they are advocating, regardless of their actual applicability. In my paper, I point out quite clearly that the 30%-50% range of premium value would be correct if the grid operator utilized almost no reserve capacity and instead relied on very high price spikes to ration back demand during peak periods. That, of course, is not how grids are actually run today, as B&M are no doubt aware. Under actual operation, my paper argues that the premium value is likely to be no greater than 20%. Taking the generous figure of 20%, a generous T&D allocation of \$40/MWh (which is almost certainly much too high for the reasons I have discussed above), and the fairly accurate \$100/MWh long-run equilibrium weighted average market price of wholesale power, gets you to a value for PV power of about \$160/MWh. That is still a long ways away from the base case levelized cost for solar PV of \$408/MWh.

"H. Externalities".

B&M are aware that this \$248/MWh benefit shortfall is not going to be made up by quantification of criteria and GHG pollutants, so they make some other claims for additional benefits of solar PV.

The first claim that B&M make is that reducing demand on the grid will lower the market clearing price for all power. This claim demonstrates a deep and fundamental misunderstanding of the microeconomics of markets. First, after making a great deal of the fact that prices in the market must be sufficiently high to support investment in conventional power, B&M are now claiming that solar PV will "reduce the market clearing price for all power bought at the prevailing market price." In the long-run, prices must be sufficiently high to support investment — a point that both I and B&M make in our analyses — so the claim is not credible. Reducing demand may lower prices in the short run, but the long-run adjustment will bring them back to a level that allows producers to cover their full costs. Second, even if a short run "benefit" of lower market prices did result from building solar PV, that is not an efficiency gain, but a transfer of wealth from producers to consumers. One can express a separate view on whether such transfers of wealth are in the public interest, but they clearly do not belong as a "benefit" in an overall market analysis.

The second claim suffers much the same problem. B&M cite work by Wiser et al that concludes that reducing the demand for natural gas will reduce its market price. In fact, the paper that they quote from also says, "According to standard economic theory, lower natural gas prices that result from an inward shift in the demand curve may not lead to a gain in net economic welfare but rather represent a shift of resources from natural gas producers to natural gas consumers. Wealth transfers of this type are not a primary justification for policy intervention on economic grounds." For a number of reasons, I would also argue that the estimate by Wiser et al overstates the impact of demand reduction on the *long-run* price of natural gas, but in any case the impact is small and it is a transfer of wealth, not a gain in overall market value.

The third claim by B&M is that there is an additional value of solar PV in reducing exposure to volatility in natural gas prices. I agree with this point, but they have once again cherry picked the results to overstate the actual impact. In the tables B&M referred to in the CEC 2007 IEPR, the estimated value in reducing exposure to volatility in natural gas prices from solar PV installation in 2008 raises the value of power 10 years out by 4% and the value of power 20 years out by 13%, not 10%-15%. They have also once again ignored the option value of waiting. One would also get this stabilizing value for the out years by installing solar PV many years from now, when the costs are likely to be much lower. Finally, and most importantly, B&M here and throughout their analysis ignore the fact that there are many other alternative energy sources that are far cheaper than solar PV including wind power and central station solar thermal power, each of which are generally viewed to have production costs that are far lower than costs I estimate for solar PV. My analysis was in no way intended to suggest that we are best off sticking with conventional fossil fuel generation.

The last claim that B&M make in this section is that solar PV is good for California because it will stimulate the California economy rather than the economies of other states. To the extent that this is true these are transfers, not net economic value. In any case, B&M cite a paper that claims to find that solar PV creates more jobs than conventional fossil fuel power. The paper they cite, however, does not support their claim. First, it makes no attempt at assessing long-run macroeconomic net employment effects taking into account the higher cost of electricity from solar PV. Instead, the paper simply reviews a number of studies that compare direct labor inputs across electricity production technologies. The paper also says nothing about the wage levels of those jobs. Second, those jobs the paper asserts would be created would not necessarily be in California. In reality, most of the solar PV equipment production, which is about half the system value, occurs outside of California.[19]

What the critiques of my paper have not pointed out

As I said at the beginning of this response, the analysis I did was an attempt at a balanced examination of solar PV. Some of the assumptions that I made tended to undervalue solar PV while others tended to overvalue it. Solar advocates criticizing the paper have pointed out the ways in which the analysis might undervalue PV, but they omitted factors that would tend to overvalue the technology.

First, the analysis assumes that the panels operate flawlessly for 25 years and have no maintenance costs other than replacements of the inverter. In reality, the panels have to be cleaned to reduce soiling losses and are subject to damage from wind and falling objects. I also assumed that the panels were completely unshaded, the most favorable possible assumption. In addition, the systems I studied — facing south, southwest and west, and tilted at the commonly recommended angle for optimal performance — represent a best-case scenario. Due to building and location restrictions, many PV systems are installed in much less favorable conditions. On commercial buildings, for instance, they are often installed with no tilt on a flat roof, which lowers production by about 11% compared to south-facing at a 30 degree angle.

Second, the price I used of $8 per watt is probably a reasonably accurate number for a 10 kW (nameplate) system. It is a favorable number for a more standard 3 kW home solar PV system. In the CSI database, systems between 2kW and 4kW report an average installed cost of $8.33/watt, which would raise the baseline levelized cost of solar PV power from $408/MWh to $425/MWh.

Third, the cost of financing assumed in the baseline case (that yields the levelized cost

[19] In a careful search of the paper B&M are referring to, I was unable to find the 1.6-2.2 additional jobs created per MW installed that they claim. A full critique of the economics in the Kammen et al review paper is beyond my scope here, but the paper — written by a physicist and two of his graduate students — reviews 13 studies, nearly all of which were produced by environmental NGOs or alternative energy industry groups. Only one of the 13 papers had been published in a peer-reviewed journal and that one is characterized as "Not possible to tease out impact of renewables only from the paper."

of \$408/MWh) is 3% above the inflation rate. This would correspond to about 5.5% nominal interest rate today, an extremely favorable cost of capital. Investors in renewable energy face a substantially higher opportunity cost of capital. In part, this is due to the risk of default the causes wealth transfers away from investors and so shouldn't enter this calculation,[20] but in part it is because of real risks of poor performance and low returns. One could easily argue that a cost of capital equal to 5% or more above the inflation rate is more realistic, which would raise the levelized cost of solar PV power to around \$500/MWh.

Fourth, the baseline case on which I focused, and which B&M used as the starting point to which they add additional costs, assumed electricity prices will rise at a rate 3% above the inflation rate. This implies that the price of electricity will more than double in real terms over the next 25 years. Even if no technological progress were made in wind power, central station solar thermal generation, and a number of other renewable technologies, those renewable technologies would be completely economic without any subsidies well before prices got that high.

That brings me to a final point. There is no question that we need to move electricity generation away from fossil fuels. The costs of the current fossil generation technologies were used in my paper in order to establish a time-varying pattern of prices so that the incremental value attributable to solar PV from its favorable timing could be properly analyzed. In no way did I suggest that the best public policy is to continue generating electricity in that way.

As we move away from fossil fuels, the overall cost comparison for solar PV should not be to coal-based or natural gas-based generation, but to other renewable energy sources, with each adjusted for its favorable and unfavorable attributes. My paper was a first step in doing that. Section 8 of my paper on the market economics of solar PV — the section that has generated so much response — points out that a careful analysis of the costs of solar PV indicates that they are very high. I very much hope that will not be true 5 or 10 years from now, but it will be important to continue to do detailed analyses of the costs and benefits, and not to rely on anecdotes and rules of thumb to formulate public policy that will allow us address the threat of climate change in the most effective and least costly way.

[20] Actually, investor cost of capital could be lower than the full market cost of capital, because bankruptcy protection causes some of the downside risk to be borne by non-investor participants in the market such as employees, customers and vendors.