Build-Up of PV Value in California – Methodology
13 April 2005

* Asterisk on chart indicates that associated values are derived wholly or in part based on the E3 Avoided Cost Study.

Avoided Generation Cost - The avoided generation cost includes separate estimates for avoided capacity costs and avoided energy/generation costs.

Capacity: Peaking capacity is constructed to serve those limited hours each year, driven by air conditioning load, when the system reaches its maximum demand. PV has a high availability factor during those periods of peak power demand. For PV to be fairly valued, this capacity to meet peaking needs must be recognized.

The range of Avoided Generation Capacity Capital Cost is calculated here based on the annualized capacity value of a gas peaking turbine (low end of range) and a combined cycle gas turbine (high end of range). The unadjusted avoided capacity cost is the annual capacity charge rate (15% from Duke, *et al*., p. 9) times the capital cost for the technology ($419 per kW-yr for a peaking turbine from Duke, *et al.* , p. 9, and $616 per kW-yr for a combined cycle gas turbine from the E3 Avoided Cost Study, p. 63.) The Avoided Generation Capacity Fixed Operation & Maintenance (O&M) Cost is an additional avoided capacity cost, with an unadjusted range of $4.33/kW-yr for a combined-cycle gas turbine and $10.20/kW-yr for a peaking turbine, derived from the same sources as above.

System peak loads are predominantly driven by air conditioning demand on sunny days. The capacity credit (avoided cost) for PV should be set based on the ELCC (effective load carrying capacity) of the PV at a certain area within the system. The ELCC is the capacity of any electricity generator, whether PV or conventional, to contribute effectively to a utility's capacity to meet its peak load. The chart assumes 65% as the notional average ELCC for California and adjusts both the Avoided Generation Capacity Capital Cost and the Avoided Generation Capacity Fixed O&M Cost to reflect this state-wide average ELCC. While solar generation is reduced on cloudy days, so too is the peak load; the PV availability factor on system peak days has proven to be highly reliable. (*See* Atmospheric Sciences Research Center; Herig; and, Letendre, *et al.*) ***Note that for any given PV project, the capacity-related avoided costs should reflect the localized system average ELCC.***

To recognize the dispersion value of distributed PV, the generation-related avoided capacity costs are multiplied by 1.14, the California electric generation reserve margin that is not applied to PV projects. In addition, distributed PV reduces the amount of electricity generated at central stations that must pass through the electric grid, thereby relieving potential overloading of many grid components (*e.g.*, transformers). To the extent that reduced overloading reduces the likelihood of load loss, distributed PV may have additional value in avoiding blackouts (though such value is not reflected here).

To convert $/kW-yr capacity values to cents/kWh, it is necessary to divide the $/kW-yr capacity value by the number of hours per year during which a PV project is expected to generate electricity; this number is derived from the annual capacity factor for PV. For California, the annual capacity factor for PV is estimated by Wenger, *et al.*, to be 22%. The 2003 weighted average annual capacity factor for operational PV systems under the CPUC's Self-Generation Incentive Program was approximately 18%, based on data provided by Itron (pp. 9-15 and 9-16). Using a midpoint of 20% for the PV annual capacity factor yields 1,752 hours of expected PV generation per year (*i.e.*, 8760 hours/year x 0.20).

Although converting $/kW-yr capacity values to cents/kWh facilitates presentation, it is important to note that the significant value of PV peaking capacity is largely masked by the averaging process.

Energy/Generation*:* The energy should be valued at the avoided real-time cost on at least an hourly basis. Avoided energy/generation costs include the avoided cost of natural gas (3.24-9.71 cents/kWh) and avoided variable O&M costs (0.01-0.14 cents/kWh). The avoided generation variable O&M cost range values are taken from Duke, *et al.* on the low side and from the E3 Avoided Cost Study on the high side, with the value of avoided water use subtracted out as a separate variable, as discussed below. The avoided cost of natural gas is derived by multiplying the range of prompt-month natural gas futures contract prices on the New York Mercantile Exchange ("NYMEX") throughout 2004 (*i.e.*, $4.570-$8.752/MMBtu, Henry Hub) times the range of heat rates assumed in the E3 Avoided Cost Study and in Duke, *et al.* (i.e., 7,100-11,100 Btu/kWh). Prices of the NYMEX prompt-month natural gas futures contract throughout the first quarter of 2005 have remained within the range set in 2004.

Avoided Transmission & Distribution ("T&D") Cost (All T&D costs allocated to Summer Peak) - The value of avoided T&D is very much dependent on location and on the adequacy of T&D infrastructure relative to load growth in that location. PV installations in "load pockets" where transmission capacity is constrained will provide maximum value. The same applies to areas located within a constrained distribution grid, or in a new housing development where marginal investment can be directly avoided.

The range of avoided T&D costs is from Tables 21-24, 26, 28, and 30 of the E3 Avoided Cost Study, adjusted to reflect the assumed 65 percent California notional average ELCC and converted to cents/kWh using the assumed 20 percent annual PV capacity factor.

The Schell Opening Testimony in this docket (Exhibits LSS-6 and LSS-7) starts with the same initial avoided T&D costs (from the E3 Avoided Cost Study) and makes adjustments using ELCCs representative of specific customer types (*e.g.*, residential, commercial).

Avoided Generation and T&D Losses – This category of avoided cost includes avoided generation-related losses of 9% applied to the Avoided Generation Capacity Capital Cost and Fixed O&M Cost, and avoided T&D losses of 7.4% applied to each of the other line items, except for: (i) the Avoided Transmission Cost and the Avoided Distribution Cost (which have losses built into the underlying E3 values) and (ii) the Value of Fossil Fuel Price Hedge (which is not volume-sensitive). The 16.4% total avoided generation-related losses and T&D losses is equivalent to the average cumulative on-peak losses of the three California utilities as estimated in Table 8 of the E3 Avoided Cost Study (p. 66).

Avoided NOx Emissions – The category of regulated emissions includes only generation-related emissions for which emissions allowances are currently mandated. The E3 Avoided Cost Study assumes that the cost of regulated emissions is captured in the market price of electricity. However, due to the decision made in this analysis to separate capacity value from energy value, the Avoided Generation Fuel Cost acts as a surrogate for the market price of electricity. Since NYMEX natural gas futures contract prices do not include the cost of emissions allowances, the value of avoided NOx emissions permits is calculated separately. The Value of Avoided NOx Emissions is calculated by applying the heat rates for the two types of gas-fired generators for which capacity value is calculated to the NOx emissions rates estimated in Figure 26 of the E3 Avoided Cost Study. The Value of Health Benefits related to reduced emissions has been removed from the Value of Avoided NOx Emissions and is discussed separately below.

Avoided Fuel Cost (Natural Gas) – The avoided natural gas price is based on the daily settlement prices for prompt-month natural gas futures on NYMEX for calendar year 2004: $4.570-8.752/MMBtu. The gas price is converted to cents per kWh using a heat rate of 7,100 Btu/kWh for a combined cycle gas turbine plant and 11,100 Btu/kWh for a peaking turbine. (From the E3 Avoided Cost Study and Duke, *et al.*, respectively.)

Value of Hedge Against Volatile Fossil Fuel Prices – The range of estimates is based on applying the heat rate end-points of 7,100 Btu/kWh and 11,100 Btu/kWh (discussed above) to the estimates derived by Bolinger, *et al.* The value reflects the fact that PV generation requires no fuel input, thereby avoiding the financial impact of fuel price volatility (e.g., budget uncertainty, uneconomic projects).

Value of Deployment Ease and Speed – PV systems can be sited and installed in a short period of time given available equipment. The carrying costs associated with the lead times necessary for siting, permitting and construction are largely avoided. Emission-free PV systems can be rapidly deployed with minimal to no "greenfield" or unmanageable "NIMBY" impact. The value created through PV modularity is especially dependent on the localized circumstances and hard to quantify on an average basis. But,

in much of California, opposition to new infrastructure usually results in opponents availing themselves of the full suite of administrative remedies to thwart or delay investment. No specific estimate is provided as value will vary by PV project site.

Value of Grid Support – The estimated Value of Grid Support reflects the avoided ancillary services costs associated with the load displaced by PV generation. The value is based on 2.84% of the Avoided Generation Fuel Cost (Natural Gas), the same value that the E3 Avoided Cost Study applies to the avoided market price of electricity to estimate avoided ancillary services (pp. 146-147).

Value of Avoided CO2 Emissions – CO2, methane and other greenhouse gas (GHG) emissions associated with fossil energy production, transmission and combustion are avoided with PV generation. (Emissions associated with manufacturing of PV units should be internalized in the cost of the unit as is the case with other generating equipment.) In addition to CO2 from natural gas and coal combustion, methane is lost at the production stage and from pipeline compressors and equipment valves. While GHGs are not yet subject to mandatory regulation in the US, investment in PV eliminates the risk of additional costs associated with a future control regime. This is especially valuable given the long lifetimes of PV systems.

The E3 Avoided Cost Study (p. 79) uses a cost estimate of $0.004/lb of CO2, the equivalent of $8/ton of CO2. The E3 Avoided Cost Study (pp. 74-75) estimates a linear relationship between CO2 emissions and heat rate between a heat rate floor of 6,240 Btu/kWh and a heat rate ceiling of 14,000 Btu/kWh, with a carbon intensity of natural gas of 117 pounds CO2 per MMBtu. (See E3 supporting file cpucAvoided21.xls for detailed derivation.) Based on the 7,100-11,100 Btu/kWh heat rate range used in this analysis, the associated range of avoided CO2 costs is $3.32-$5.19/MWh. The 0.33 cents/kWh equivalent of the low end of this range sets the low end of the range of the Value of Avoided CO2 Emissions.

In terms of carbon, rather than of CO2, the E3 Avoided Cost Study assumption of $8/ton of CO2 is the equivalent of $29/ton of carbon. This is in contrast to the $100/ton of carbon assumed in Duke, *et al.*, p. 9. Applying a cost of $100/ton of carbon to the 7,100-11,100 Btu/kWh heat rate range used here, the associated range of avoided CO2 costs is $11.33-$17.71/MWh. The 1.77 cents/kWh equivalent of the high end of this range is used as the high end of the range of the Value of Avoided CO2 Emissions in the chart.[1]

Value of Health Benefits – The estimates here are derived a similar methodology to that used by Hoff and Margolis, calculated specifically for California rather than on a nationwide basis. The health benefits of reduced power plant emissions derived in the Abt Associates study were used to calculate California-specific benefits from nationwide

[1] The 1.77 cents/kWh calculated here as the high end of the range is almost identical to the weighted average of 1.78 cents/kWh Avoided GHG Emissions derived from estimates by Duke, *et al.* (calculated by applying 200 hours to Duke, *et al.*'s on-peak estimate of 1.93 cents/kWh and 1366 hours to their off-peak estimate of 1.76 cents/kWh Avoided GHG Emissions).

benefits based on the proportion of California-specific avoided health-related incidences to nationwide totals. (See Abt Associates, Exhibits 6-2 and 6-7.) Total California health benefits were divided by 75% of California's total 1999 NOx and SO2 power plant reductions to arrive at a value of $1.94/lb (1999$) of reduced emissions. (The 75% reduction is as assumed in the Abt Associates study and 1999 California electricity utility emissions as reported by EIA were used to correspond to the 1999 value of health benefits derived in the study.) The $1.94/lb (1999$) of reduced emissions was inflated to 2005$ and converted to cents/kWh using estimated emissions rates from the E3 Avoided Cost Study (p. 73) for the heat rate range of 7,100-11,100 Btu/kWh. The resultant Value of Health Benefits was deducted from the Value of Avoided NOx Emissions to avoid double counting.

A summary of the Abt Associates study can be found in the Clean Air Task Force report.

Value of Avoided Water Use – PV systems use no water in the generation of electricity. The Value of Avoided Water Use that PV generation provides is calculated based on avoided water consumption by a central station generating station, as estimated in Figure 3 of the Hewlett Foundation Report. The central generating station is assumed to be a natural gas combined cycle plant using re-circulating cooling that consumes 0.18 gallons of water per kWh of generation. The range of water costs applied to the 0.18 gal/kWh of avoided central station water use is $0.5093-$2.1878 per hundred cubic feet of metered water and is taken from 2005 rates for the California Water Service Company as approved by the Commission in D.03-09-021. The Value of Avoided Water Use varies depending on location and commercial prices for water will underestimate the Value of Avoided Water Use to the extent that those prices do not fully reflect the societal cost of the water used. Since the cost of water usage is typically included in the Avoided Generation Variable O&M Cost, the Value of Avoided Water Use has been subtracted from the values derived in that category to avoid double counting.

Economic Benefits from Job Creation - The PV Roadmap estimates that every megawatt of solar power currently supports 32 jobs, with 8 of these jobs in system design, distribution, installation, and service created where the systems are installed. The value of these economic benefits has not been estimated explicitly in the chart, given its dependence on the specific types of jobs created and on local wage rates.

Other Values - The estimated values in the chart are not all-inclusive, and do not reflect many of the distributed value elements identified in the PLEASE matrix from the Opening Testimony (Exhibit LSS-4). Among those distributed value elements not yet quantified are the impact on likelihood of system outages, the impact on urban "heat islands," and the impact on local control of resources.

DATA SOURCES

Abt Associates, Inc., October 2000, "The Particulate-Related Health Benefits of Reducing Power Plant Emissions." http://www.abtassociates.com/reports/particulate-related.pdf

Atmospheric Sciences Research Center, State University of New York, "Peak Shaving with PV", http://www.asrc.cestm.albany.edu/research/energy2.htm

Bolinger, Mark, Ryan Wiser and William Golove, January 2004, "Accounting for Fuel Price Risk When Comparing Renewable to Gas-Fired Generation: The Role of Forward Natural Gas Prices." http://eetd.lbl.gov/EA/EMP/

California Public Utilities Commission, September 4, 2003, D.03-09-021, "Opinion Authorizing Rate Increases (Attachment G)." http://www.cpuc.ca.gov/Published/Final_Decision/29515.htm

Clean Air Task Force, October 2000, "Death, Disease & Dirty Power: Mortality and Health Damage Due to Air Pollution from Power Plants." http://www.catf.us/publications/reports/Death_Disease_Dirty_Power.pdf

Duke, Richard, Robert Williams and Adam Payne, 2004, "Accelerating Residential PV Expansion: Demand Analysis for Competitive Electricity Markets," *Energy Policy*. http://www.nrel.gov/ncpv/thin_film/pdfs/energy_policy_pv_expansion_residential_demand_issues.pdf

Energy and Environmental Economics, Inc. and Rocky Mountain Institute, October 25, 2004, "Methodology and Forecast of Long Term Avoided Costs for the Evaluation of California Energy Efficiency Programs," report prepared for the California Public Utilities Commission. ("E3 Avoided Cost Study") http://www.ethree.com/cpuc_avoidedcosts.html

Herig, Christy, "Using Photovoltaics to Preserve California's Electricity Capacity Reserves," National Renewable Energy Laboratory. NREL/BR-520-31179 September 2001. http://www.nrel.gov/docs/fy01osti/31179.pdf

Hewlett Foundation Energy Series, April 2003, "The Last Straw: Water Use by Power Plants in the Arid West." ("Hewlett Foundation Report") http://www.catf.us/publications/reports/The_Last_Straw.pdf

Hoff, Thomas E., and Robert Margolis, 2003, "Distributed Photovoltaics in New Jersey," under contract to the Department of Energy through the National Renewable Energy Laboratory.

Itron, Inc., October 29, 2004, "CPUC Self-Generation Incentive Program Third-Year Impacts Assessment Report."

Letendre, Steven, Richard Perez, and Christy Herig, "Solar and Power Markets: Peak Power Prices and PV Availability for the Summer of 2002." http://www.greenmtn.edu/faculty/Letendre_paper_1.pdf

"PV Roadmap," Our Solar Power Future: The US Photovoltaics Industry Roadmap through 2030 and Beyond. http://www.seia.org/media/pdfs/pvroadmap.pdf

Schell, Lori Smith, October 4, 2004, Opening Testimony filed before the California Public Utilities Commission in Docket No. R.04-03-017, Order Instituting Rulemaking Regarding Policies, Procedures and Incentives for Distributed Generation and Distributed Energy Resources.

Wenger, Howard, Christy Herig, Holly Thomas, and Richard Perez, March 1997, "Customer-Sited Photovoltaics Focusing on Markets that Really Shine: A Study Highlighting The Best Markets In The United Stated For Grid-Connected Photovoltaic Systems," produced for the U.S. Department of Energy by the National Renewable Energy Laboratory. http://www.nrel.gov/ncpv/documents/cust-sited.html