NATIONAL RENEWABLE ENERGY LABORATORY

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**Subcontract Report**
NREL/SR-6A20-48043
October 2010

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# Executive Summary

The U.S. Department of Energy (DOE) Solar Energy Technologies Program (SETP) conducted a 2009 Technical Risk and Uncertainty Analysis to better assess its cost goals for concentrating solar power (CSP) and photovoltaic (PV) systems, and to potentially rebalance its R&D portfolio. This report details the methodology, schedule, and results of this technical risk and uncertainty analysis. Technical experts were recruited by the Risk Analysis Team to provide estimates, in the form of probability density functions, on specific metrics such as total system cost (TSC) and operations and maintenance (O&M) cost. Probability is the most prevalent method for measuring uncertainty. The experts were asked to provide inputs for creating triangular probability distributions, which show the relative likelihood of any given value for a metric when the actual value is uncertain. More specifically, experts were asked to predict future values for specified target years (i.e., 2015, 2020, and 2025 for CSP; 2010, 2015, and 2020 for PV) and based on the following three funding scenarios: no DOE, planned DOE, and expanded DOE R&D funding. Once these estimates were obtained, they were aggregated in @Risk, a probabilistic model utilizing Latin Hypercube simulation to perform quantitative risk analysis.

For CSP, the technologies analyzed were utility-scale parabolic troughs and power towers, both with six hours storage. Experts provided cost estimates including solar field ($/kilowatt or kW), heat transfer fluid/receiver ($/kW), thermal energy storage ($/kWht), power block and balance of plant ($/kW), and O&M ($/kW-yr). TSC ($/kW) was calculated from these inputs. For PV, experts were asked to provide inputs for the utility, commercial, and residential market sectors. Rather than specifying the PV technology, experts were asked to select from crystalline silicon, thin-film, and concentrating PV when providing their estimates. This was done so the experts could select a technology they believe would produce the lowest cost throughout the time frame examined. Experts provided estimates for TSC ($/kW), inverter lifetime (years), inverter replacement cost ($/kW), module cost ($/kW), and O&M ($/kW-yr).

The results of the analyses are expressed in a number of ways, including summary statistics, vigntile tables (i.e., values of a metric at every 5th percentile probability from 0% to 100%), and fan diagrams that graph the 10th, 50th, and 90th percentiles for each funding scenario over time, as well as the SETP goal values. Two of the TSC fan diagrams follow to illustrate some results from the analysis.

First, for CSP troughs, Figure E1 shows the Program goals (light blue line) for TSC may be overly aggressive under the planned budget scenario. However, under the expanded budget scenario, a noticeable cost improvement when compared to no DOE and planned DOE funding (the space between solid colored lines) occurs and, while still an aggressive target, the likelihood of achieving the program goals increases significantly.

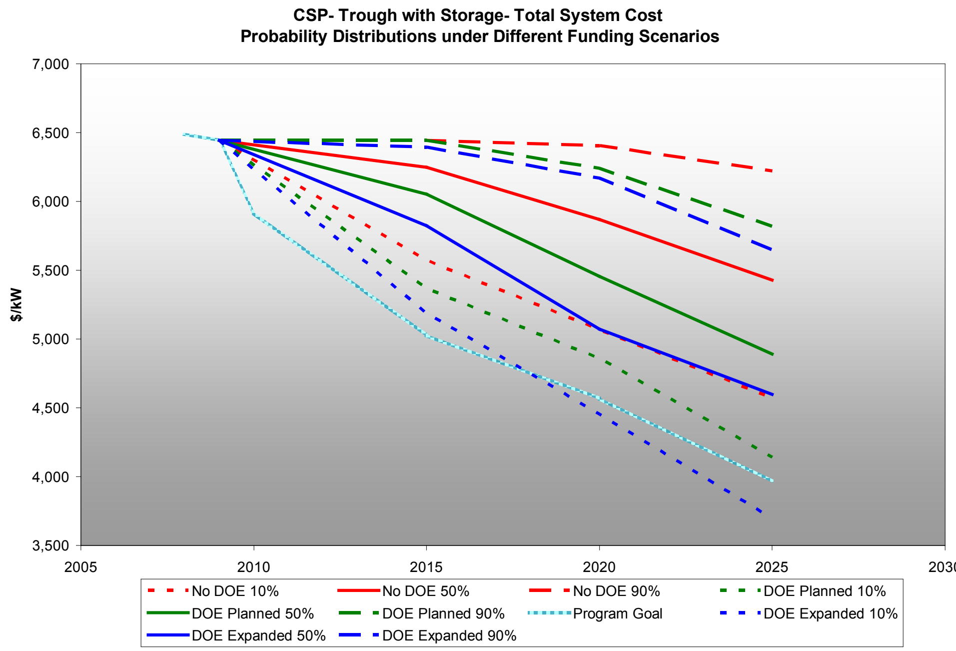


**Figure E1. Total system cost probability distributions for CSP trough with storage**

For utility PV, the results in Figure E2 indicate that experts think the 2015 Program goal value of \$2,200/kW is very aggressive; and, while unlikely to be reached without DOE funding, the goal becomes more likely under the DOE Planned (>10% probability) and DOE Expanded (>20% probability) funding scenarios. When looking at the Program's 2020 goal value of \$2,100/kW, the experts think that the DOE planned budget is more likely to be achieved (>33% probability) than the 2015 goal value, and the expanded budget increases the likelihood to nearly 50% probability.

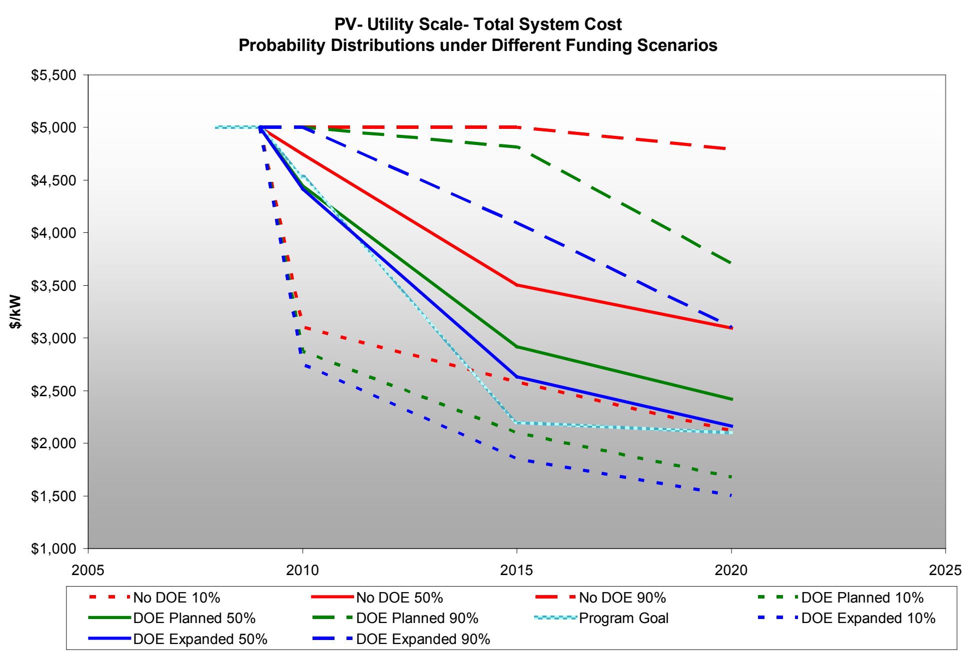


**Figure E2. Total System Cost Probability Distributions for Utility PV Systems**

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# 1 Solar Program Approach to Risk Analysis

## 1.1 Introduction

The Office of Energy Efficiency and Renewable Energy (EERE) of the U.S. Department of Energy (DOE) is tasked with assessing the risk and uncertainty in the benefit estimates of its Technology Development (TD) programs. These risk assessments require technical experts to express their best judgment about the effect of Research and Development (R&D) programs on the future cost and performance of each technology in the form of estimated probability distributions on parameters, such as capital costs ($/kW) and operations and maintenance (O&M) costs ($/kW-yr).

The main objectives of the EERE risk analysis of its R&D Programs are to: 1) meet the National Academy of Science's requirement to report uncertainty; 2) improve project, portfolio, and program performance; 3) clarify issues associated with accepting, managing, or rejecting risks; 4) link science research opportunities with applied energy R&D; and 5) increase decision-maker understanding of potential R&D results. Stated in another manner, results from the technical risk and uncertainty analysis equip management teams with the ability to consistently assess and manage tasks down their administrative chain, and also to evaluate and communicate program performance up the chain.

Technology experts convened for this task were asked to judge the potential successes of Solar Energy Technologies Program (SETP or the Program) research in the areas of concentrating solar power (CSP) technologies (i.e., parabolic trough, power tower, and dish-engine) in the utility market, and solar photovoltaics (PV) technologies (i.e., crystalline silicon, thin films, and concentrating PV) in the residential, commercial, and utility markets.

Information was obtained on each technology from experts who prepared probabilistic estimates of future performance, based on planned R&D programs. Assessments are presented in the form of probability distributions to express uncertainty about technology performance in future goal years. The Risk Analysts and Facilitators team was tasked with aggregating these distributions across the expert subgroups and providing the results of the analysis to DOE and national laboratory staff for use in Program and portfolio evaluation.

The 2009 SETP Risk Analysis effort was based on a similar pilot-scale risk analysis conducted in 2008. The DOE and SETP updated the analysis to include recent technology improvements and market realities, as well as to incorporate several lessons learned and feedback from the experts on how to enhance the expert elicitation process.

## 1.2 Methodology for the 2009 Solar Risk Assessment

Through a series of webinars, conference calls, and email communications, the Solar Risk Analysis Team coordinated efforts across a group of technology experts from national labs, academia, and industry. Virtual meetings (i.e., webinars and conference calls) were held separately for CSP and PV to introduce the process and methodology, communicate the inputs requested from the experts, and support the experts during the elicitation process. The schedules for CSP and PV varied with respect to the days in which activities were conducted, but both were completed between February and June 2009. A more detailed explanation of the schedule can be found in Section 1.2.6 Webinars - Kickoff Meetings and Expert Reviews.

The experts were asked to estimate, via probability distributions, specific technology cost reductions under three different DOE funding scenarios and three different time periods. In order to effectively elicit the inputs or probability distributions from the experts on the range of performance measures, technology evaluation input sheets were developed. Once collected from the experts, the probability distributions were aggregated and run through @Risk, a probabilistic model utilizing Latin Hypercube simulation to perform quantitative risk analysis.

### *1.2.1 Risk Analysis Team*

The Solar Risk Analysis Team was composed of risk analysts, facilitators, and SETP staff advisors. Risk analysts and facilitators were tasked with the following: clearly explaining the information needed, providing simple forms to elicit input from the experts, answering questions from experts, receiving and aggregating inputs, discussing an expert's response one-on-one as needed, providing initial results to the experts, finalizing results, and preparing the final report.

The risk analysts and facilitators for the 2009 solar risk assessment were James McVeigh, Mark Lausten, Arun Soni, and Ed Eugeni, all from Sentech, Inc. The SETP staff advisors for the 2009 solar risk assessment were Tex Wilkins (DOE) for CSP, and Scott Stephens (DOE) and Robert Margolis (NREL) for PV. Methodology development, guidance, and advice were provided by the DOE Risk Working Group members Sam Baldwin (DOE), Thomas Jenkin (NREL), James McVeigh (Sentech, Inc.), and Max Henrion (Lumina Decision Systems, Inc.).

### *1.2.2 Expert Team Members*

#### *Concentrating Solar Power*

The Solar Risk Analysis Team contacted 48 CSP experts from more than 20 different organizations, based on the following criteria:

- **By expertise:** parabolic trough, power tower, dish-engine
- **Global:** national and international experts
- **Variety:** national labs, academia, industry.

Of these, the Solar Risk Analysis Team received a total of eight (8) expert responses (6 industry and 2 lab).

*Photovoltaics*

The Solar Risk Analysis Team contacted 45 PV experts from over 25 different organizations, based on the following criteria:

- **By expertise:** crystalline silicon, thin film, and concentrating PV
- **Global:** national and international experts
- **Variety:** national labs, academia, industry.

Of these, the Solar Risk Analysis Team received the following results from experts: five (5) utility-scale (3 industry, 1 laboratory, 1 academia); nine (9) commercial-scale (6 industry, 2 laboratory, 1 academia); and four (4) residential-scale (2 industry, 1 laboratory, 1 academia).

### *1.2.3 Distribution of Expert Briefing Reports and Score Sheets*

Solar experts were provided with a set of "common information" in the form of expert briefing documents and detailed instructions regarding how to complete the CSP and PV assessment forms, referred to as score sheets. This was done through "Expert Kickoff Meetings" held for both CSP and PV. Additionally, the experts were provided a brief report summarizing the identified studies, reports, and data (i.e., current status of the technology, planned and potential R&D, and projections of future cost and performance improvements) relevant to the risk analysis. During these meetings, the Risk Analysis Team identified and reviewed the expert briefs and score sheets, and asked experts to provide any content suggestions. Following these forums, the materials were emailed to the participants.

The CSP Expert Briefing Report provided to the Expert Team included:

- DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology. 2007 DOE Study by H. Price of the National Renewable Energy Laboratory (NREL), D. Brosseau of Sandia National Laboratories (SNL), D. Kearney (Kearney & Associates), and B. Kelly (Nexant), (2007)
- DOE Solar Program 2007-2011 Multi Year Program Plan, (2007)
- Arizona Renewable Energy Assessment, Black & Veatch, (9/2007)
- Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California, prepared by L. Stoddard, J. Abiecunas, and R. O'Connell, of Black & Veatch, for NREL, Subcontract Report NREL/SR-550-39291, (4/2006)
- Solar Task Force Report, Western Governor's Association, , (1/2006)
- Assessment of Parabolic Trough and Power Tower Technology Cost and Performance Forecasts, prepared by Sargent & Lundy, for DOE and NREL, Final Report, SL-5641, (5/2003);
- USA Trough Initiative- Thermal Storage for Rankine Cycle and Combined Cycle Power Plants, NREL, presented by Bruce Kelly, Nexant Inc., and Ulf Herrmann, FLABEG Solar International GmbH., (2/2006)
- Evaluating the Carbon Dioxide Abatement Potential of EERE Technologies- Solar Power Discussion, McKinsey & Company, presentation made to EERE Programs, (10/7/2008).

The PV Expert Brief provided to the Expert Team included:

- Technology Pathway Partnerships, Projections of Cost Improvements, DOE, SETP (2006)

- A Review of Industry and Financial Analysts Projections for Solar Technologies- An Analysis of Industry Forecasts including Photon Consulting (2008), Piper Jaffray (2008), Goldman Sachs (10/2008), Lazard (11/2008), Prometheus (10/2008), Deutsche Bank (05/2008), FBR (11/2008). Documents obtained via personal contact with Scott Stephens, DOE, on January 7, 2009
- PV Cost Projections, Photon Consulting, , Photon Magazine, (January 2008)
- Arizona Renewable Energy Assessment, prepared by Black & Veatch for Arizona Public Service Company, Salt River Project, and Tucson Electric Power Corporation, B&V Project Number 145888, (September 2009)
- Tiered Carbon Impacts Analysis, DOE, EERE, Draft, (October 14, 2008);
- Evaluating the Carbon Dioxide Abatement Potential of EERE Technologies- Solar Power Discussion, Presentation made by McKinsey & Company to EERE Programs, (October 7, 2008);
- A Review of PV Inverter Technology Cost and Performance Projections, Navigant Consulting, Inc., presentation to NREL, (January 12, 2006)
- Corporate Overview Q2 2008, First Solar, PowerPoint Presentation, (2008)
- Opportunities and Challenges for Development of a Mature Concentrating Photovoltaic Power Industry, S. Kurtz of NREL, Technical Report, NREL/TP-520-43208, (Revised February 2009)
- Solar Photovoltaic Industry- Looking through the storm, Deutsche Bank, (January 2009).

Innovative and streamlined technology evaluation input sheets were developed to collect specific metrics data from the technology experts, including: the expert's self rating; the extreme future technical or economic limits; learning by doing rates; the probability of advance; and the improvement distribution in the form of $10^{th}$ percentile, most likely, and $90^{th}$ percentile estimates. Figure 1.1, which follows, represents a sample of the 2009 Solar Risk Analysis score sheets.

## EERE- Solar Energy Technologies Program CSP R&D Risk Assessment

**ELICITATION INFORMATION:**

| | |
|---|---|
| 2a. Date of assessment: | |
| 2b. Assessor name: | |
| 2c. R&D Program: | DOE-EERE -Solar Energy Technologies Program |
| 2d. Technology Type: | CSP |

**TPM INFORMATION:**

| | | |
|---|---|---|
| 2e. Assessor Self-rating: | | (for this TPM) |
| 2f. Quantity (TPM): | Solar Field Cost | |
| 2g. Units and Description: | $/kWe | 2008 US dollars per kilowatt-electric |
| 2h. Improvement: | Decreasing | |

| | | | | DISTRIBUTION | | |
|---|---|---|---|---|---|---|
| 2i. Reference value: | | Reference Yr: | Single Value | 10%ile | Most Likely | 90%ile |
| | Single Value | 2008 | $2,616 | | | |
| 2j. Extreme Future Limits: | | | | Minimum: $500 | | Maximum: $5,000 |
| 2k. Learn by Doing: | | Start Year: 2025 | LBD Range: | 8% | 12% | 15% |

**TOTAL IMPROVEMENT (FROM ALL TIOs)**

| | Goal Years | If no Advance Value = | Probability of Advance | DISTRIBUTION 10%ile | (mode) Most Likely | 90%ile | Input Values CHECK |
|---|---|---|---|---|---|---|---|
| | (a) | (b) | (c) | (d) | (e) | (f) | (g) |
| 2l. No DOE R&D: | 2015 | 2,616 | 85% | $2,200 | $2,300 | $2,500 | OK |
| | 2020 | 2,300 | 90% | $2,100 | $2,200 | $2,300 | OK |
| | 2025 | 2,200 | 95% | $2,000 | $2,100 | $2,200 | OK |
| 2m. DOE Planned R&D: | 2015 | 2,300 | 90% | $2,100 | $2,200 | $2,300 | OK |
| | 2020 | 2,200 | 95% | $2,000 | $2,100 | $2,200 | OK |
| | 2025 | 2,100 | 100% | $1,800 | $2,000 | $2,100 | OK |
| 2n. DOE Expanded R&D: | 2015 | 2,300 | 95% | $2,000 | $2,100 | $2,200 | OK |
| | 2020 | 2,200 | 100% | $1,800 | $2,000 | $2,100 | OK |
| | 2025 | 2,100 | 100% | $1,500 | $1,700 | $1,800 | OK |

2o. Comments:

Technology Assumptions | **Solar Field** | HTF | TES | PB&BOS | O&M

**Figure 1.1. Example score sheet for the 2009 Solar Risk Assessment**

### *1.2.4 Specific Budget and Timeframe Assumptions*

Experts provided estimates of technology improvements based on three funding scenarios: 1) baseline industry R&D 2) current planned DOE budget for R&D, and 3) an expanded DOE budget for R&D.

The baseline industry R&D case accounts for improvements over time due to investment in R&D by industry and other governments, while assuming zero DOE funding for R&D activities. The DOE planned program budget case accounts for improvements over time due to the current amount of U.S. federal government R&D funding being held constant through time (inflation adjusted). The expanded program, or over-target case, accounts for technology improvements caused by a doubling in U.S. federal government R&D funding over the current plan (inflation adjusted). Table 1 lists the DOE Solar Program funding levels from 2007 and 2009, along with funding that the risk analysis assumed for the years 2010 through 2025.

**Table 1. U.S. Department of Energy Solar Energy Technologies Program Funding Levels**

| Technology | FY 2007 | FY2008 | FY2009 | Assumed FY 2010-2025 | Expanded FY 2010-2025 |
|---|---|---|---|---|---|
| Concentrating Solar Power | $16 million | $30 million | $30 million | Constant at $30 million | Constant at $60 million |
| Photovoltaic Energy Systems | $138 million | $137 million | $145 million | Constant at $140 million | Constant at $280 million |

For baseline industry R&D, both CSP and PV DOE funding were considered to be $0. For the current planned DOE R&D budget, funding was considered $30 million and $140 million for CSP and PV, respectively. For an expanded DOE R&D budget, funding was considered $60 million and $280 million for CSP and PV, respectively.

For each of the funding scenarios, three future goal-years were identified for the two technologies so that experts could provide cost projections. The CSP goal-years were 2015, 2020, and 2025, whereas the PV goal-years were 2010, 2015, and 2020. The difference between the two was a result of analyst judgment on the current state of the solar market for both of these technologies.

### *1.2.5 Technology Performance Measures and Base Case Scenarios*

The Solar Program has developed a set of Technology Improvement Opportunities (TIOs) in its Multi-Year Program Plan. These TIOs represent the projects and R&D activities (or set of activities) that can be undertaken to improve the technology. The quantifiable metrics (e.g., capital cost or efficiency) that characterize the technology and show how much improvement occurs are called Technology Performance Measures (TPMs). Utilizing the Program's TPMs in R&D planning can create a clearer image of the technology's future. CSP TPMs are listed in Table 2, and PV TPMs are listed in Table 9.

Experts provided the estimates on the probability of advance (POA), and a distribution (assumed to be triangular) of what the advance would be in the form of the 10th percentile, most likely (or mode), and 90th percentile values for each TPM. The POA is defined as the probability that R&D will improve the technology relative to the current state of the technology. The inverse of this probability (1 minus the POA) is the probability of R&D failure (i.e., the likelihood that R&D will not improve the technology and the TPM will remain at the current value. The distributions (10%/Most Likely/90%) represent the range of outcomes that could occur if the R&D is successful and some improvement is made.

*Concentrating Solar Power*

The 2009 Solar Risk Analysis looked at the TPMs listed below in Table 2 for the various CSP technology applications. It should be noted that results for tower without storage and dish-engine results are not available, as there were not enough responses provided by the experts.

**Table 2. Technology Performance Measures Utilized in the 2009 Solar Program Risk Analysis**

| CSP Technology | Technology Performance Measures (TPMs) |
|---|---|
| CSP Line Focused (Trough or CLFR) with 6 Hr Thermal Storage | 1) Solar Field (Reflector, Receiver) System ($/kW) |
| | 2) Heat Transfer Fluid (HTF) System ($/kW) |
| | 3) Thermal Energy Storage (TES) System ($/kWh$_t$) |
| | 4) Power Block & Balance Of System (BOS) ($/kW$_e$) |
| | 5) Operations and Maintenance (O&M) (($/kW-yr) |
| CSP Tower With 6 Hr Thermal Storage | 1) Solar Field (Heliostats) ($/kW) |
| | 2) Receiver and Tower System($/kW) |
| | 3) Thermal Energy Storage (TES) System ($/kWh$_t$) |
| | 4) Power Block & Balance Of System (BOS) ($/kW$_e$) |
| | 5) Operations and Maintenance (O&M) ($/kW$_e$-yr) |
| CSP Tower With No Thermal Storage | 1) Solar Field (Heliostats) ($/kW) |
| | 2) Receiver and Tower System ($/kW) |
| | 3) Power Block & Balance Of System (BOS) ($/kW$_e$) |
| | 4) Operations and Maintenance (O&M) (($/kW-yr) |
| CSP dish-engine | 1) Solar Field (Concentrator, Reflector) System ($/kW) |
| | 2) Receiver ($/kW) |
| | 3) Engine/Generator ($/kW) |
| | 4) Operations and Maintenance (O&M) Cost (($/kW-yr) |

The base-case model for a CSP trough plant for the 2009 Solar Risk Assessment study is that of a 100-megawatt (MW) plant with 6 hours of thermal energy storage as identified in Solar Advisor Model- Version 2.5.0.2 February 13, 2007—using Daggett, California resource (950 W/m$^2$ design point). Costs are expressed in 2009 dollars and are based on historical data of CSP plants and previous studies adjusted for inflation and escalation. It should be noted that 2008 and 2009 have seen significant commodity price swings. All attempts were made to convert prior studies' project costs to current dollars.

Tables 3 and 4 list the base-case CSP trough model plant configuration and plant costs (in 2009 dollars).

**Table 3. Base-Case Model CSP Trough Plant Configuration**

| **100-MW Plant with 6 hour TES storage** | | |
|---|---|---|
| System Size | 100 | MW |
| Solar Field | 871,936 | $m^2$ |
| Solar Field Row Spacing to Aperture Ratio | 3:1 | |
| Solar Multiple | 2 | |
| Solar Field Parasitics (Drives And Electronics) | 232 | $kW_e$ |
| Solar Field Optical Efficiency | 77.6 | % |
| Storage | 1,748.80 | $MWh_t$ |
| HTF and TES Pumping Parasitics | 12.3 | $MW_e$ |
| Solar Field, HTF And TES Thermal Losses | 59.5 | $MW_t$ |
| Thermal Energy Storage Round Trip Efficiency | 98.5 | % |
| Power Block & BOP Parasitics | 7.7 | $MW_e$ |
| Steam Turbine Gross Efficiency | 37.74 | % |
| Steam Turbine Inlet Temperature | 370 | Deg C |
| Power Block Availability | 94 | % |
| Capacity Factor | 41 | % |

**Table 4. Base-Case Model CSP Trough Plant Costs in $2009**

| **100 MW Plant with 6 hour TES storage** | | **Units** | **Total $2009** | **$/kWe peak** |
|---|---|---|---|---|
| Direct Installed Costs | | | | |
| Solar Collection Field | $350 | $/m^2$ | $305,177,670 | $3,052 |
| HTF System | $150 | $/kW_e$ | $15,000,000 | $150 |
| Storage System | $45.00 | $/kWh_t$ | $78,696,343 | $787 |
| Site Improvements* | $4.50 | $/m^2$ | $3,923,713 | $39 |
| Power Plant* | $1,080 | $/kW_e$ | $108,000,000 | $1,080 |
| Contingency Percent | 10 | % | $51,079,773 | $511 |
| Direct Costs Sub Total | | | $561,877,499 | $5,619 |
| Indirect Costs | | | | |
| Engineering, Procurement, Construct (EPC) of Direct | 15 | % | $76,619,659 | $766 |
| PLM Percent of Direct | 5 | % | $25,539,886 | $255 |
| Sales Tax applied to 80% Percent of Direct | 7.25 | % | $29,626,268 | $296 |
| Indirect Costs Subtotal | | | $131,785,813 | $1,318 |
| Total Installed Cost | | | $693,663,312 | $6,936 |
| Operating Costs | | | | |
| Fixed O&M | $69.00 | /kW-yr | | |
| Variable O&M | $0.67 | /MWh | | |
| Annual Variable O&M | $2.52 | /kW-yr | | |
| Annual Total O&M | $73.99 | /kW-yr | | |

* Assumed to be part of BOS&PB TPM costs

For CSP Tower plants, the Risk Analysis relied heavily on the data available in the Sargent & Lundy study, "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts" (NREL/SR-550-34440). This is considered the most comprehensive study available to date for towers. The following parameters and costs reflect an adjustment to those specifications and costs to align with a 40% capacity factor for a plant built in 2015, but reflected in 2009 dollars.

Tables 5 and 6 list the base-case CSP tower model plant configuration and plant costs (in 2009 dollars).

**Table 5. Base-Case Model CSP Tower Configuration**

| 100 MW Plant with 6-Hour TES storage | | |
|---|---|---|
| System Size | 100 | MW |
| Solar Field | 960,000 | $m^2$ |
| Solar Multiple | 1.7 | |
| Solar Field and Receiver Optical Efficiency | 45 | % |
| Storage | 1,571 | $MWh_t$ |
| Thermal Energy Storage Round Trip Efficiency | 99.5 | % |
| Power Block & BOP parasitics | 10 | $MW_e$ |
| Steam Turbine Gross Efficiency | 42 | % |
| Steam Turbine Inlet Temperature | 550 | Deg C |
| Power Block Availability | 94 | % |
| Capacity Factor | 40 | % |

**Table 6. Base-Case Model CSP Tower Plant Costs in $2009.**

| 100 MW Tower Plant with 6 hour TES storage | | Units | Total $2009 | $/kWe peak |
|---|---|---|---|---|
| Direct Installed Costs | | | | |
| Heliostat Field | $208 | $/m^2$ | $199,490,566 | $1,995 |
| Tower and Receiver | $751 | $/kW_e$ | $75,100,000 | $751 |
| Storage System | $18 | $/kWh_t$ | $27,756,500 | $278 |
| Site Improvements* | $4.50 | $/m^2$ | $4,320,000 | $43 |
| Power Plant* | $1,050 | $/kW_e$ | $105,000,000 | $1,050 |
| Contingency Percent | 10 | % | $41,166,707 | $412 |
| Direct Costs Sub Total | | | $452,833,772 | $4,528 |
| Indirect Costs | | | | |
| Engineering, Procurement, Construct (EPC) of Direct | 15 | % | $61,750,060 | $618 |
| PLM Percent of Direct | 5 | % | $20,583,353 | $206 |
| Sales Tax applied to 80% Percent of Direct | 7.25 | % | $23,876,690 | $239 |
| Indirect Costs Subtotal | | | $106,210,103 | $1,062 |
| Total Installed Cost | | | $559,043,875 | $5,590 |
| Operating Costs | | | | |
| Fixed O&M | $69.00 | /kW-yr | | |
| Variable O&M | $0.67 | /MWh | | |
| Annual Variable O&M | $2.52 | /kW-yr | | |
| Annual Total O&M | $73.87 | /kW-yr | | |

* Assumed to be part of BOS&PB TPM costs

*Photovoltaics*

The PV Expert Team evaluated PV systems within the following three market sectors: residential, commercial, and utility. Table 7 lists this information, along with the five TPMs covered in the risk analysis. A new and unique element was added to the PV Risk Analysis this year to gain the experts' perspectives on which revolutionary technology advances were expected to occur in the future. Each expert was asked to rate the likelihood that a specific disruptive advancement in PV technologies would occur by certain dates (see Section 2.6 for a list of disruptive technology advancements assessed and the results).

**Table 7. PV Market Applications, Technologies, and Performance Measures**

| **PV Market Applications** | PV Technology | Technology Performance Measures (TPMs) | |
|---|---|---|---|
| Residential | Crystalline Silicon | PV Module Cost ($/kW) | O&M Cost ($/kW-yr) |
| Commercial | Thin Film | Inverter Cost ($/kW) | Inverter Life (years) |
| Utility | Concentrating PV | Total System Installed Cost ($/kW) | |

Additional TPMs that have been identified and were assessed in the pilot 2008 Solar Program Risk Analysis (i.e., jobs; scalability; and water usage for CSP) were excluded from this year's analysis to simplify the process and reduce the number of estimates that the experts had to make.

### *1.2.6 Webinars - Kickoff Meetings and Expert Reviews*

The process of eliciting expert input for the 2009 Solar Risk Analysis was conducted through multiple online webinars. Through these separate webinar series, CSP and PV experts were asked to estimate specific technology cost and performance improvements that would occur during three different time periods, and with three different DOE funding scenarios. Tables 8 and 9 summarize the timelines.

**Table 8. Schedule for the 2009 CSP Risk Analysis**

| **Activity** | **Date** |
|---|---|
| Webinar kickoff meeting | February 25 |
| Webinar kickoff meeting 2 | March 3 |
| Score sheet distribution to experts | March 23 |
| Score sheet review and Q&A | March 30 and 31 |
| Input sheet responses | Due from experts: April 18<br>Submitted to SEDS/NEMS/MARKAL: May 1 |
| | |
| Expert review webinar meeting | June 22 |
| Input sheets revisions | Due from experts: June 29 (no revisions were provided, so previous submission to SEDS/NEMS/MARKAL was unchanged |
| Final report | Fall 2009 |

**Table 9. Schedule for the 2009 PV Risk Analysis**

| Activity | Date |
|---|---|
| Webinar kickoff meeting | March 3 and 6 |
| Score sheet review and Q&A | March 18 and 19 |
| Input sheet responses | due from experts: March 20<br>Accepted from experts until March 31 |
| Expert review webinar meeting | April 2 |
| Input sheets revisions (if needed) | Due from experts: April 9<br>Submitted to SEDS/NEMS/MARKAL: May 1 |
| Final report | Fall 2009 |

### *Concentrating Solar Power*

The CSP webinar kickoff meetings were held in February 2009 to discuss the process, assumptions, and briefing document. As part of the introduction, probability density functions were reviewed and an explanation on the estimation input format was provided. A second round of webinar kickoff meetings were held in early March to continue the discussion on the risk brief and reference values. In addition, the risk analysts and facilitators walked through an example of how to complete the score sheets.

Score sheets were distributed to the experts after the kickoff webinars. Approximately one week after disseminating the score sheets, the risk analysts and facilitators were available via webinar during two 4-hour windows to answer specific questions and help the experts fill in the score sheets in real time if necessary. Inputs were due from experts in mid-April, and upon receipt, results were aggregated in a probabilistic risk analysis model utilizing the @Risk software. The initial results of this model were then provided back to the experts in a final webinar where the risk analysts and facilitators presented and explained the results. The experts were given a chance to discuss amongst themselves and then provided a chance to revise their inputs if there was any confusion or misunderstanding on what was being asked of them, or if new information or rationale was discussed that caused them to alter their opinions. None of the CSP experts made changes to their initial estimates, so the aggregated results previously submitted remained the same.

### *Photovoltaics*

The PV webinars were conducted in a similar manner to those for CSP, with two separate webinar kickoff meetings held during the first week of March 2009 to accommodate participants' schedules. Discussion of the process, assumptions, and briefing document occurred, and afterwards, score sheets were sent to experts.

Similar to the CSP group, risk analysts and facilitators were available during two 4-hour windows in mid-March to answer questions and provide real-time support on filling out score sheets. Input sheets were accepted from experts until the end of March, and upon receipt, results were aggregated in a similar @Risk model. The results were summarized and provided back to the expert teams for discussion. An expert review webinar was then held in April, in which the risk analysts and facilitators presented on the results and the experts discussed aggregated results with each other. Afterward, experts were given one week to modify their individual projections if they deemed necessary. It should be noted that consensus was not forced on the group and no expert was asked or suggested to revise his or her estimates simply because their opinion was an outlier relative to others in the group.

### *1.2.7 Final Aggregation of Expert Inputs*

Probability distributions provided by the experts were aggregated and run through @Risk, a probabilistic model utilizing Latin Hypercube Simulation (LHS) to perform the quantitative technical risk and uncertainty analysis. Once finalized, these results were fed into the Stochastic Energy Deployment Systems (SEDS) model, and were also utilized in deterministic models such as the National Energy Modeling System (NEMS) and the Market Allocation Model (MARKAL), as part of DOE's Portfolio Development Support (PDS) and Government Performance and Results Act (GPRA) benefits processes. These models project future market penetration of various technologies, and the associated energy security, economic, and environmental benefits (e.g., barrels of oil displaced, consumer savings, and carbon reductions) due to Program R&D funding. Results of the 2009 Solar Risk Assessment can be found in Section 2.0 Summary of Results.

# 2 Summary of Results

The Total Installed Cost/Total System Cost results of the 2009 Solar Energy Technologies Program's Technical Risk and Uncertainty Analysis are presented below for CSP and PV. The full results of the analysis are provided in Appendices A through G, which include the following: details on the fan diagrams for TPMs in each time period and funding scenario; aggregated probability distributions; market model inputs; and aggregated PV disruptive technology advancements.

Each figure for Total System Cost includes three projections of future improvements:

1. Baseline: The aggregated expert team risk distributions, shown for the 10%, 50%, and 90% scenarios, assuming no DOE R&D funding of the technology;
2. DOE planned (target funding) or DOE expanded (over-target funding):
   a. DOE planned—The first figure in each set shows the aggregated expert team risk distributions, shown for the 10%, 50% and 90% scenarios, assuming the planned DOE R&D funding.
   b. DOE expanded—The second figure in each set shows the aggregated expert team risk distributions, shown for the 10%, 50% and 90% scenarios, assuming expanded DOE R&D funding.
3. Program goal: A point estimate trajectory of improvements formulated assuming that the Program achieves its goals (i.e., this information has typically been provided by EERE programs in prior years as inputs into the NEMS and the MARKAL models for market penetration modeling and program benefits calculations).

## 2.1 Concentrating Solar Power—Trough Risk Analysis Results

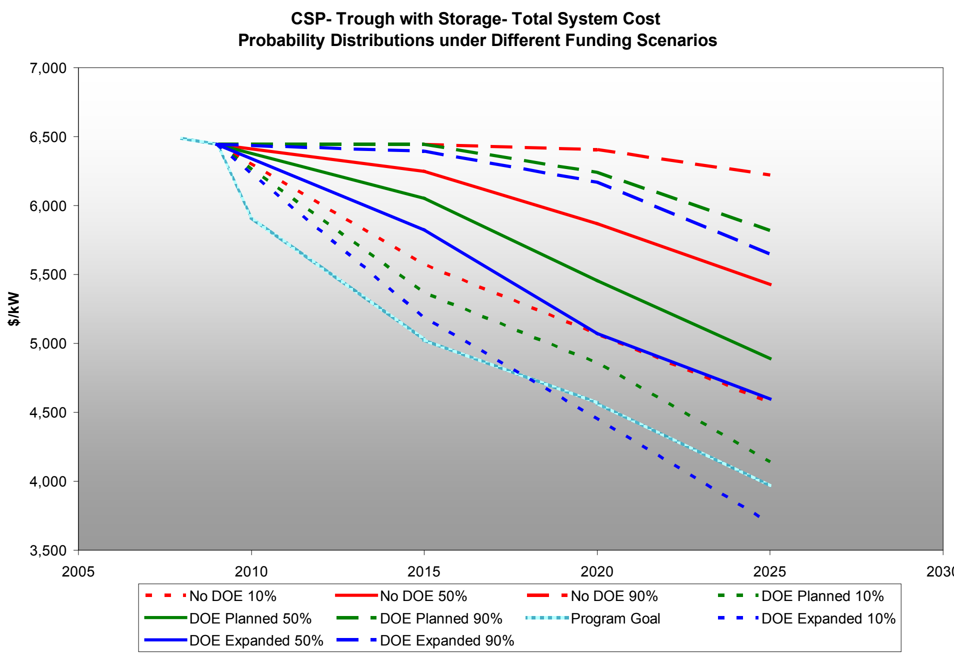



**Figure 2.1. Total system cost probability distributions for CSP trough with storage**

Figure 2.1 indicates that the planned budget should allow for a relatively pronounced cost decrease in troughs when compared to no DOE funding. Similarly, an expanded budget should allow for an even more noticeable cost reduction when compared to the other scenarios (resulting in \$4,597/kW when considering the 50th percentile input). Nonetheless, while significant trough improvements can occur with DOE monetary support, the Program goal values are relatively unlikely to be achieved according to expert inputs, and therefore may need to be revised.

## 2.2 Concentrating Solar Power—Tower Risk Analysis Results

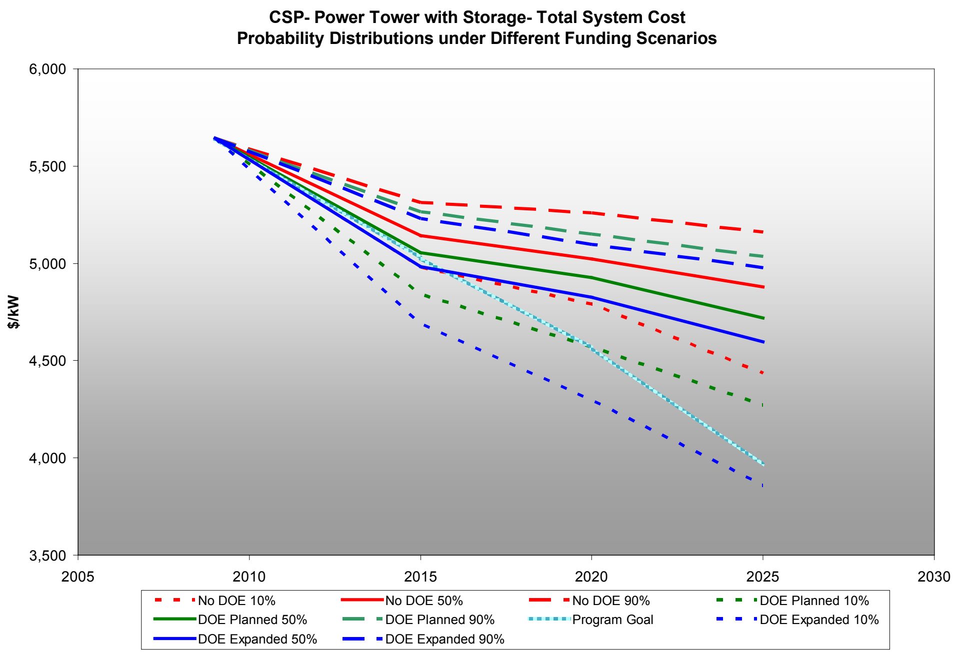



**Figure 2.2. Total system cost probability distributions for CSP tower with storage**

Figure 2.2, representing tower total installed probability distributions, shows a gradual cost decrease out to 2025 (reaching \$4,598/kW based on the 50th percentile expanded funding case). Results demonstrate that the Program's 2015 goal can likely be achieved with planned funding, but the 2025 goal is not likely to be realized without expanded funding levels.

It should be noted for the CSP cost curves (both trough and tower) that the probability of achieving a "goal-based" value does not necessarily need to be at or above 50%. Many have argued that the role of DOE is to undertake R&D that industry may consider too risky. In fact, many DOE programs have been tasked with setting aggressive goals for improving those technologies. Furthermore, the likelihood of achieving a particular value may be misleading for the following reason: improving the technology, but not quite reaching a deterministic target, will still yield benefits. These benefits may be lost if achieving at least the goal value is seen as the pass/fail measure.

## 2.3 Photovoltaics—Utility Risk Analysis Results

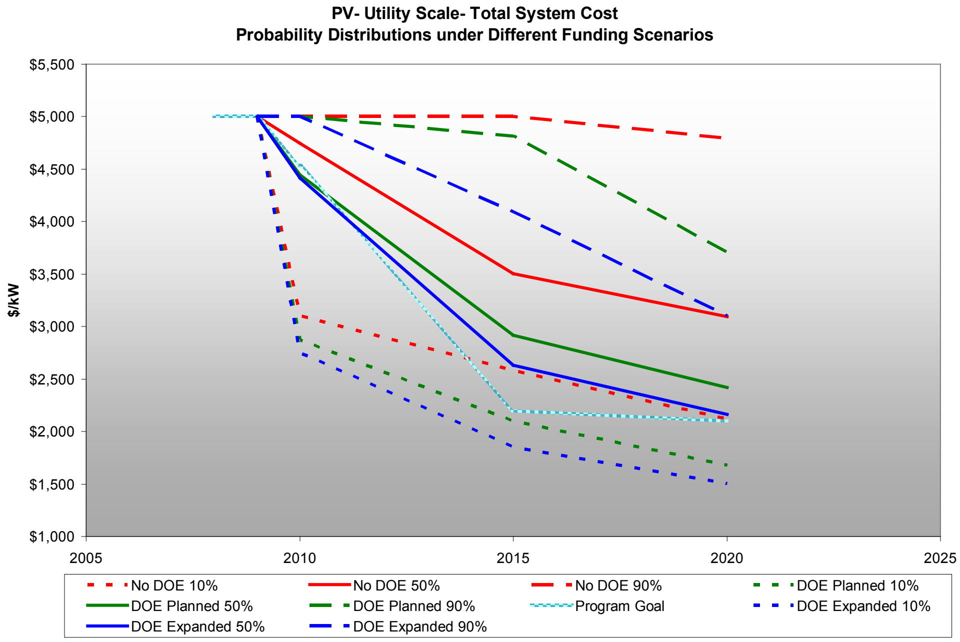



**Figure 2.3. Total system cost probability distributions for PV utility**

As shown in Figure 2.3, PV experts foresee a noticeable decrease in total system cost at the utility level even without DOE funding, achieving $3,094/kW in 2020 when considering the 50th percentile input. However, they believe the cost would drop to $2,418/kW in 2020 when considering the 50th percentile input for the planned funding scenario. This latter amount is approaching the Program goal of $2,100/kW. If an expanded DOE budget is provided, the experts indicate there is a 50% chance the 2020 objective will be met or exceeded, and a 10% chance that Program expectations will be surpassed to the point that TSC will be at or below $1,505/kW.

## 2.4 Photovoltaics–Commercial Risk Analysis Results

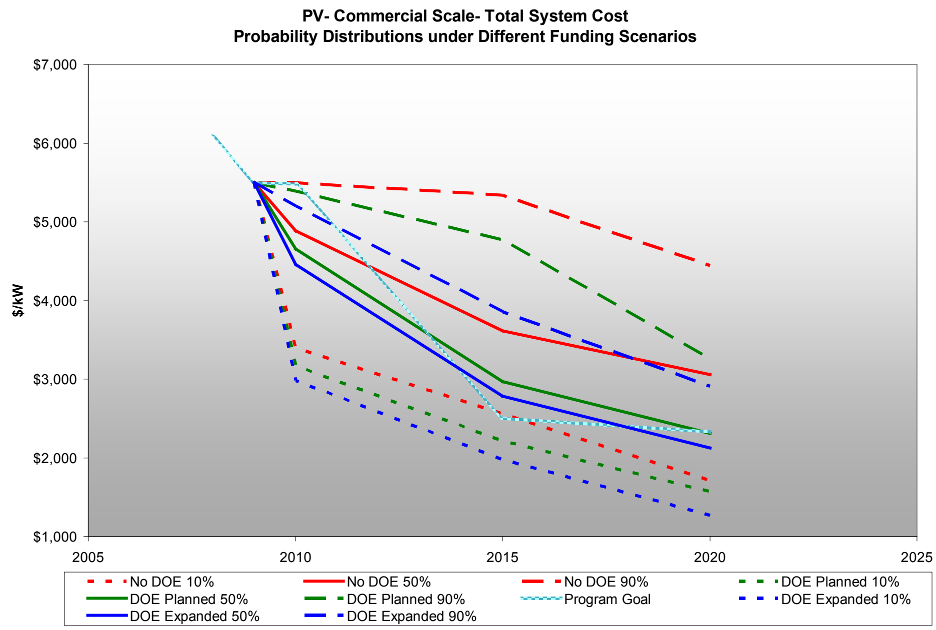



**Figure 2.4. Total system cost probability distributions for PV commercial**

Similar to utility PV, Figure 2.4 expresses a noticeable decrease in TSC out to 2020 in all funding scenarios. A greater amount of cost reduction is projected to occur between 2010 and 2015, as indicated by the steepness in slopes for the 50$^{th}$ percentile lines. With planned DOE funding, it is anticipated that the 2020 Program goal of $2,330/kW will be met, and possibly even surpassed, potentially reaching $1,570/kW. When considering the expanded budget, the experts reveal more optimism, as is evident by the 50$^{th}$ and 10$^{th}$ percentile lines.

## 2.5 Photovoltaics—Residential Risk Analysis Results

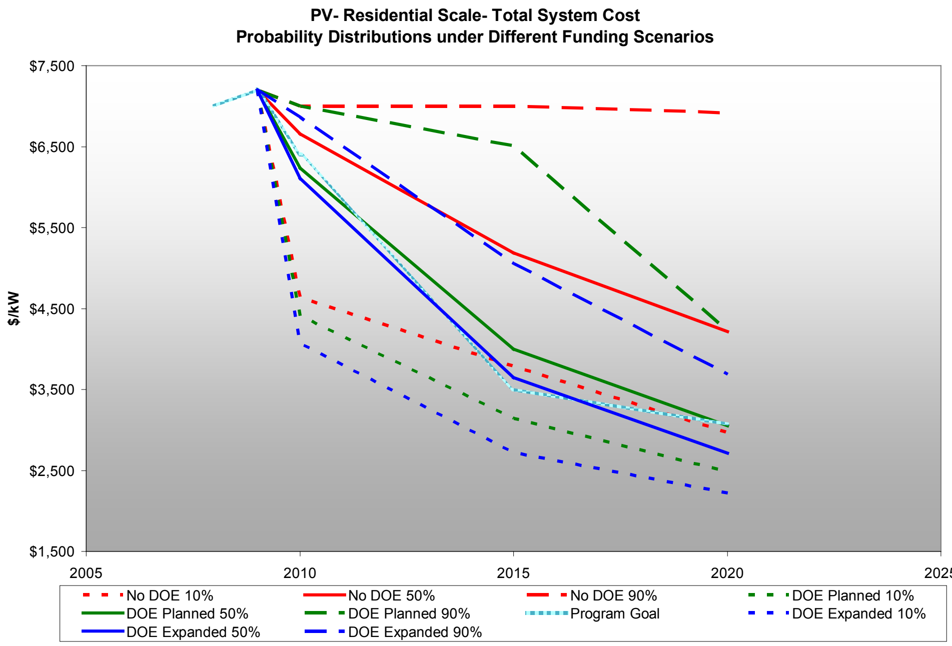



**Figure 2.5. Total System Cost Probability Distributions for PV Residential**

Figure 2.5 illustrates that without DOE funding experts forecast a steady decline in TSC, with a 2020 result of $4,228/kW (based on 50th percentile inputs). This is well above the Program goal of $3,070/kW. When planned funding occurs, however, experts are more confident that the 2020 goal will be reality. Expanding the DOE budget may allow for additional cost reductions according to expert input (achieving $2,713/kW), but this is not a considerable decrease in cost when compared to the planned funding scenario.

## 2.6 Photovoltaics—Disruptive Technology Advancements Results

Along with the probability density functions, PV participants were asked to indicate the likelihood of specific disruptive PV technology advancements occurring in the future. These disruptive technology advancements include improvements across various technologies and material types, at the component level up through large scale manufacturing processes, and across the different market applications. Again, the experts were asked to give estimates for different years (i.e., every 10 years from 2010 to 2050) and under the three funding scenarios. Table 10 provides a list of the specific disruptive technology advancements that the experts were asked to assess.

**Table 10. Disruptive PV Technology Advancements by Category.**

| | |
|---|---|
| **Silicon Modules** | 1) Kerfless wafering at about 1g/W achieving at least 20% of wafering industry's annual production |
| | 2) Upgraded metallurgical-grade (UMG) silicon (no Siemens or Fluidized Bed Reactor processing) provides greater than 20% of industry's annual cell manufacturing |
| | 3) ultrathin (≤100 μ) wafer thickness achieved in greater than 20% of annual wiresaw wafering production |
| **Thin Films** | 1) Greater than 15% thin film module efficiency in unconcentrated, terrestrial commercial modules |
| | 2) Flexible modules make up more than 20% of annual market |
| | 3) Organic PV modules make up more than 20% of annual market |
| | 4) Copper indium gallium selenide (CIGS) modules make up more than 20% of annual market |
| **Other Module Advancements** | 1) Use of III-V devices in non-tracking modules to achieve commercial modules with greater than 25% efficiency at a competitive cost |
| | 2) Multi-exciton photogeneration or intermediate band structure devices sold in a commercial terrestrial PV product |
| | 3) Commercial concentrating photovoltaic (CPV) modules at greater than 30% efficiency |
| | |
| **Inverters and Systems** | 1) Economical 30-year warrantee available on greater than 20% annual inverter market |
| | 2) Alternating-current PV modules (microinverters) achieve at least a 20% annual market share of residential rooftop installations |
| | 3) 20% of new inverter installations employ time-of-use pricing operation |
| | 4) 20% of grid tied systems incorporating energy storage functionality (i.e., battery or plug-in hybrid electric vehicle) |
| **Installations** | 1) Physical installation of building-integrated PV shingle by non-PV-trained roofer achieves greater than 20% of annual residential installations |
| | 2) Commercial roofing PV membrane makes up more than 20% of annual commercial rooftop installations |
| | 3) Highly automated ground installations (~1 MW/year/installer) |
| | 4) Concentrating PV (>100x concentration) achieves 20% of annual ground mount installations (green) |

The following graphs present the aggregated results of the disruptive technology advancements analysis in the form of the average likelihood of achieving the advancement by a given time period and funding level. In the graphs, the solid line represents no DOE funding for the variable being measured. The thicker dotted line represents the planned DOE funding scenario, and the thinner dotted line signifies the expanded funding scenario. One of the keys here is to gauge how large the gap is between lines of the same color, as this allows one to understand how experts perceive different funding levels impact the likelihood of realizing specific disruptive technology advancements.

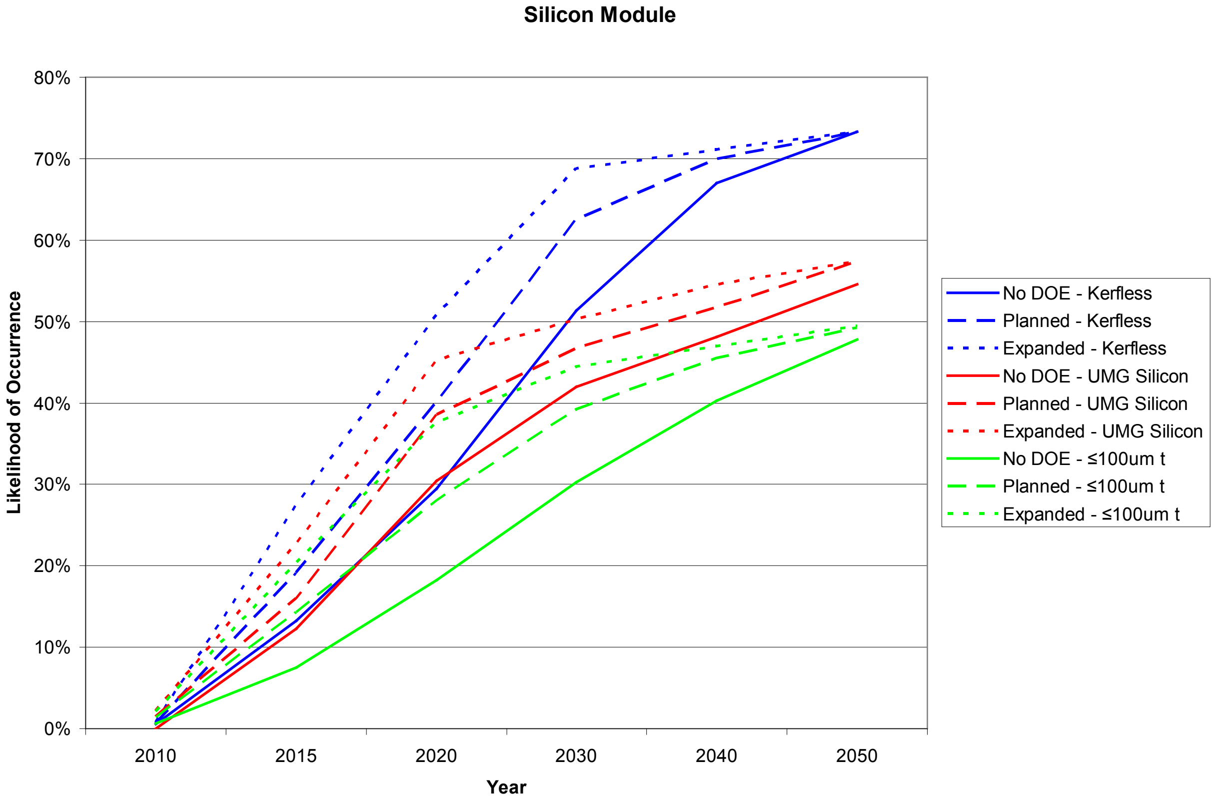



**Figure 2.6. Disruptive advancements for silicon modules**

Figure 2.6 refers to experts' predictions of disruptive advancements for the following three characteristics related to silicon modules: 1) Kerfless wafering at about 1gram per Watt (g/W) achieving at least 20% of the wafering industry's annual production (blue lines), 2) UMG silicon (no Siemens or FBR processing) provides greater than 20% of the industry's annual cell manufacturing (red lines), and 3) ultrathin (≤100um) wafer thickness is achieved in greater than 20% of the annual wiresaw wafering production (green lines).

Experts are more confident that Kerfless wafering improvements will be realized by 2050, when compared to the other two module characteristics. Furthermore, they predict that all of the module traits will have a greater chance of occurring at an earlier time under expanded funding. However, although the federal R&D budget is expected to have a more substantial impact on the acceleration of achieving these traits, the likelihood of occurrence does not break 80%, even in 2050.

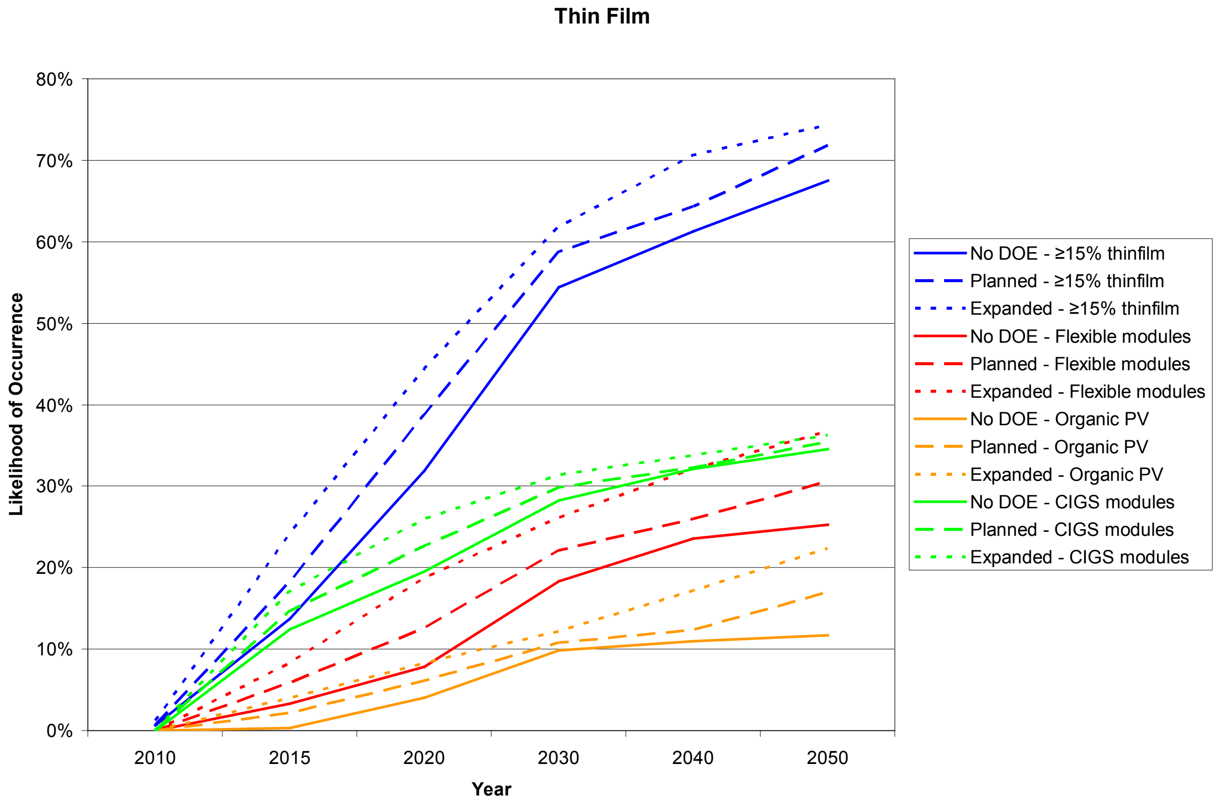



**Figure 2.7. Disruptive advancements for thin film technologies**

Figure 2.7 refers to experts' predictions of disruptive advancements for the following four characteristics related to thin films: 1) Greater than 15% thin film module efficiency in unconcentrated, terrestrial commercial modules (blue), 2) Flexible modules make up more than 20% of the annual market (red), 3) Organic PV modules make up more than 20% of the annual market (orange), and 4) CIGS modules make up more than 20% of the annual market (greens).

Experts believe thin film efficiency of at least 15% is most likely to occur out of the four characteristics, even without DOE funding. The flexible modules' market share will benefit noticeably throughout the timeframe when comparing the no-DOE funding to the DOE-planned and -expanded funding scenarios. Nonetheless, the experts believe that the ability of flexible modules, CIGS, and organics to achieve at least a 20% market share is unlikely to occur by 2050 under any of the funding scenarios.

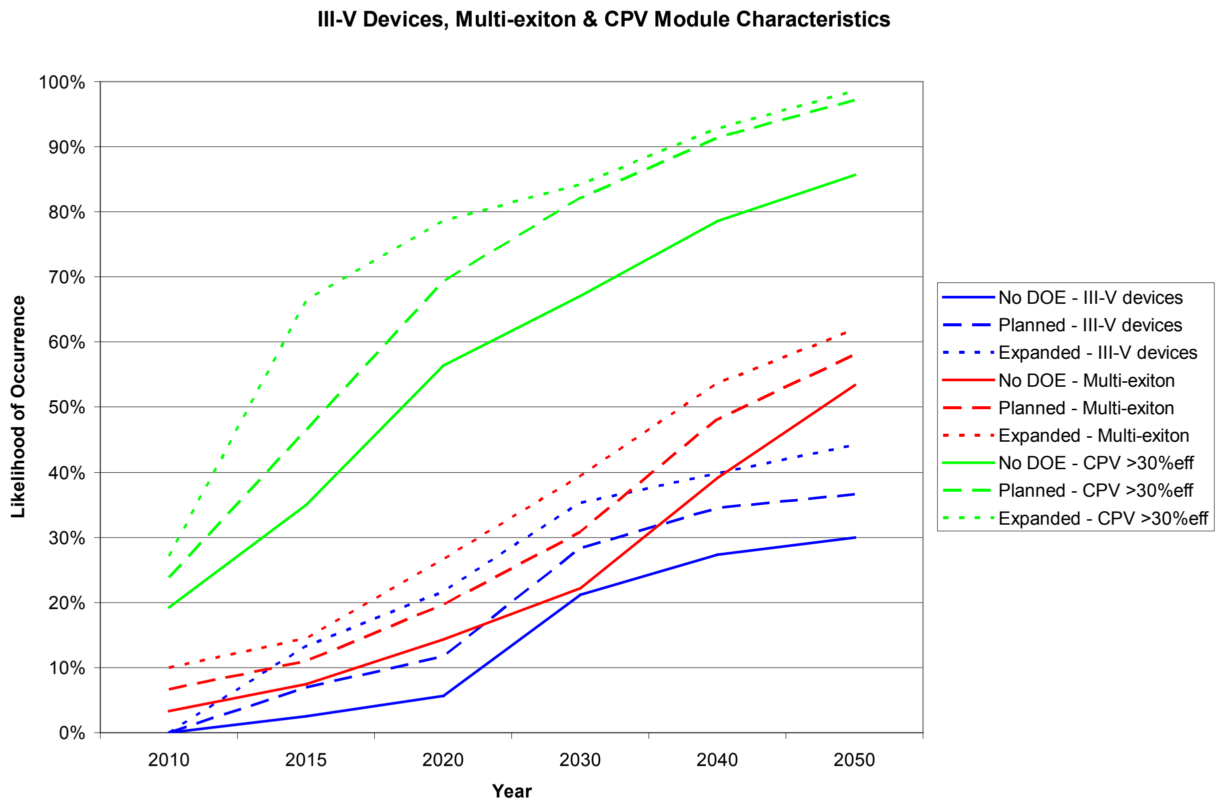



**Figure 2.8. Disruptive advancements for modules**

Figure 2.8 represents expert predictions of disruptive advancements for the following four characteristics related to modules: 1) Use of III-V devices in non-tracking modules to achieve commercial modules of at least 25% efficiency at competitive cost (blue), 2) Multi-exciton photogeneration or intermediate band structure devices sold in a commercial terrestrial PV product (red), and 3) Commercial CPV modules with greater than 30% efficiency (green).

The results suggest that the experts are very optimistic of commercially available CPV modules at greater than 30% efficiency, with a virtual certainty of occurrence by 2050 under planned DOE funding. However, experts are much less sure of technology advancements occurring in the III-IV and multi-exciton or intermediate band structure devices.

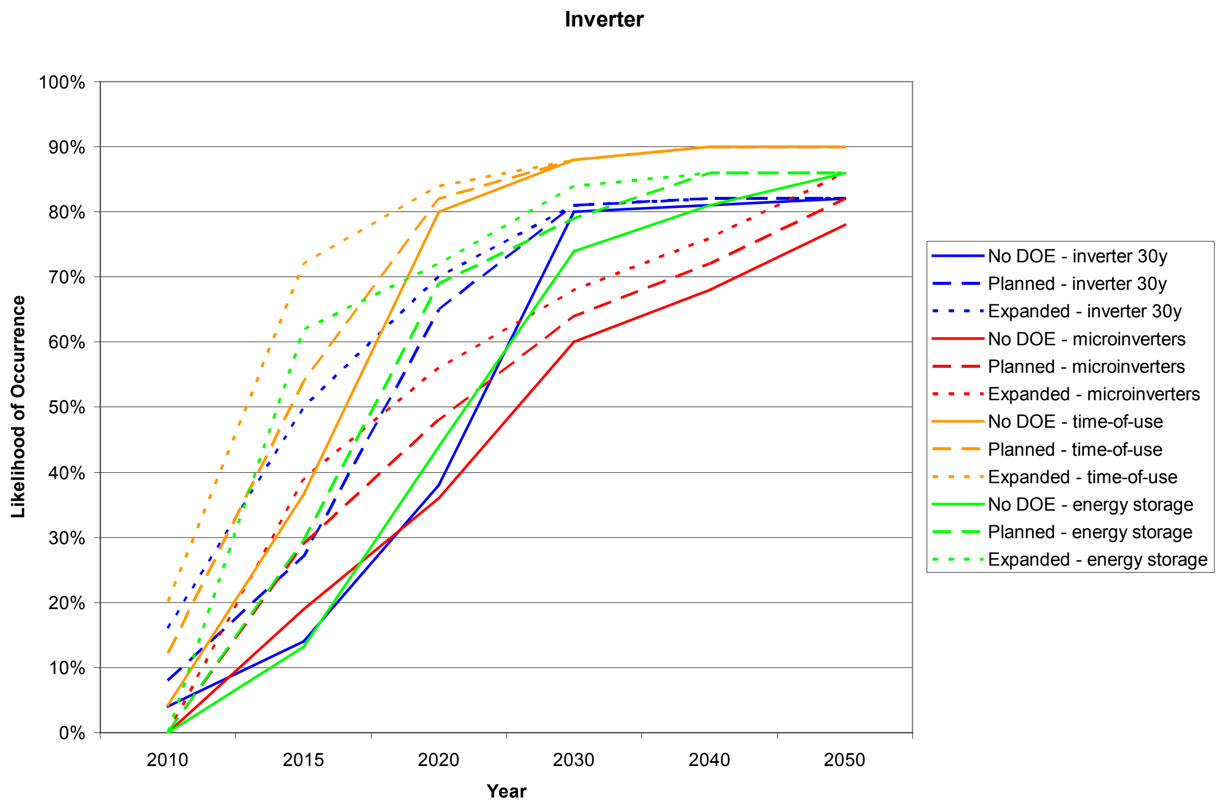



**Figure 2.9. Disruptive advancements for inverters/systems**

Figure 2.9 represents expert predictions of disruptive advancements for the following four characteristics related to inverters/systems: 1) Economical 30-year warrantee available for more than 20% of the annual inverter market (blue), 2) Alternating-current (AC) PV modules (microinverters) achieve at least a 20% annual market share of residential rooftop installations (red), 3) 20% of new inverter installations employ time-of-use pricing operation (orange), and 4) 20% of grid tied systems incorporating energy storage functionality (i.e., battery or PHEV) (green).

Experts are confident that all of these disruptive advancements will occur by 2050 even without DOE funding. Nonetheless, the impact of DOE funding is seen by advancing the timeframe that these advancements are expected to occur by 5 to 15 years in certain cases. Furthermore, the experts foresee DOE funding having the greatest impact, in terms of overall likelihood, on time-of-use inverters. In a similar light, they see DOE funding having the greatest impact, in terms of timing acceleration, on energy storage technology advancements.

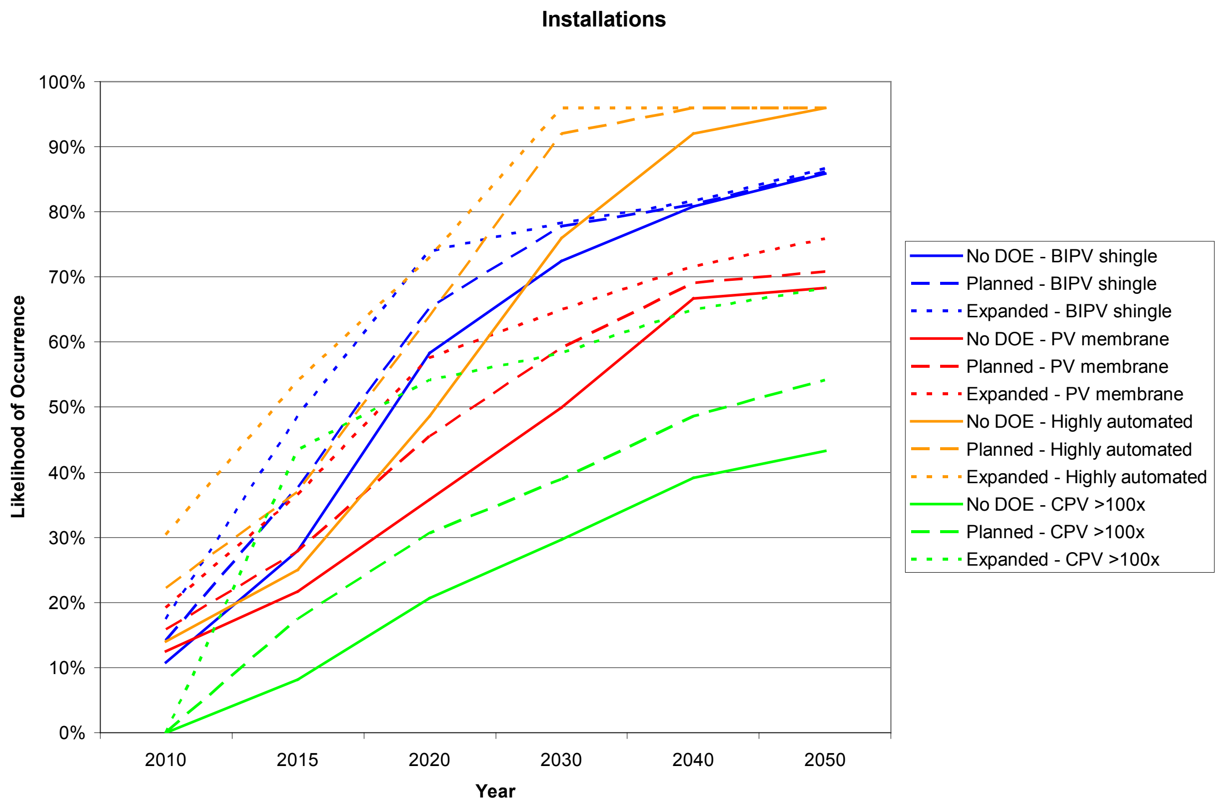



**Figure 2.10. Disruptive advancements for installations**

Figure 2.10 displays expert predictions of disruptive advancements for the following four characteristics related to installations: 1) Physical installation of BIPV shingle by non-PV-trained roofer achieves greater than 20% of annual residential installations (blue), 2) Commercial Roofing PV membrane makes up more than 20% of annual commercial rooftop installations (red), 3) Highly automated ground installations (~1 MW/year/installer) (orange), and 4) CPV (>100x concentration) achieves 20% of annual ground mount installations (green).

The opinion gauged from expert input is that highly automated ground installations will be a common feature of the industry by 2020. More specifically, they assume close to 100% likelihood that it will make up 20% of annual residential installations by 2030, when DOE planned or expanded funding is provided.

In terms of large scale CPV deployment achieving a substantial portion of the ground-mounted market, experts believe that while DOE funding can significantly improve the likelihood of this occurring, overall they are not confident this will happen (i.e., less than a 70% chance by 2050).

# 3 Program Findings on Effectiveness of Methodology

## 3.1 Experts' Responses—Questions/Issues

Out of 48 CSP experts contacted, only 8 provided inputs, resulting in a participation rate of about 15%. On the PV side, 45 experts were contacted and 13 provided inputs, for a higher participation rate of about 30%. It should be noted that some of the PV experts provided inputs for more than one capacity category (i.e., utility, commercial, and residential). Although several steps were taken to garner inputs from a multitude of individuals, the analysis could likely benefit from increased participation, particularly for some of the TPMs or technologies that garnered very little input. For PV, most experts gave inputs on the module and system costs, but very few addressed the inverter costs and lifetime. On the CSP analysis, there were a number of inputs for the trough technology, but fewer for towers and almost no responses for dish-engines. A more focused effort to recruit experts in these areas and increase participation (e.g., offering payment, stipends, or travel expenses) could be useful to augment the results of this analysis.

## 3.2 Experts' Understanding of Instructions

The 2008 analysis provided insight for better explanations of the process and instructions for filling out the forms provided to technical experts. For 2009, separate CSP and PV webinars were utilized by the risk analysts and facilitators to introduce the concepts and methodology, and walk through an example of filling in a score sheet. This provided experts with additional confidence that they were properly inputting their projections. Moreover, a follow-up webinar was held, and when requested, individually scheduled appointments occurred. These support features were provided to enable better understanding of the instructions.

## 3.3 Reference Technology Values

Through lessons learned from the 2008 analysis, the CSP portion added tower and dish-engine technologies to the assessment. Although dish-engine expert participation was too low to allow for a statistically relevant analysis, participation levels for towers with storage were sufficient. The tower results provide greater breadth to the overall analysis, making it more applicable to current market conditions and also to the Program's R&D decision-making process. At the time of this analysis, a significant and important effort was simultaneously being performed in updating and revising the Sargent & Lundy CSP cost and technology forecast report. However, since this was not available to use, either as a basis for the current reference values or to supplement the cost and performance projections in the expert briefing, it is suggested that any future CSP risk analysis effort incorporate the Sargent & Lundy data, once completed.

In 2008's PV assessment, estimates were provided for crystalline silicon, thin film, and CPV. Each of these technology types has a different reference value, making it more difficult to compare results and evaluate the expected improvements. With this in mind, the 2009 investigation made PV more agnostic by starting with a current reference value defined by the dominant technologies in the market, but then letting experts predict cost decreases on the technology as a whole, while still prescribing the utility, commercial, and residential market breakdown.

### 3.4 Confidence in Results

The 2009 risk assessment is the second such analysis conducted by the Solar Program. Lessons learned from the 2008 assessment were implemented to improve confidence in the data provided. For example, additional time and effort was made to improve participation, resulting in greater breadth of technical knowledge. With respect to CSP, tower technology was added to the 2009 analysis. Furthermore, greater emphasis was placed on explaining the process of completing score sheets, helping to ensure experts were properly inputting their projections. With these changes instituted, the risk team is more confident that 2009 results paint a helpful picture of future technology costs. On the PV side, the lack of participation and estimates from enough experts on inverter costs and lifetime leads the risk team to not be confident in the results for these metrics, and to suggest future analyses focus more heavily on these areas.

# Appendix A: Concentrating Solar Power (Trough) Risk Analysis, Summary of @Risk Results—Fan Diagrams

The following figures include projections of future improvement between 2009 and 2025:

1) Baseline: The aggregated expert team risk distributions, shown for the 10%, 50%, and 90% scenarios, assuming no DOE R&D funding of the technology
2) DOE or Expanded:
   a) DOE planned—The first figure in each set shows the aggregated expert team risk distributions, shown for the 10%, 50%, and 90% scenarios, assuming the planned DOE R&D funding.
   b) DOE expanded—The second figure in each set shows the aggregated expert team risk distributions, shown for the 10%, 50%, and 90% scenarios, assuming expanded DOE R&D funding.

In some cases the following is provided:

1) Program goal—In some (but not all) figures, a point estimate trajectory of improvements formulated assuming that the Program achieves its goals (i.e., this information has typically been provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) programs in prior years, and is input into SEDS, NEMS, and MARKAL for market penetration modeling and program benefits calculations).

## A.1 CSP Trough—Solar Field Curves

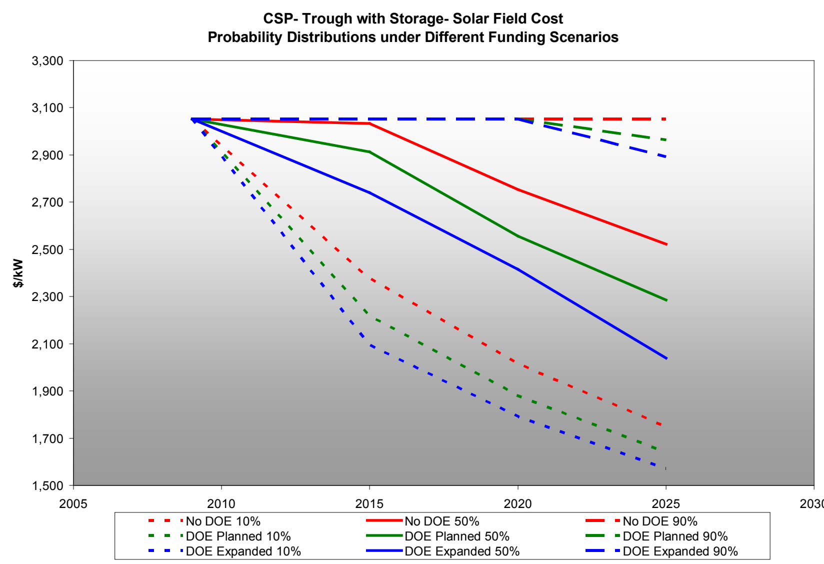



**Figure A1. Solar field cost-probability distributions for CSP trough with storage**

In Figure A1, the no DOE budget does not diverge greatly from the DOE Planned Budget, implying that experts believe noticeable solar field cost reductions will occur from industry activity alone. When expanding the budget, experts envisage an additional cost reduction of more than 10% in 2025 (based on the $50^{th}$ percentile) relative to the planned funding level (i.e., \$2285/kW to \$2038/kW).

## A.2 CSP Trough—Heat Transfer Fluid Curves

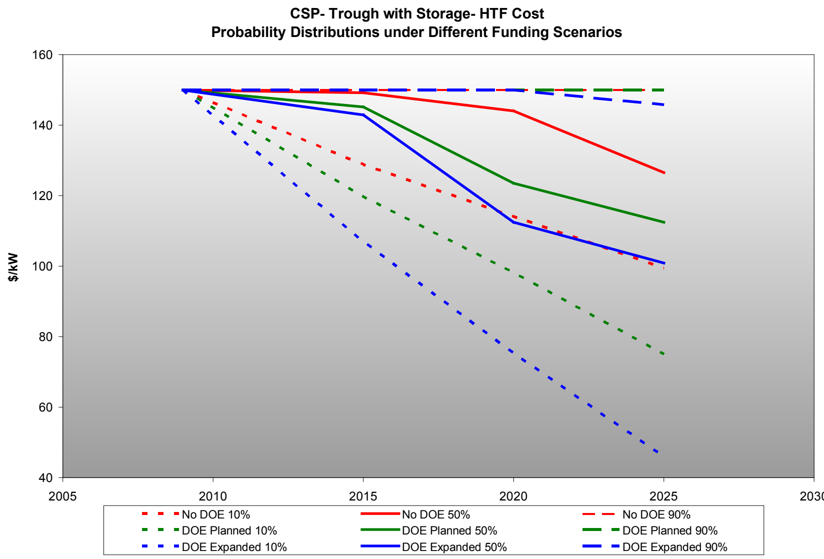



**Figure A2. Heat transfer fluid cost-probability distributions for CSP trough with storage**

Based on the 50th percentile planned and expanded funding scenarios in Figure A2, experts indicate that HTF cost reduction will be minimal between 2010 and 2015, become more prominent between 2015 and 2020, and then decelerate, but continue its downward trend between 2020 and 2025. The 10th percentile trajectories show that, though not certain to occur, even more significant improvements could be realized by 2025 with planned or expanded DOE funding levels (i.e., a reduction of nearly 70% from the 2009 reference value).

## A.3 CSP Trough—Thermal Energy Storage Curves

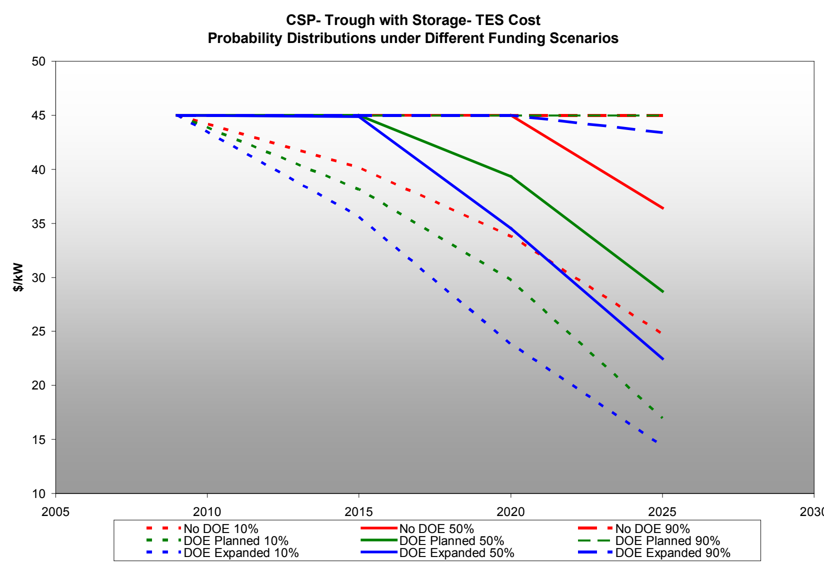



**Figure A3. Thermal energy storage—probability distributions for CSP trough with storage**

Based on Figure A3, the experts suggest almost no to very little cost reduction would occur under the no DOE budget case. However, the experts predict a substantial reduction in TES cost will occur due to R&D funding, with the greatest impact between 2020 and 2025 under planned DOE funding, and accelerated five years sooner with the expanded budget. By 2025, the difference between the no DOE and planned funding scenario is almost $8/kWht ($36.4/kWht to $28.7kWht based on the 50th percentile), with the expanded budget resulting in even greater reductions to $22.5/kWht, or ~40% below the no DOE funding scenario.

## A.4 CSP Trough—Power Block & Balance of System Curves

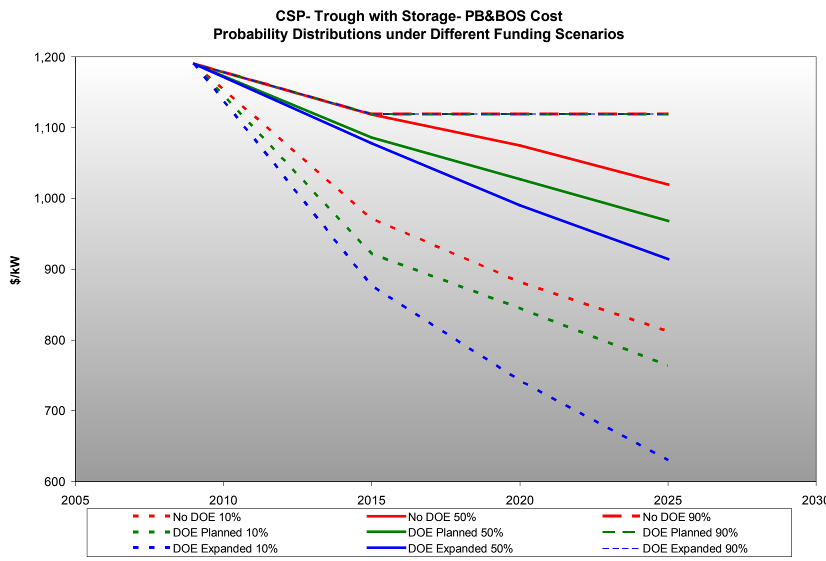



**Figure A4. Power block & balance of system—probability distributions for CSP trough with storage**

Figure A4 reveals the experts' viewpoint that very little PB&BOS improvements can occur without DOE funding (i.e., less than 10% at the 50th percentile). Furthermore, the planned and expanded funding levels will allow for only slightly greater cost reductions (i.e., 15% and 20%, respectively, at the 50th percentile).

## A.5 CSP Trough—Operations and Maintenance Curves

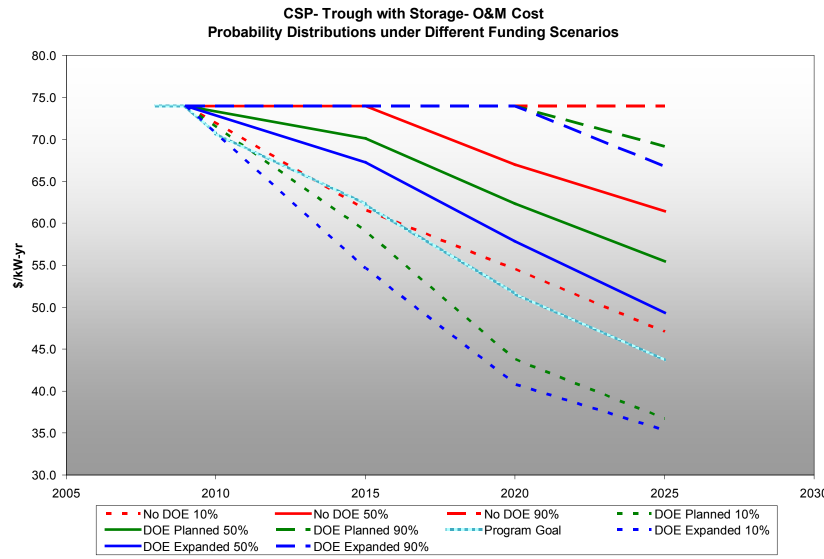



**Figure A5. O&M—Probability distributions for CSP trough with storage**

Although a noticeable O&M cost reduction is anticipated when viewing Figure A5, expert input reveals that the Program goal is an aggressive target. The experts suggest that there is only about a 20% chance that the 2015 and 2025 Program goals for O&M will be achieved under the DOE planned funding scenario. Under the expanded case, these percent likelihoods increase to 30% for both 2015 and 2025 (see appendix F for details).

# Appendix B: Concentrating Solar Power (Tower) Risk Analysis, Summary of @Risk Results—Fan Diagrams

The figures below include projections of future improvement between 2009 and 2025:

1) Baseline: The aggregated Expert Team risk distributions, shown for the 10%, 50%, and 90% scenarios, assuming no DOE R&D funding of the technology;
2) DOE or Expanded:
   a. DOE planned: The first figure in each set shows the aggregated Expert Team risk distributions, shown for the 10%, 50% and 90% scenarios, assuming the planned DOE R&D funding.
   b. DOE expanded- the second figure in each set shows the aggregated Expert Team risk distributions, shown for the 10%, 50% and 90% scenarios, assuming expanded DOE R&D funding.
3) Program goal: In some (but not all) figures, a point estimate trajectory of improvements formulated assuming that the Program achieves its goals (i.e., this information has typically been provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) programs in prior years, and is input into SEDS, NEMS, and MARKAL for market penetration modeling and program benefits calculations).

## B.1 CSP Tower—Solar Field Curves

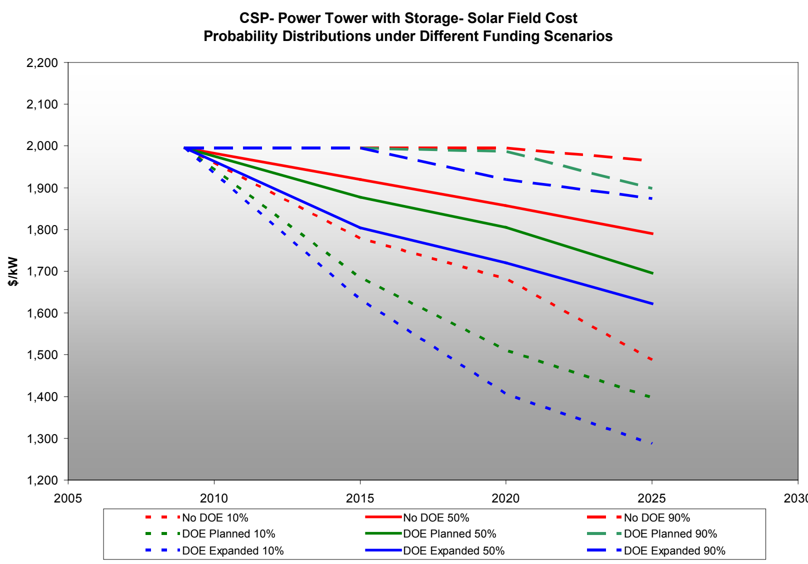



**Figure B1. Solar field cost-probability distributions for CSP tower with storage**

The 50th percentile slopes representing tower solar field cost are not overly steep, indicating a gradual decline in cost out to 2025. Under the planned DOE budget, experts foresee at least a 50% chance of reducing the cost below $1,700/kW and a 10% chance of reaching $1500/kW. Additional improvements with an expanded budget can be shown in two ways: 1) the increased likelihood of achieving those same costs (i.e., 63% and 38%, respectively), or 2) the additional cost reductions at the same probability levels (i.e. $1623/kW and $1287/kW, respectively).

## B.2 CSP Tower—Receiver Curves

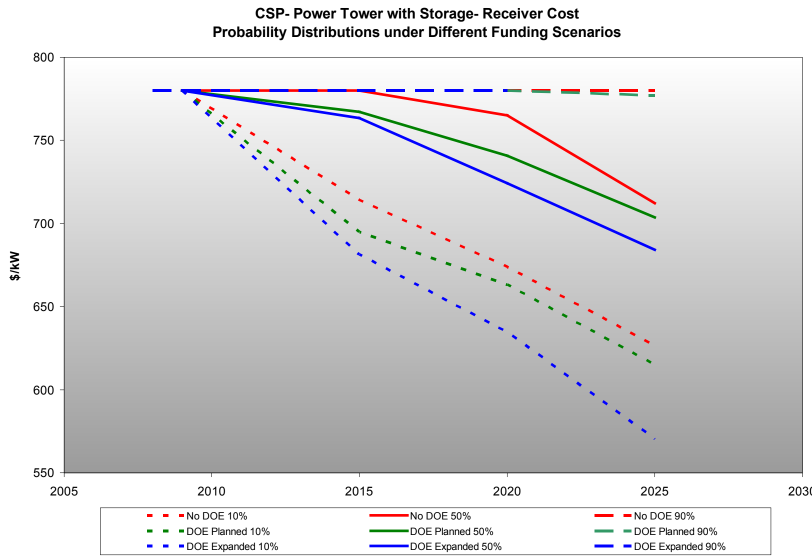



**Figure B2. Receiver cost-probability distributions for CSP tower with storage**

Although a lower receiver cost is believed to be achievable in 2015 and 2020 when comparing the 50th percentile planned budget and no budget scenarios, by 2025 the two scenarios will result in roughly the same cost (~700$/kW). On the other hand, an expanded budget is expected to have a bigger impact on lowering receiver costs throughout the timeframe of this analysis.

## B.3 CSP Tower—Thermal Energy Storage Curves

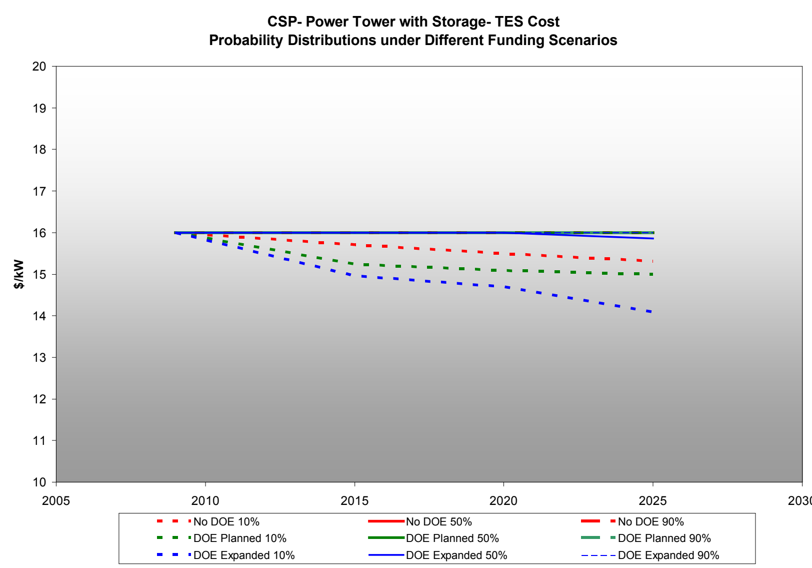



**Figure B3. Thermal energy storage-probability distributions for CSP tower with storage**

Experts are not under the impression that tower thermal energy storage costs will decrease much over time, as signified by the relatively flat 50$^{th}$ percentile lines.  This seems to be the case even with an expanded budget.

## B.4 CSP Tower—Power Block & Balance of System Curves

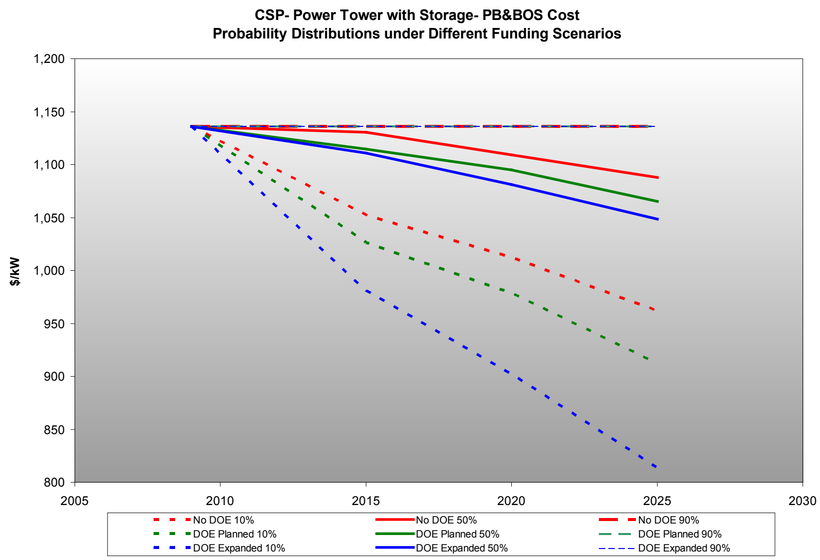



**Figure B4.  Power block & balance of system-probability distributions for CSP tower with storage**

The tower PB&BOS no funding and planned funding cases do not differ much when viewing the 50$^{th}$ percentile inputs.  This is also the case when comparing the planned and expanded cases. Cost reductions for the three funding scenarios are modest, except when considering the 10$^{th}$ percentile.  In other words, experts believe there is a relatively low likelihood that PB&BOS costs will decrease substantially throughout the timeframe.

## B.5 CSP Tower—Operations & Maintenance Curves

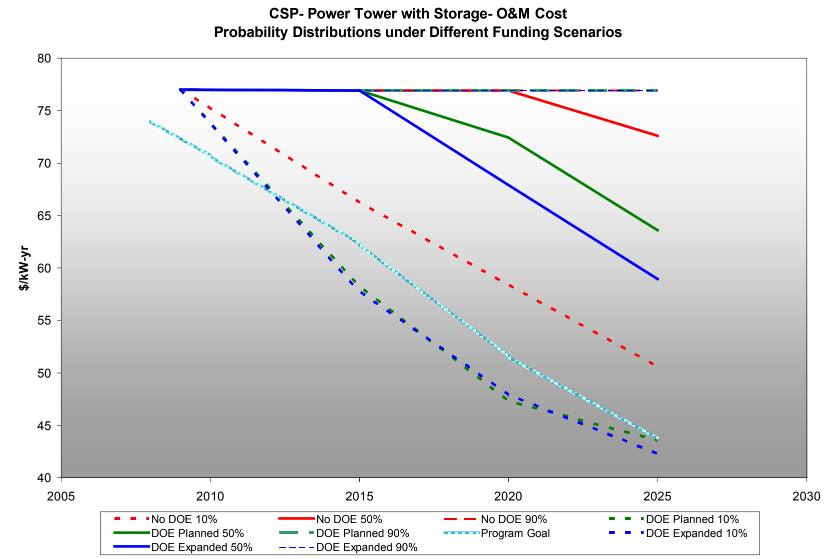



**Figure B5. O&M-probability distributions for CSP tower with storage**

The results of the expert elicitation suggest that the Program's O&M goal is very aggressive, as the goal trajectory (light blue line) falls around the 10-20% probability levels from 2015-2025.

# Appendix C: Photovoltaic (PV) Risk Analysis, Summary of @Risk Results—Fan Diagrams

1) The figures below include projections of future improvement between 2009 and 2020:
2) Baseline: The aggregated Expert Team risk distributions, shown for the 10%, 50%, and 90% scenarios, assuming no DOE R&D funding of the technology;
3) DOE or Expanded-
    a. DOE planned – The first figure in each set shows the aggregated Expert Team risk distributions, shown for the 10%, 50%, and 90% scenarios, assuming the planned DOE R&D funding;
    b. Expanded – The second figure in each set shows the aggregated Expert Team risk distributions, shown for the 10%, 50%, and 90% scenarios, assuming expanded DOE R&D funding.

In some cases the following is provided:

4. Program goal: In some (but not all) figures, a point estimate trajectory of improvements formulated assuming that the Program achieves its goals (i.e., this information has typically been provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) programs in prior years, and is input into SEDS, NEMS, and MARKAL for market penetration modeling and program benefits calculations).

## C.1 Photovoltaic—Inverter Lifetime Curves

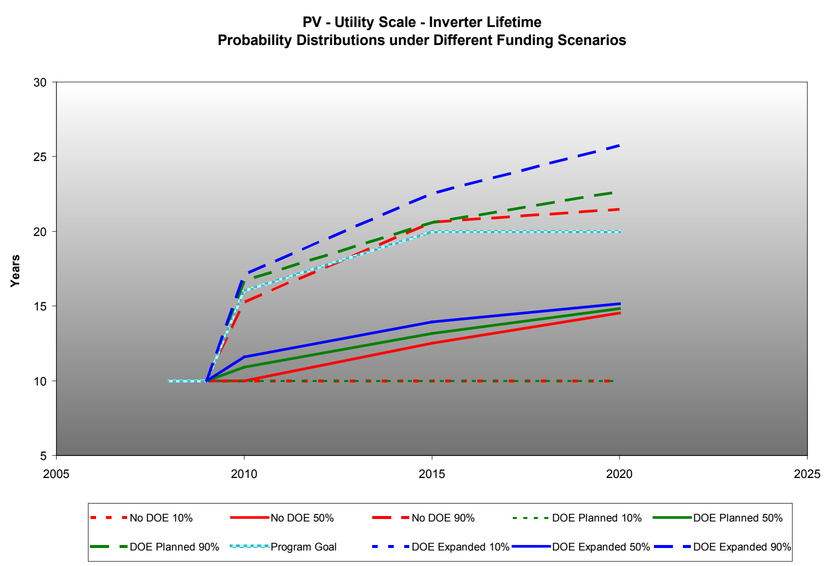



**Figure C1. Inverter lifetime-probability distributions for PV utility**

Figure C1 shows that technology experts believe improvements in utility scale inverter lifetime have a low probability of achieving or exceeding the Program goal value of 20 years by 2020 (i.e., 15% chance with no DOE funding, 20% chance with planned DOE funding, and a 33% chance with expanded DOE funding). Another noticeable trend is that only minor improvements are anticipated over time between the three funding scenarios, as the experts noted little DOE R&D activities in this area.

Furthermore, for all of the aggregated 10th percentile cases, the inverter lifetimes are held constant at the current (2009) reference value of 10 years. This is partly because in some cases the experts actually provided distributions that resulted in a decrease in inverter lifetime from the current reference case. For the 2009 Solar Risk Assessment, the @Risk model was designed to truncate a "negative improvement or "worst case" and refer to the current reference value when aggregating all expert distributions, unless a specific reason for a performance decrease or cost increase was cited by the expert (i.e., R&D funding should not result in a worse technology over time, unless tradeoffs between metrics, such as a lower lifetime to achieve a much lower costs are considered).

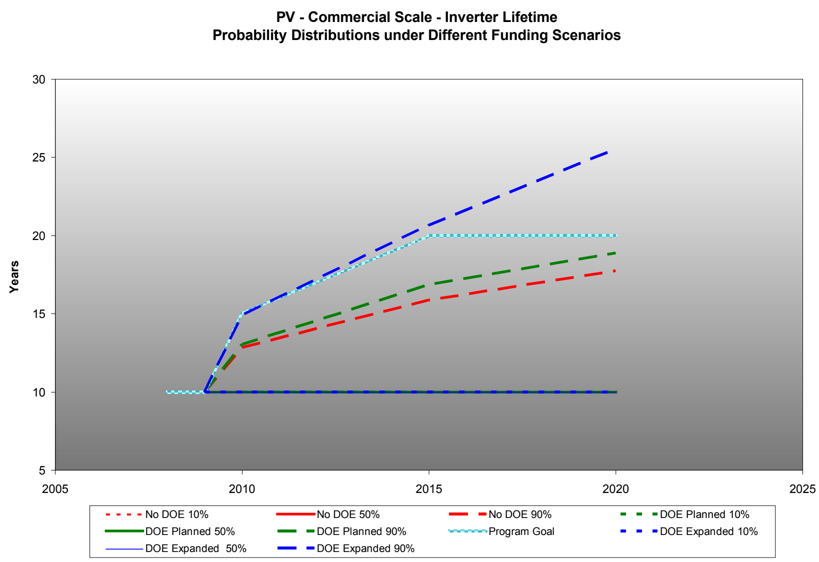



**Figure C2. Inverter lifetime-probability distributions for PV commercial**

As shown in Figure C2, again the experts suggest that the Program goals for commercial scale inverter lifetime are very aggressive (i.e., 2% chance with no DOE funding, 5% chance with planned DOE funding, and a 28% chance with expanded DOE funding). Additionally, only minor improvements are anticipated over time between the no DOE case and the DOE planned case, again reflecting the lack of a large dedicated DOE R&D program focused on inverters. As in the Utility scale analysis, the 10th percentile distributions for inverter lifetimes are held constant at ten years under the three funding conditions. Similar trends can be seen in the Residential Scale inverter lifetime analysis in Figure C3.

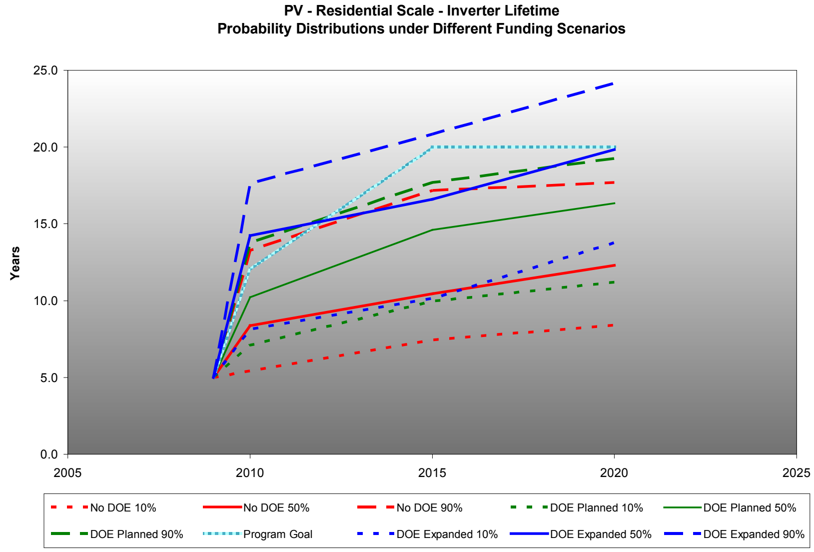



**Figure C3. Inverter lifetime-probability distributions for PV residential**

## C.2 Photovoltaic—Inverter Replacement Cost Curves

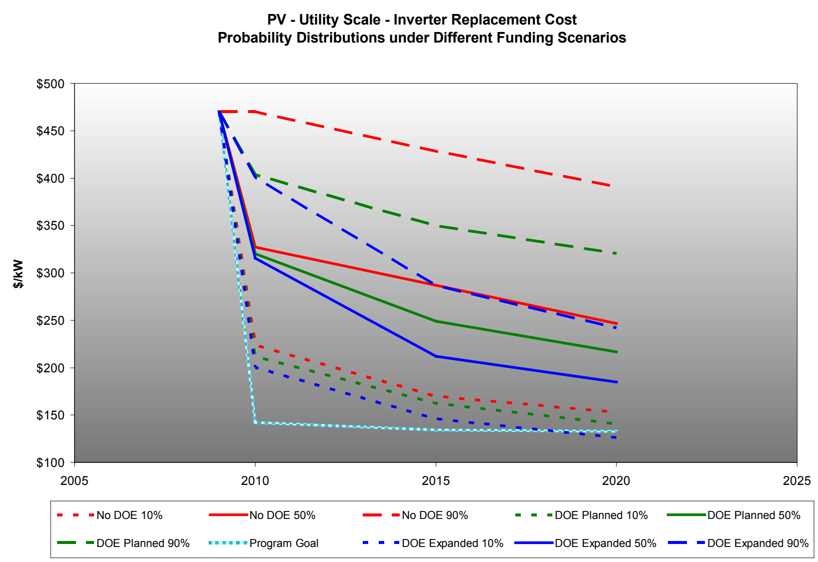



**Figure C4. Inverter replacement cost-probability distributions for PV utility**

Figure C4 expresses utility scale PV inverter replacement costs decreasing as funding levels are increased and over time. Even though expanded funding should allow for deeper cost reductions, it will unlikely be enough to achieve the 2015 or 2020 Program goals. Similar trends can be seen in Figure C5 for commercial scale PV inverter replacement costs.

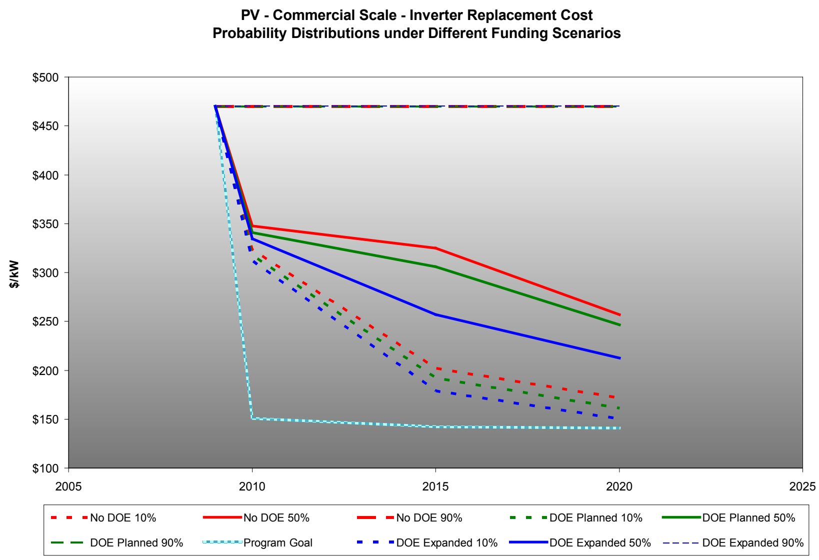



**Figure C5. Inverter replacement cost-probability distributions for PV commercial**

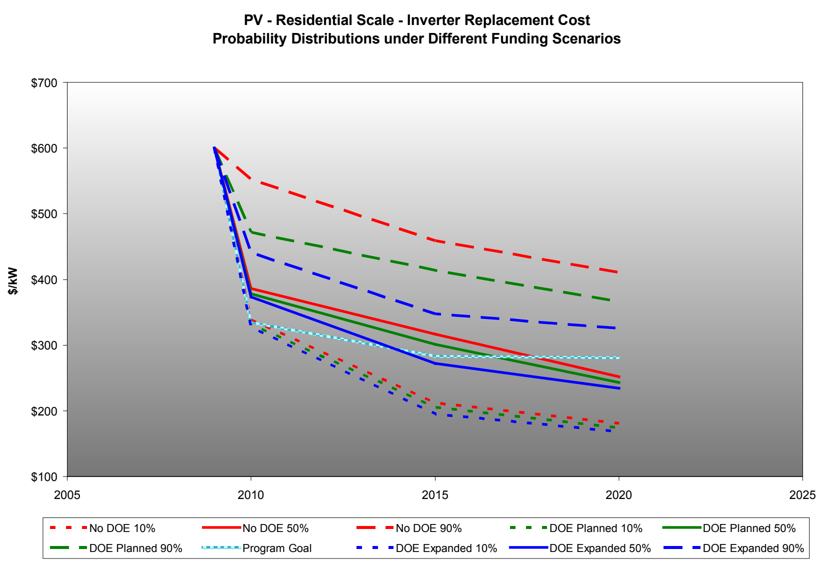



**Figure C6. Inverter replacement cost-probability distributions for PV residential**

Figure C6 exhibits a gradual reduction in residential inverter replacement costs through time. Expanded funding does not show a noticeable difference when compared to the no DOE funding scenario, and while all three funding cases are more than likely to exceed the 2020 Program goal value, only the expanded DOE funding case has a greater than 50% chance of exceeding the 2015 Program goal value.

## C.3 Photovoltaic—Module Cost Curves

Figures C7 through C9, representing utility, commercial and residential module cost distributions, respectively, show noticeable cost reductions through time, and as funding levels are increased. One interesting note is that module costs for all three market sectors are forecast to be quite similar by 2020, suggesting the higher margins in the residential and commercial sectors will start to come more in line with the utility sector.

Though no specific Program goal trajectory is plotted on these graphs, since these trajectories are forecast at the system level and not for modules, an oft cited target for modules is $1/W (i.e., $1000/kW). As can be seen in the Figures C7 through C9, the likelihoods of module costs hitting this target are:

1) Utility market- 17% with no DOE funding, 33% with planned DOE funding and 53% with expanded DOE funding;
2) Commercial market- 17% with no DOE funding, 28% with planned DOE funding and 47% with expanded DOE funding; and
3) Residential market- 12% with no DOE funding, 19% with planned DOE funding and 40% with expanded DOE funding.

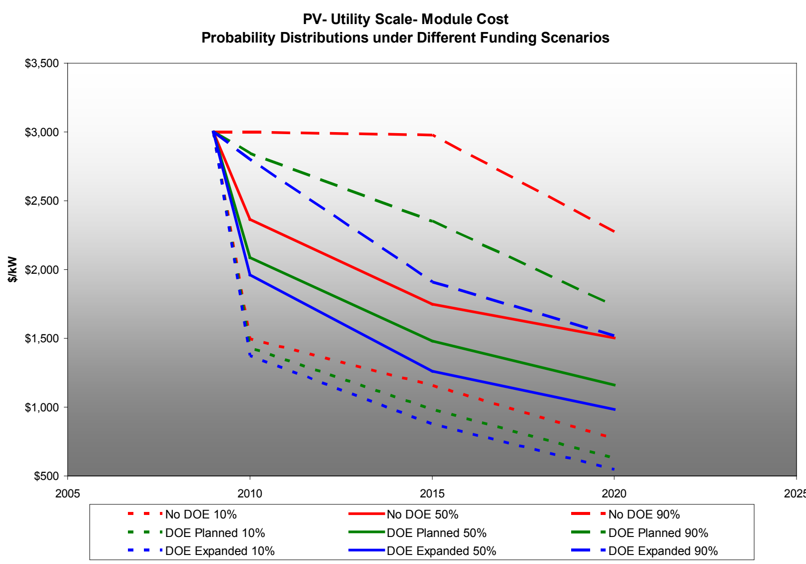



**Figure C7. Module cost-probability distributions for PV utility**

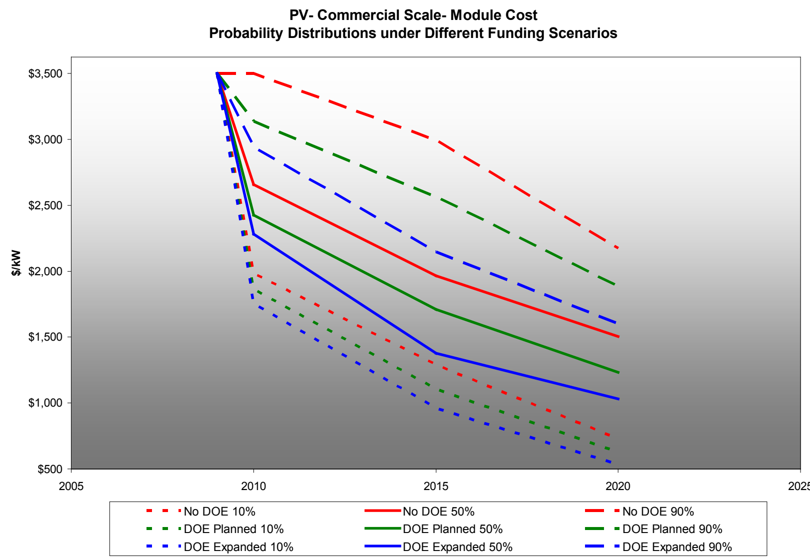



**Figure C8. Module Cost-Probability Distributions for PV Commercial**

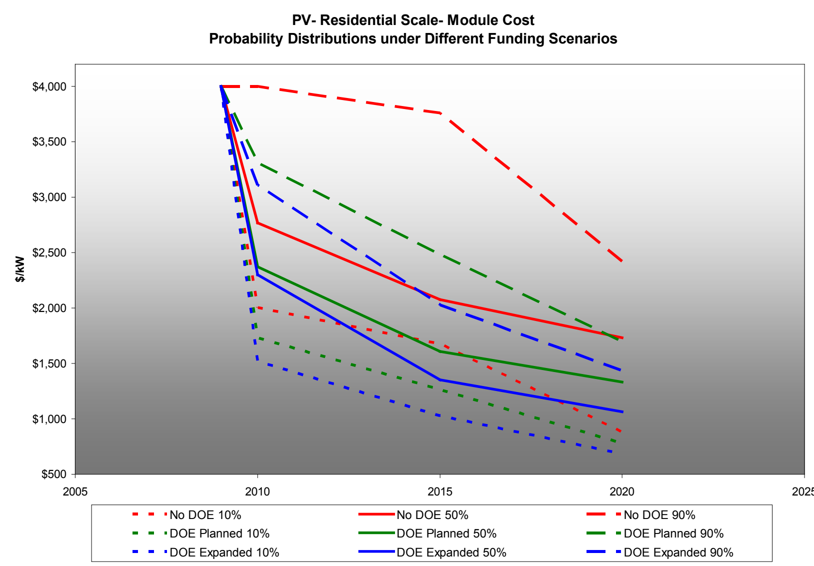



**Figure C9. Module cost-probability distributions for PV residential**

## C.4 Photovoltaic—Operations and Maintenance Cost Curves

Figures C10 through C12 illustrate that significant reductions in PV O&M costs are likely for the Utility, Commercial, and Residential market sectors. However, without DOE funding, the 2015 and 2020 Program goals have a low probability of success. Furthermore, experts do not foresee substantial differences in O&M cost when going from planned to expanded DOE funding levels, indicating that expanded budget activities focusing on O&M improvements might not provide an optimal return on investment.

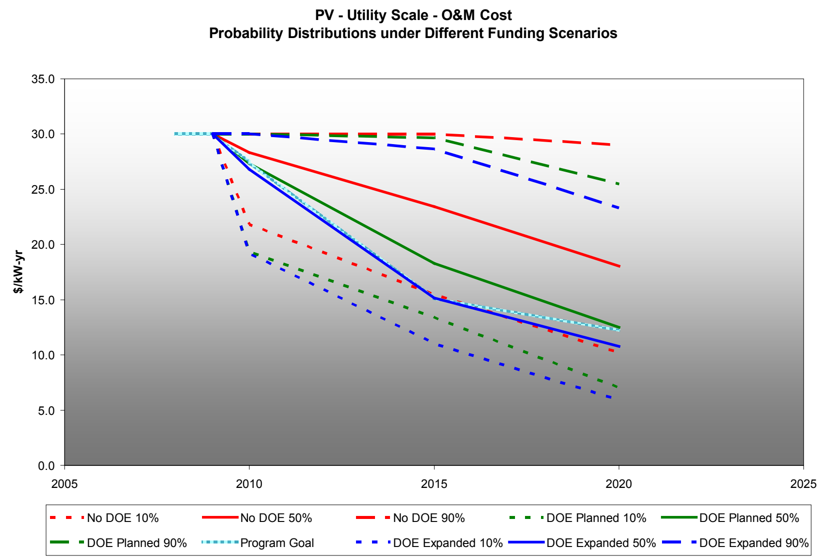



**Figure C10. O&M cost-probability distributions for PV utility**

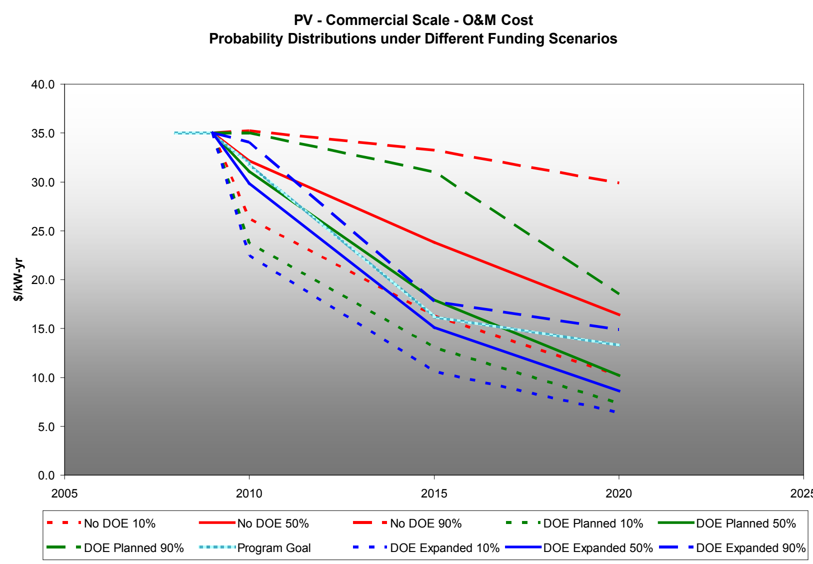



**Figure C11. O&M cost-probability distributions for PV commercial**

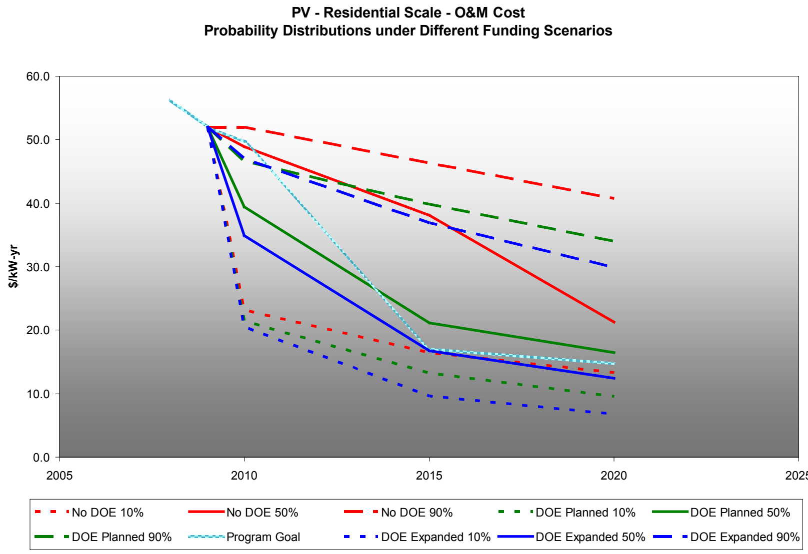



**Figure C12. O&M cost-probability distributions for PV residential**

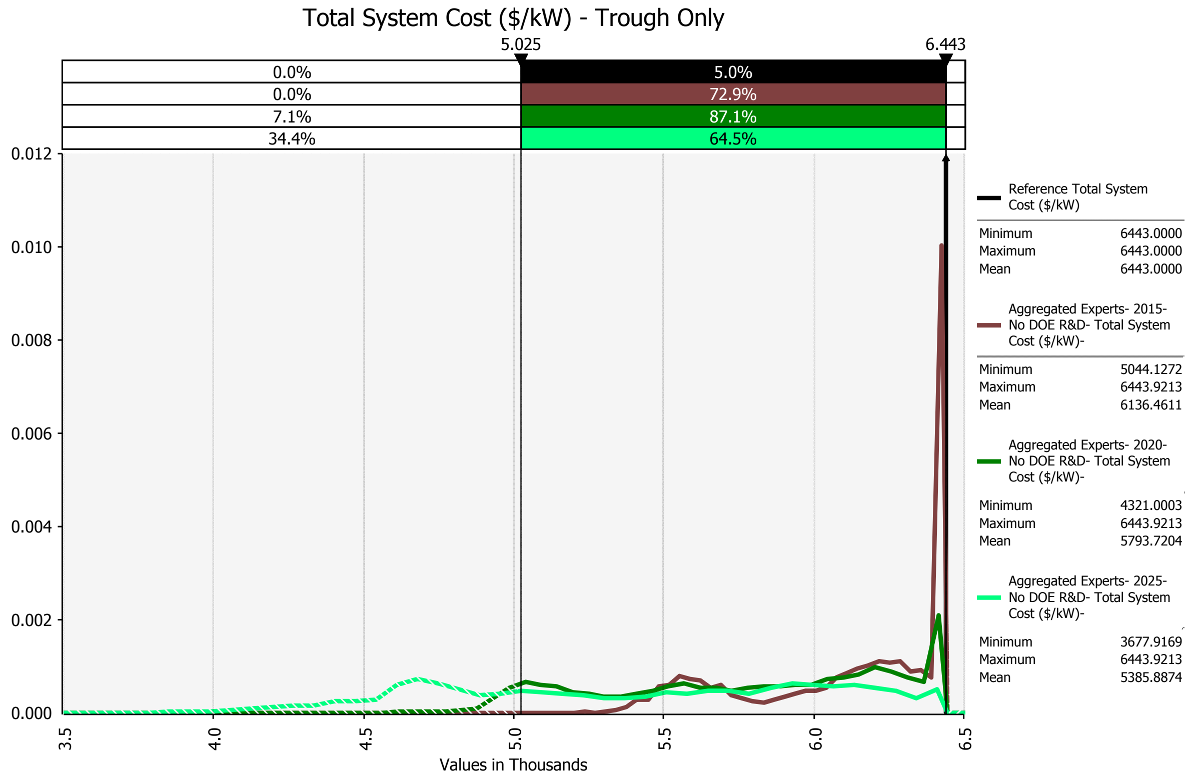
# Appendix D: Concentrating Solar Power (CSP) Risk Analysis, Summary of @Risk Results—Aggregated Probability Distributions

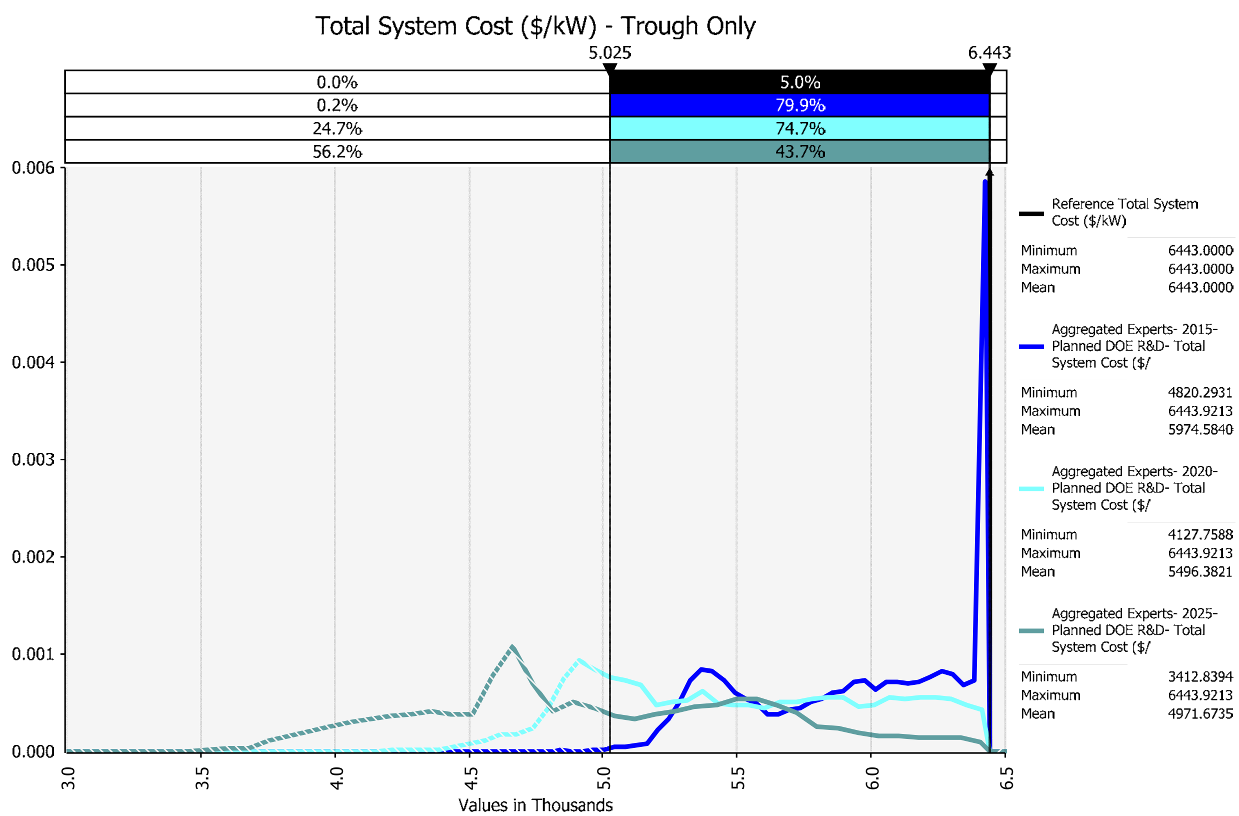
## D.1 Technical Risk and Uncertainty Analysis—Solar Utility CSP Trough

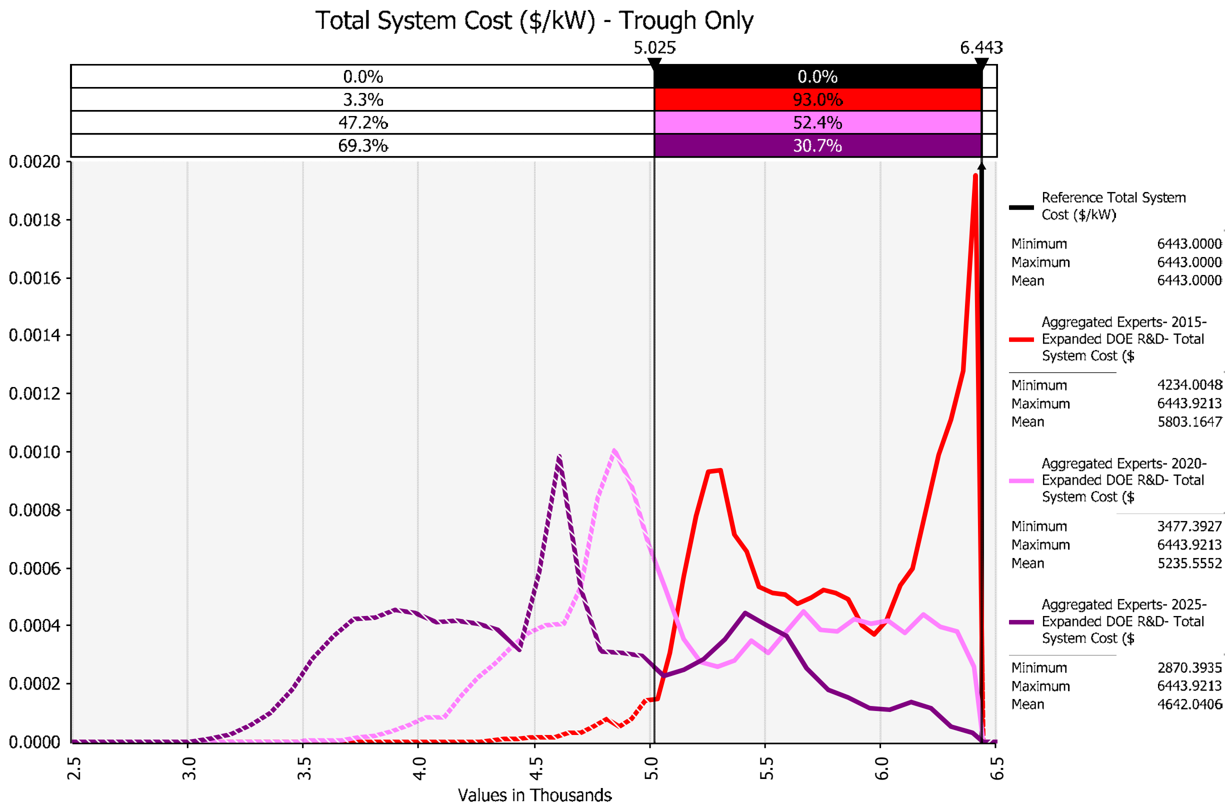
The following figures represent the aggregated total system costs provided by the experts in the three budget scenarios for CSP Utility - Trough with Storage ($0, $30M, and $60M).

The three colored lines in each of these graphs represent the aggregated expert inputs for the three time periods for CSP Utility—Trough with Storage (2015, 2020, and 2025). In each of the graphs, the 2009 reference values are represented by the black line on the right of the graphs, and the FY10 GPRA Program goal-based input value for 2015 is represented by the delimiter (i.e., thin black vertical lines) on the left of each graph. The percentages to the left side of the delimiter represent the likelihood of at least achieving the "goal-based" value. The percentages between the delimiters represent the likelihood of improving to somewhere between the "goal-based" value and reference value. Furthermore, the key to the right of each graph also lists the minimum, maximum, and mean for each aggregated distribution.

## *Total System Cost-by Funding Level*

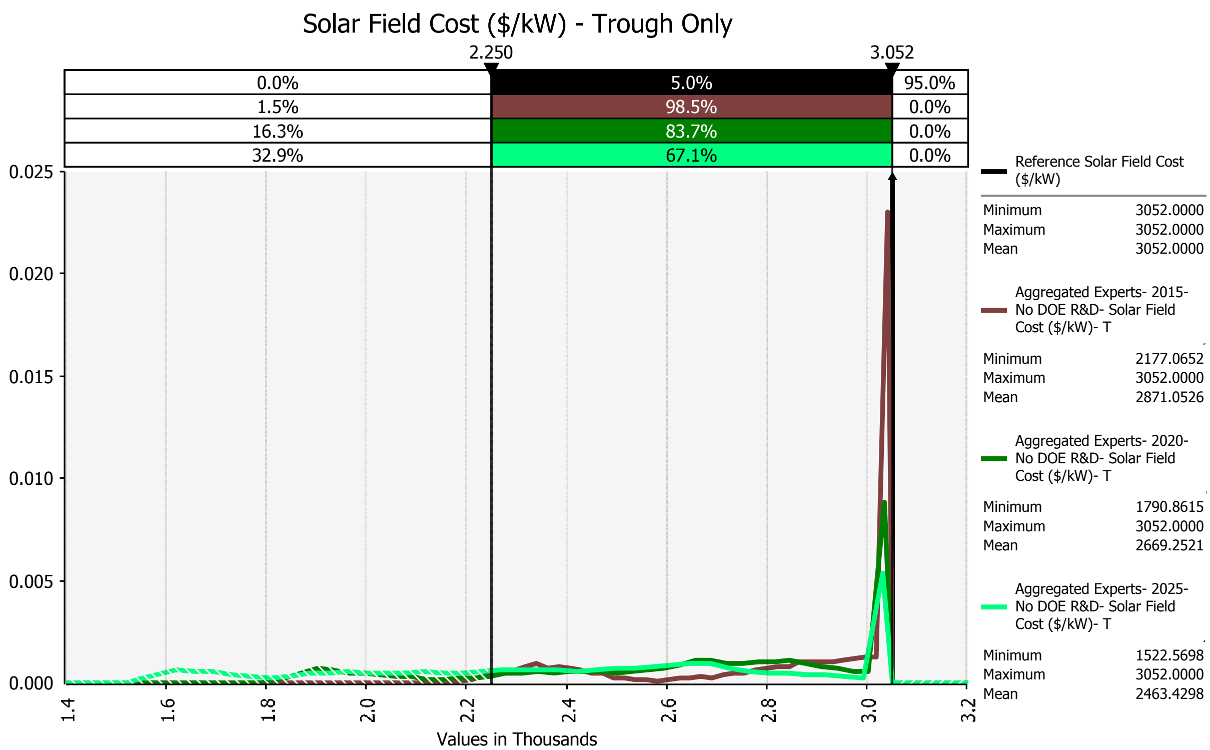


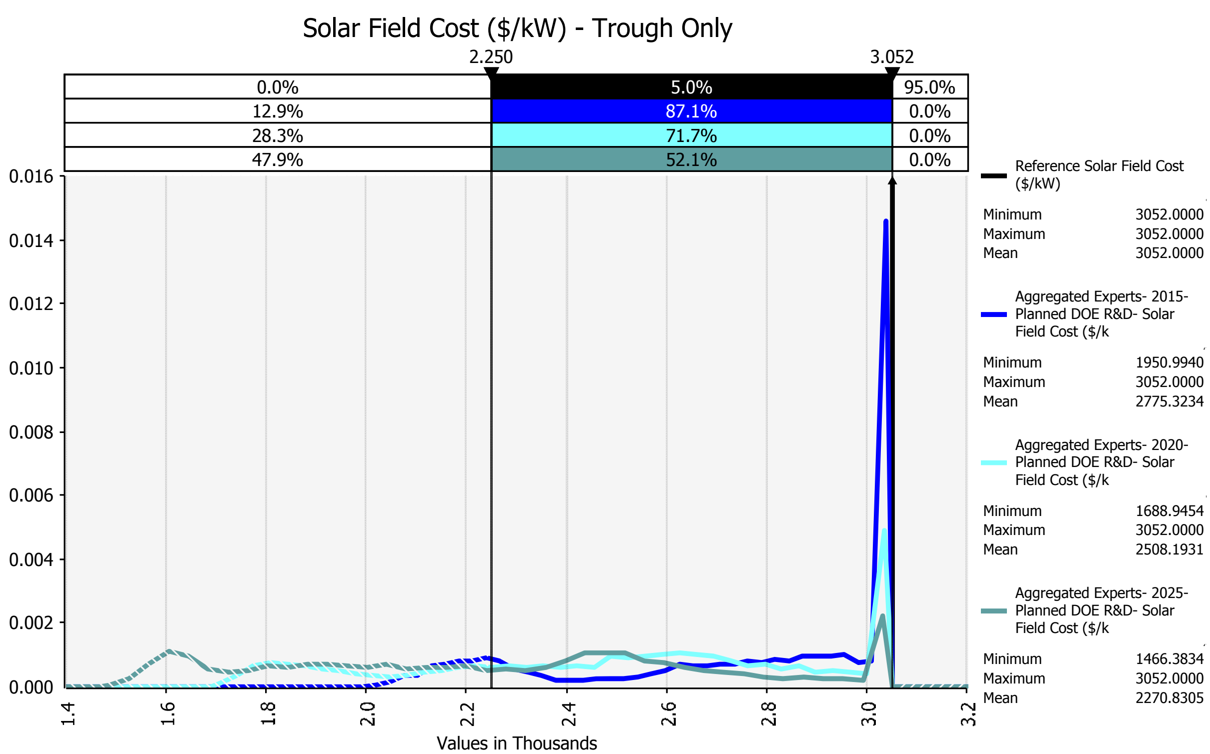



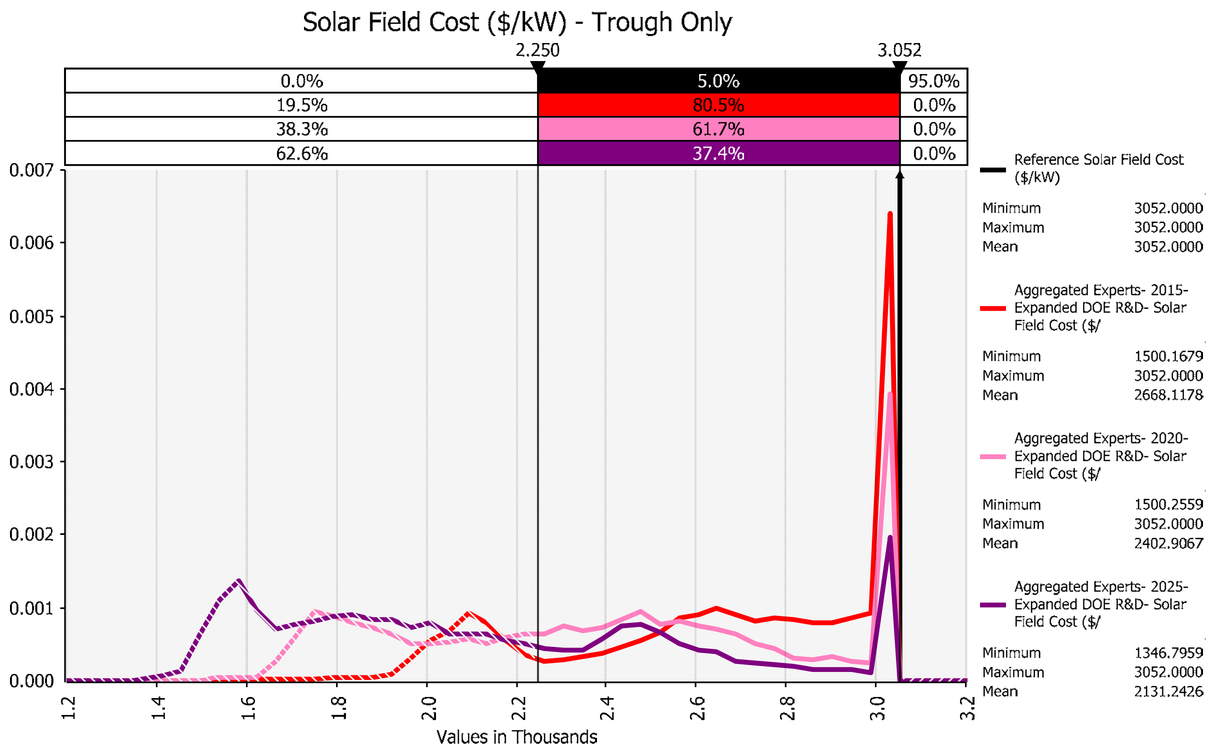


Total System Cost ($/kW) - Trough Only
5.025
6.443
0.0%
0.0%
3.3%
93.0%
47.2%
52.4%
69.3%
30.7%
0.0020
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
Values in Thousands
Reference Total System Cost ($/kW)
Minimum 6443.0000
Maximum 6443.0000
Mean 6443.0000
Aggregated Experts- 2015- Expanded DOE R&D- Total System Cost ($
Minimum 4234.0048
Maximum 6443.9213
Mean 5803.1647
Aggregated Experts- 2020- Expanded DOE R&D- Total System Cost ($
Minimum 3477.3927
Maximum 6443.9213
Mean 5235.5552
Aggregated Experts- 2025- Expanded DOE R&D- Total System Cost ($
Minimum 2870.3935
Maximum 6443.9213
Mean 4642.0406

## *Solar Field Cost-by Funding Level*

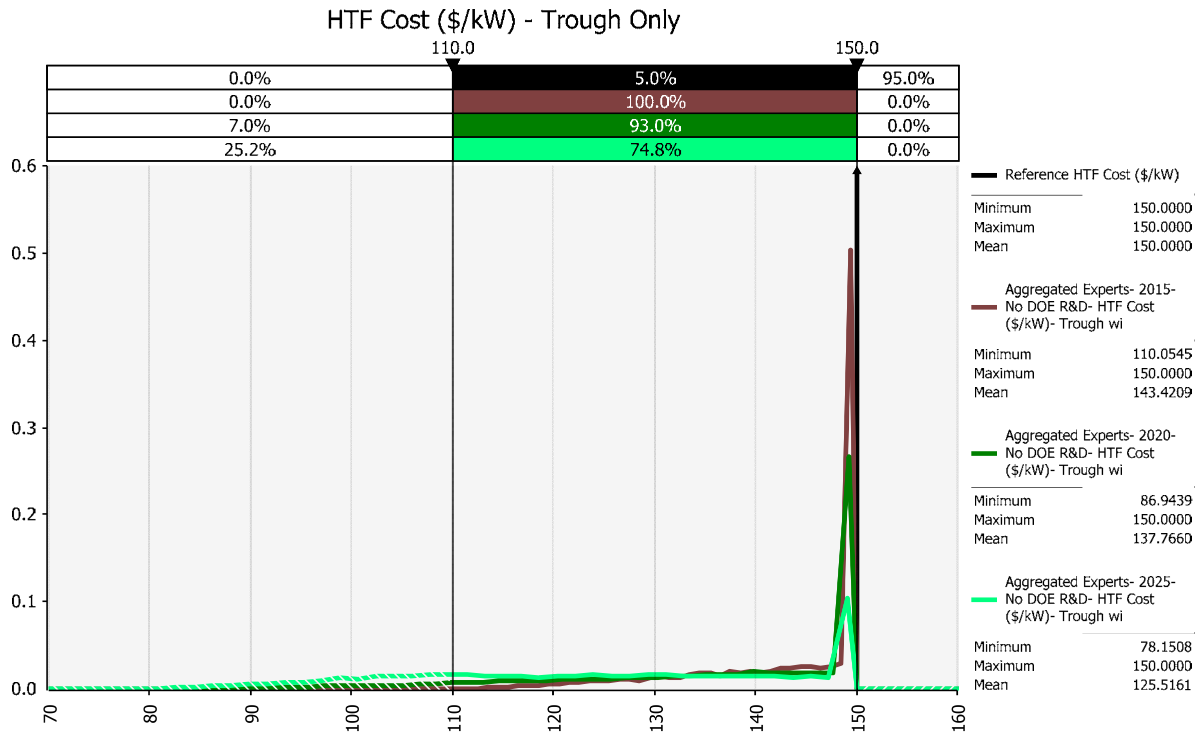


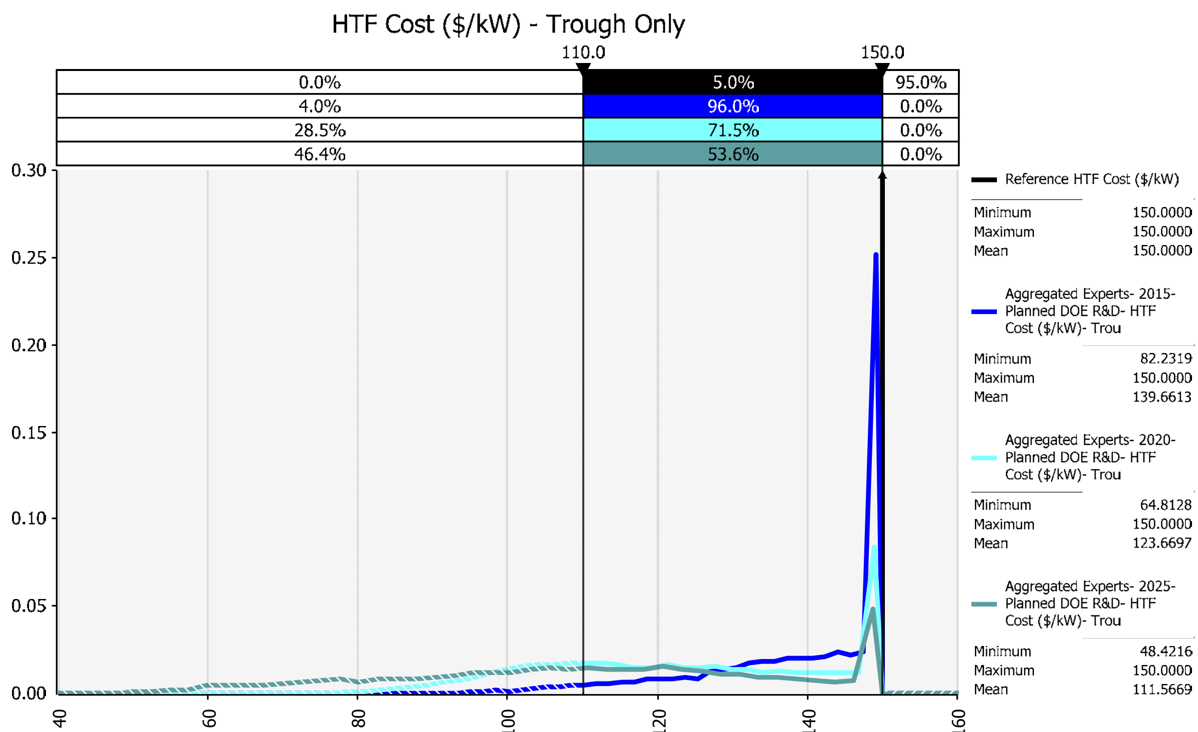



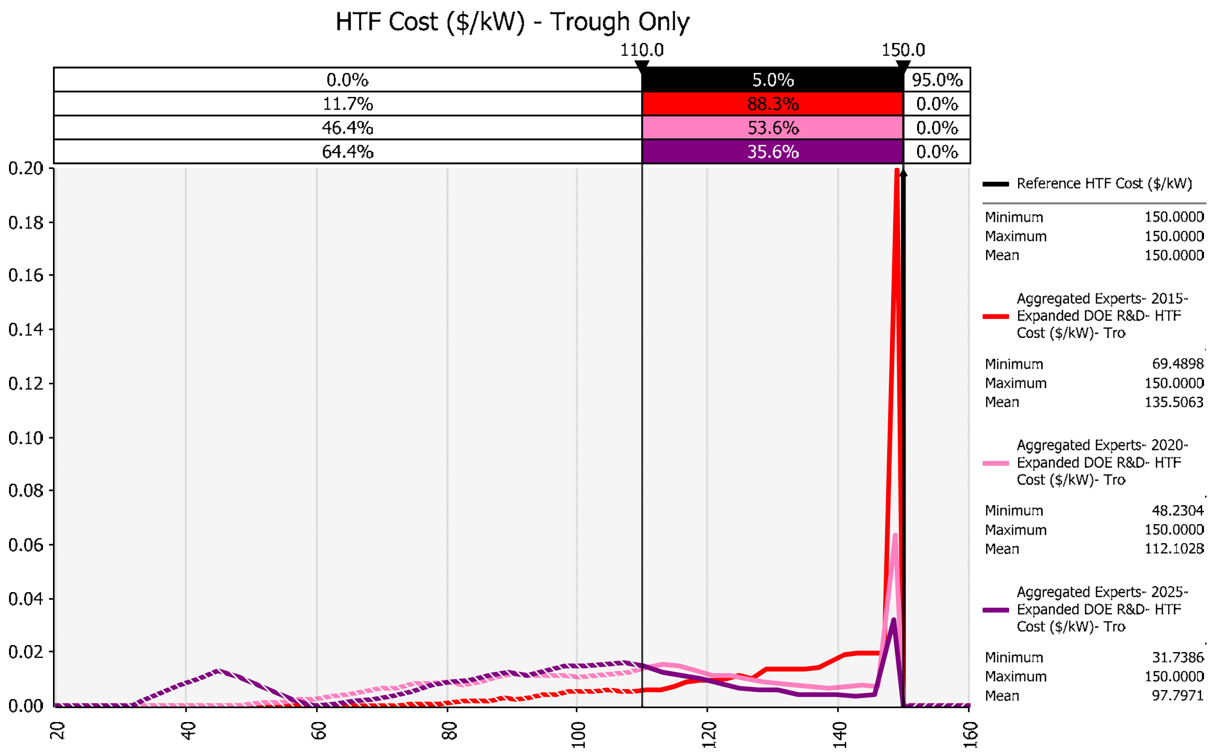


Solar Field Cost ($/kW) - Trough Only
2.250
3.052
0.0%
5.0%
95.0%
19.5%
80.5%
0.0%
38.3%
61.7%
0.0%
62.6%
37.4%
0.0%
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
Values in Thousands
Reference Solar Field Cost ($/kW)
Minimum 3052.0000
Maximum 3052.0000
Mean 3052.0000
Aggregated Experts- 2015- Expanded DOE R&D- Solar Field Cost ($/
Minimum 1500.1679
Maximum 3052.0000
Mean 2668.1178
Aggregated Experts- 2020- Expanded DOE R&D- Solar Field Cost ($/
Minimum 1500.2559
Maximum 3052.0000
Mean 2402.9067
Aggregated Experts- 2025- Expanded DOE R&D- Solar Field Cost ($/
Minimum 1346.7959
Maximum 3052.0000
Mean 2131.2426

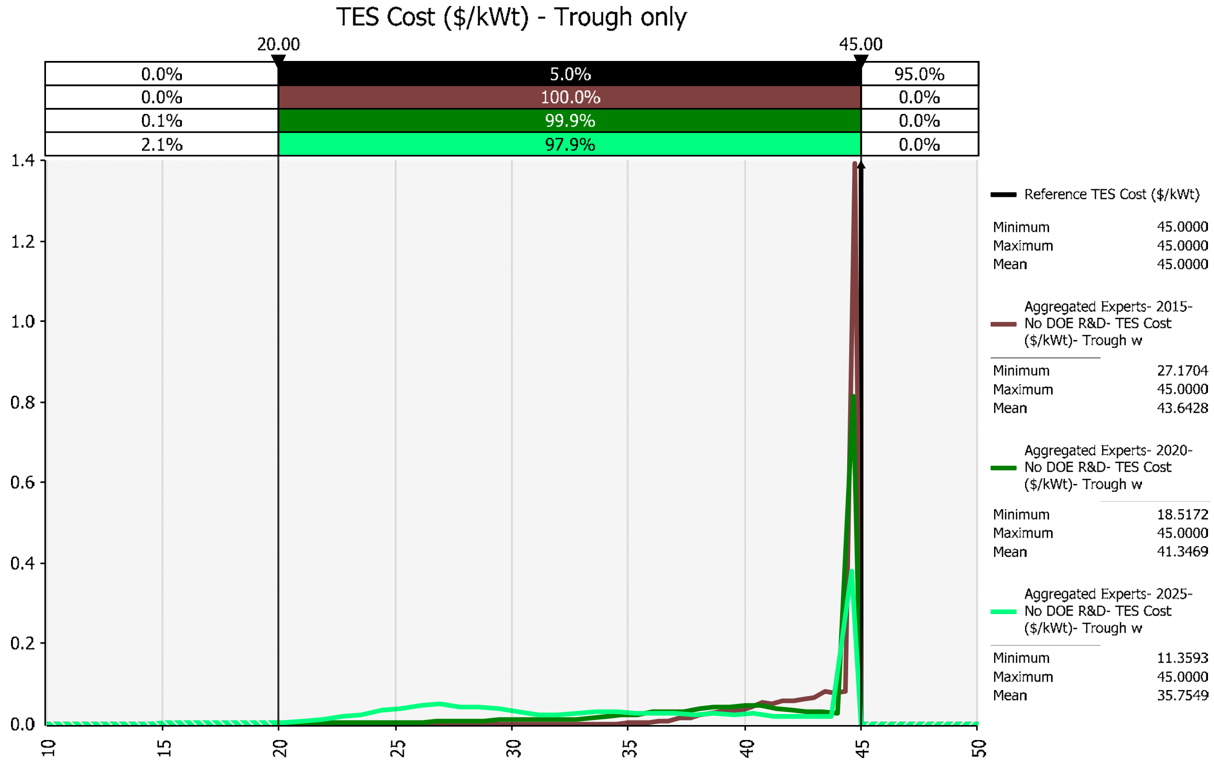
### *HTF/Receiver Cost-by Funding Level*

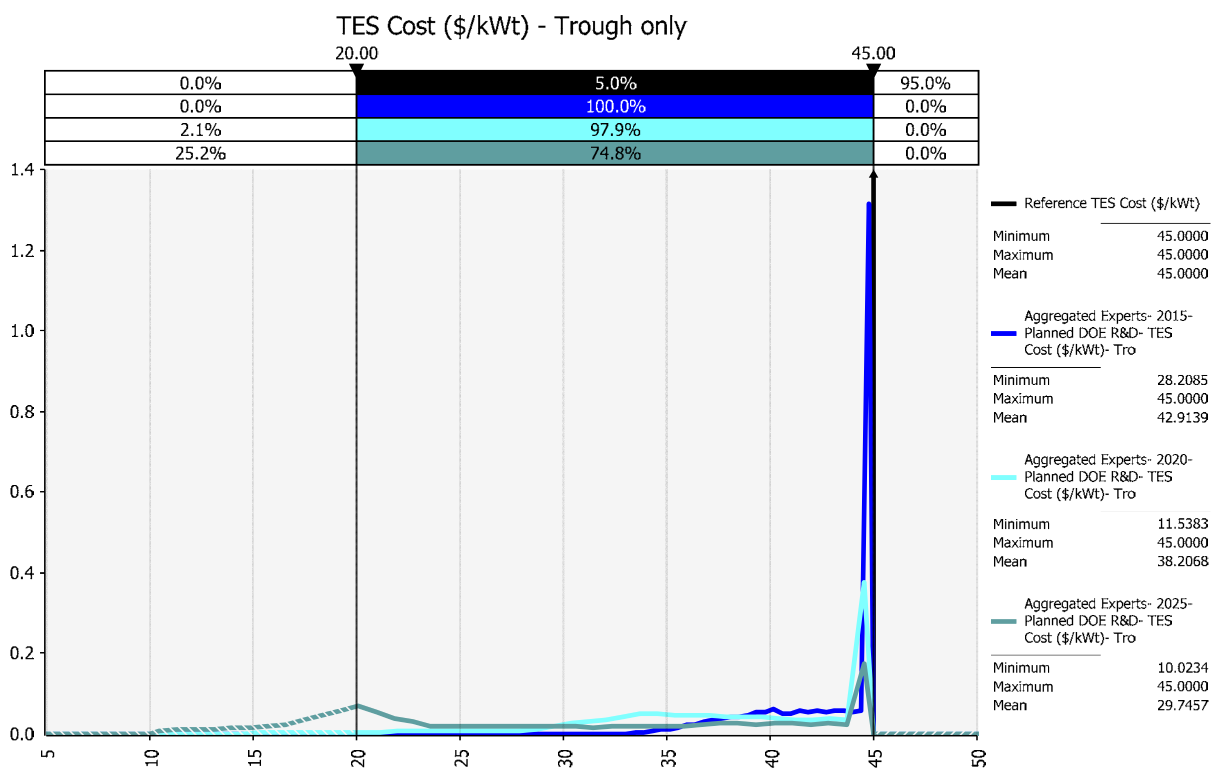


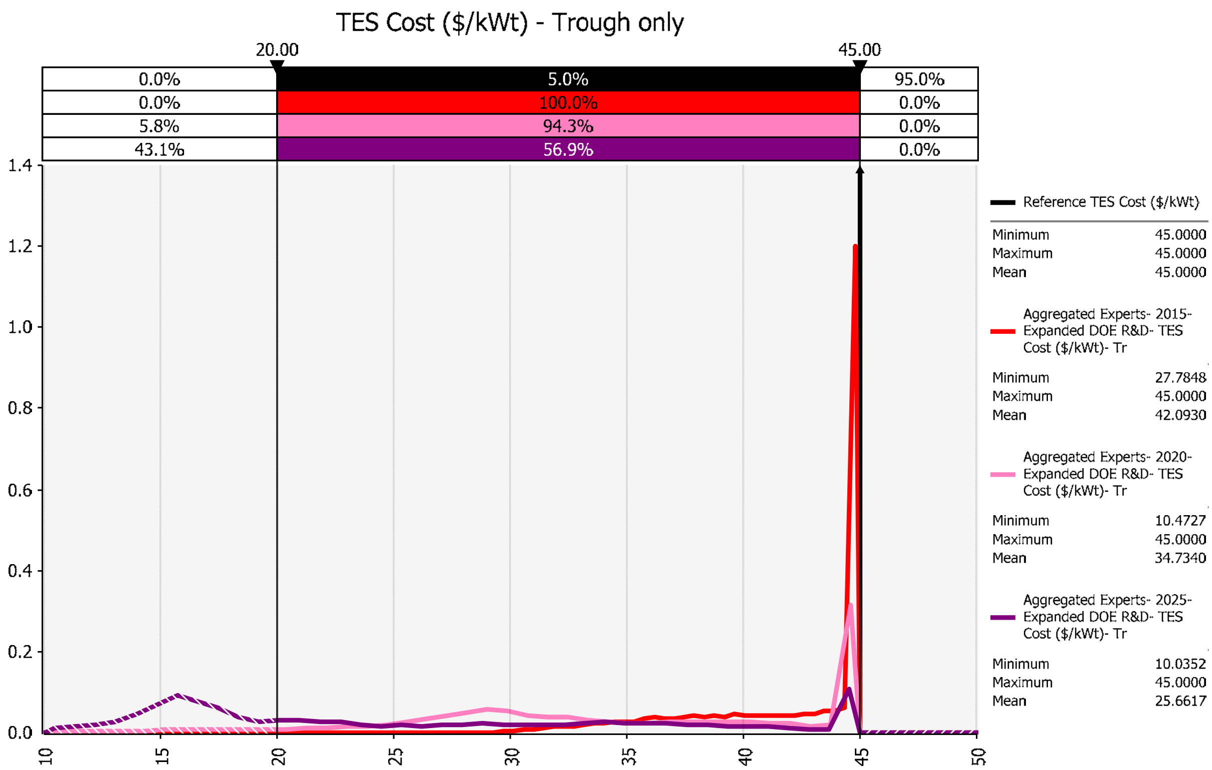




HTF Cost ($/kW) - Trough Only
110.0
150.0
0.0%
5.0%
95.0%
11.7%
88.3%
0.0%
46.4%
53.6%
0.0%
64.4%
35.6%
0.0%
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
20
40
60
80
100
120
140
160
Reference HTF Cost ($/kW)
Minimum 150.0000
Maximum 150.0000
Mean 150.0000
Aggregated Experts- 2015- Expanded DOE R&D- HTF Cost ($/kW)- Tro
Minimum 69.4898
Maximum 150.0000
Mean 135.5063
Aggregated Experts- 2020- Expanded DOE R&D- HTF Cost ($/kW)- Tro
Minimum 48.2304
Maximum 150.0000
Mean 112.1028
Aggregated Experts- 2025- Expanded DOE R&D- HTF Cost ($/kW)- Tro
Minimum 31.7386
Maximum 150.0000
Mean 97.7971

*TES Cost-by Funding Level*

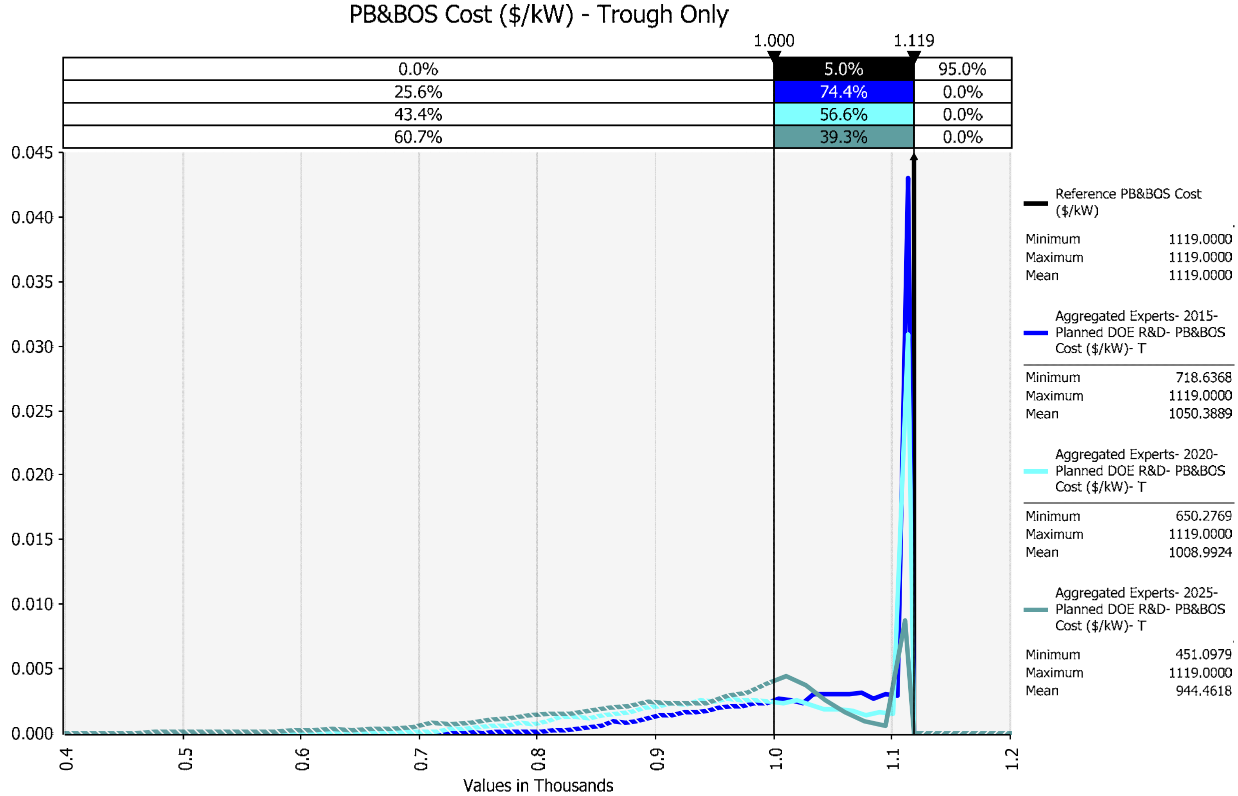


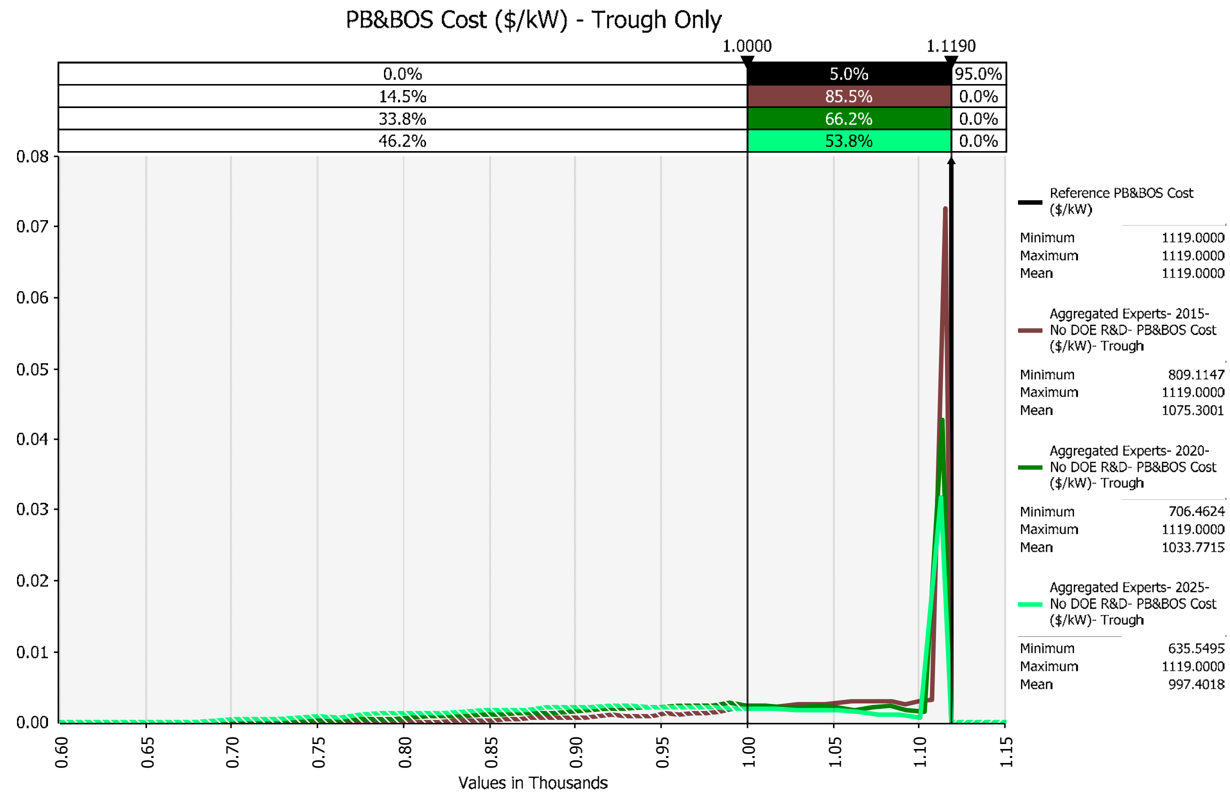



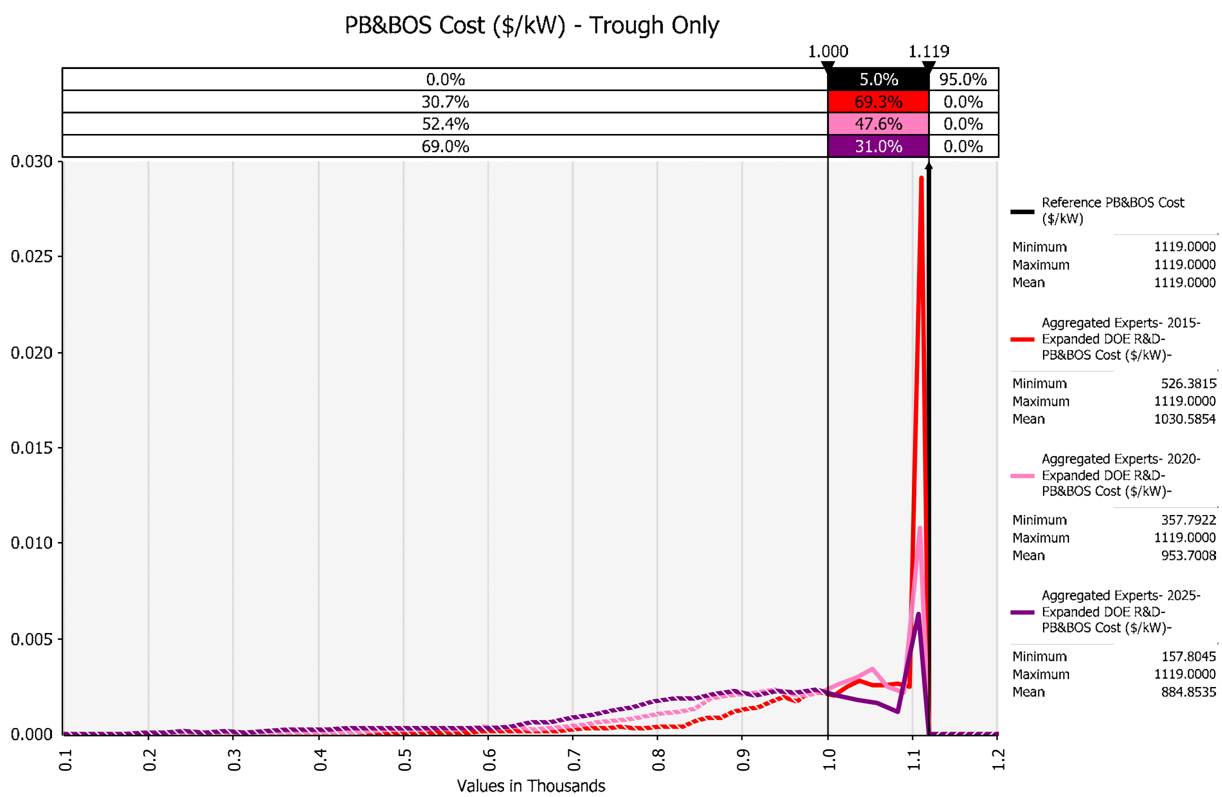


TES Cost ($/kWt) - Trough only
20.00
45.00
0.0%
5.0%
95.0%
0.0%
100.0%
0.0%
5.8%
94.3%
0.0%
43.1%
56.9%
0.0%
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10
15
20
25
30
35
40
45
50
Reference TES Cost ($/kWt)
Minimum 45.0000
Maximum 45.0000
Mean 45.0000
Aggregated Experts- 2015- Expanded DOE R&D- TES Cost ($/kWt)- Tr
Minimum 27.7848
Maximum 45.0000
Mean 42.0930
Aggregated Experts- 2020- Expanded DOE R&D- TES Cost ($/kWt)- Tr
Minimum 10.4727
Maximum 45.0000
Mean 34.7340
Aggregated Experts- 2025- Expanded DOE R&D- TES Cost ($/kWt)- Tr
Minimum 10.0352
Maximum 45.0000
Mean 25.6617

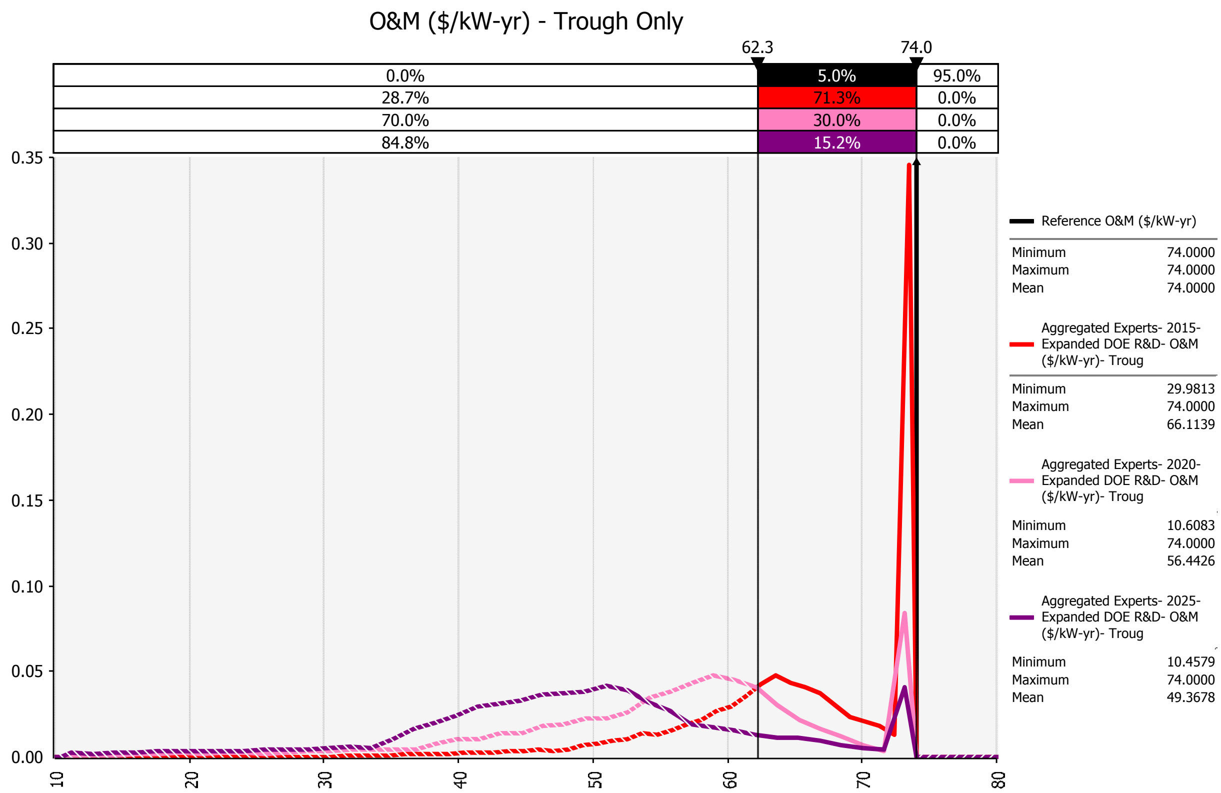
## *PB&BOS Cost-by Funding Level*

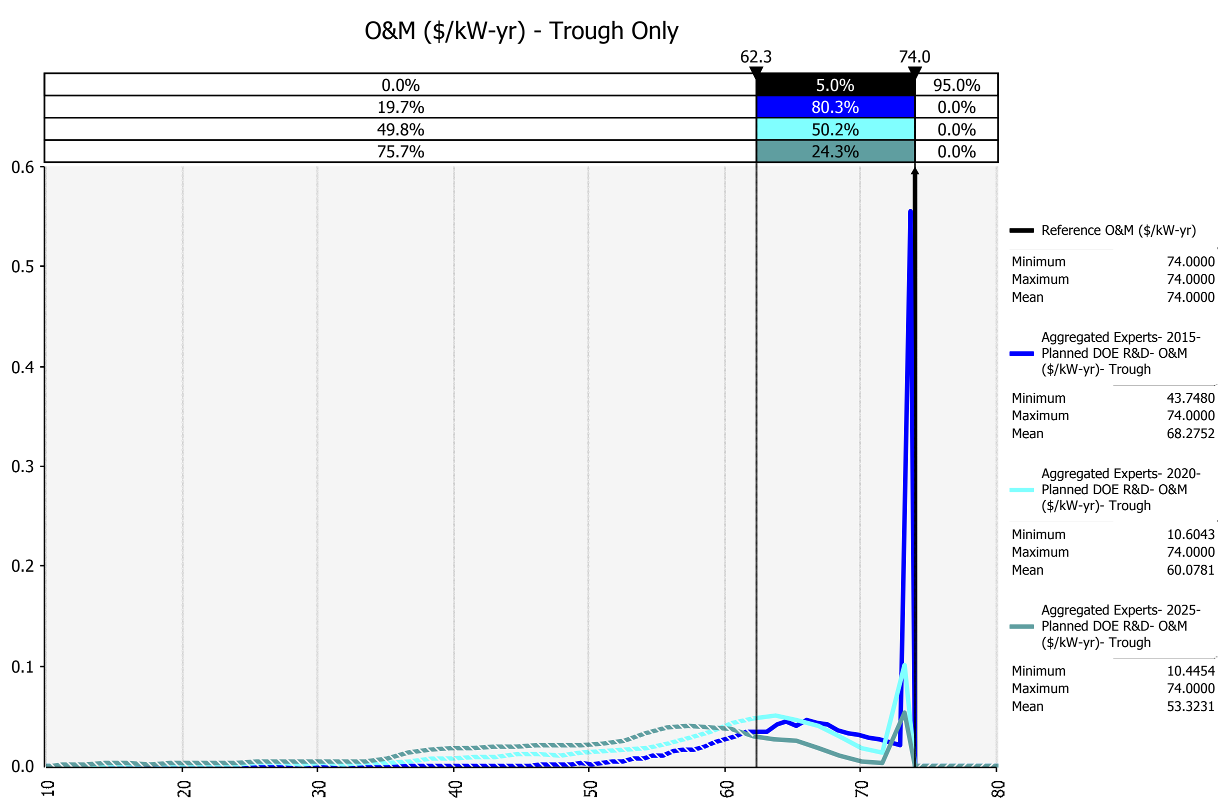



PB&BOS Cost ($/kW) - Trough Only
1.0000
1.1190
0.0%
5.0%
95.0%
14.5%
85.5%
0.0%
33.8%
66.2%
0.0%
46.2%
53.8%
0.0%
Values in Thousands
Reference PB&BOS Cost ($/kW)
Minimum 1119.0000
Maximum 1119.0000
Mean 1119.0000
Aggregated Experts- 2015- No DOE R&D- PB&BOS Cost ($/kW)- Trough
Minimum 809.1147
Maximum 1119.0000
Mean 1075.3001
Aggregated Experts- 2020- No DOE R&D- PB&BOS Cost ($/kW)- Trough
Minimum 706.4624
Maximum 1119.0000
Mean 1033.7715
Aggregated Experts- 2025- No DOE R&D- PB&BOS Cost ($/kW)- Trough
Minimum 635.5495
Maximum 1119.0000
Mean 997.4018


PB&BOS Cost ($/kW) - Trough Only
1.000
1.119
0.0%
5.0%
95.0%
30.7%
69.3%
0.0%
52.4%
47.6%
0.0%
69.0%
31.0%
0.0%
Values in Thousands
Reference PB&BOS Cost ($/kW)
Minimum 1119.0000
Maximum 1119.0000
Mean 1119.0000
Aggregated Experts- 2015- Expanded DOE R&D- PB&BOS Cost ($/kW)-
Minimum 526.3815
Maximum 1119.0000
Mean 1030.5854
Aggregated Experts- 2020- Expanded DOE R&D- PB&BOS Cost ($/kW)-
Minimum 357.7922
Maximum 1119.0000
Mean 953.7008
Aggregated Experts- 2025- Expanded DOE R&D- PB&BOS Cost ($/kW)-
Minimum 157.8045
Maximum 1119.0000
Mean 884.8535

## *O&M System Cost-by Funding Level*



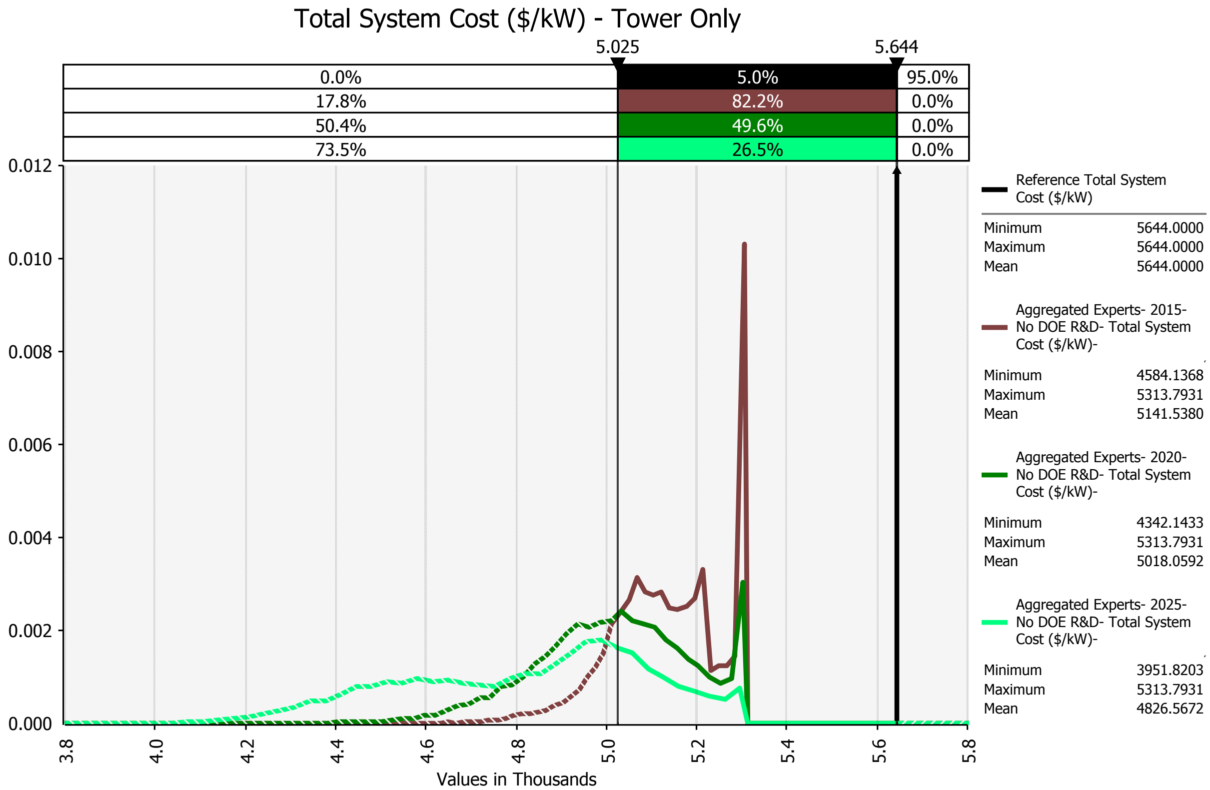



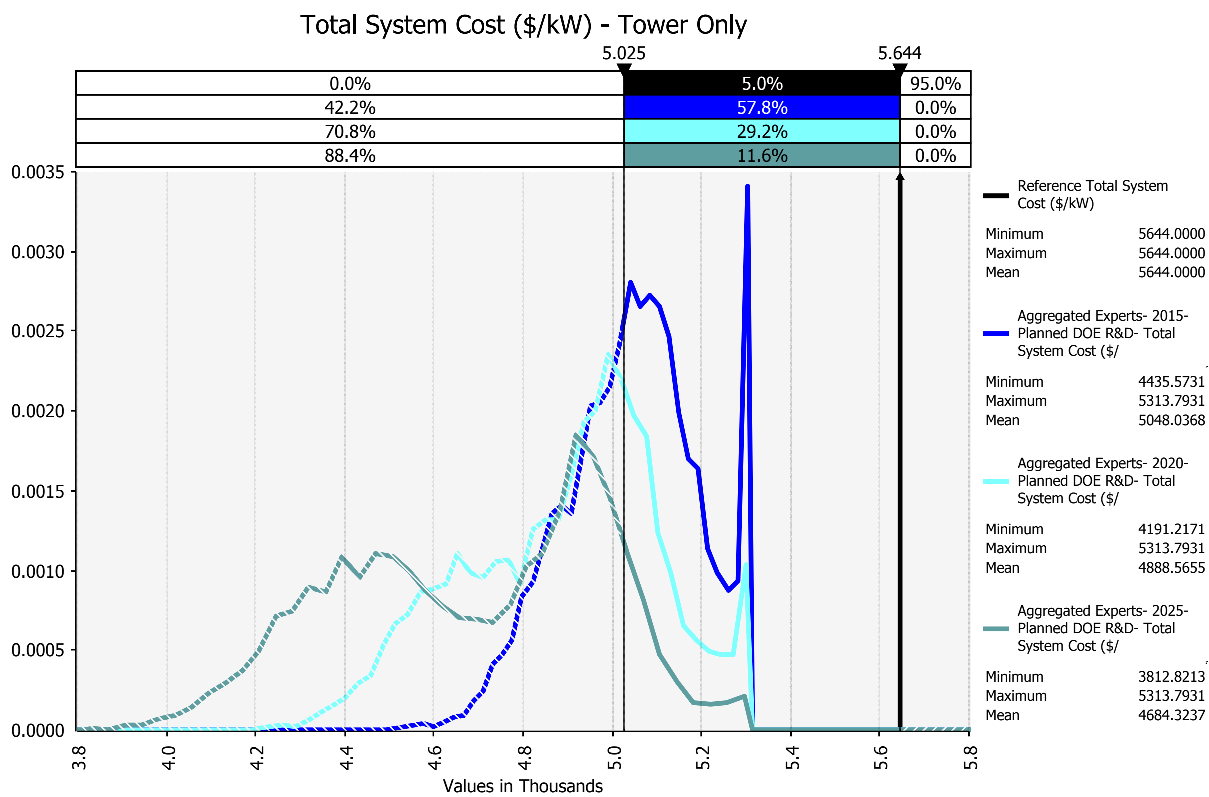
## D.2 Technical Risk and Uncertainty Analysis-Solar Utility CSP Tower

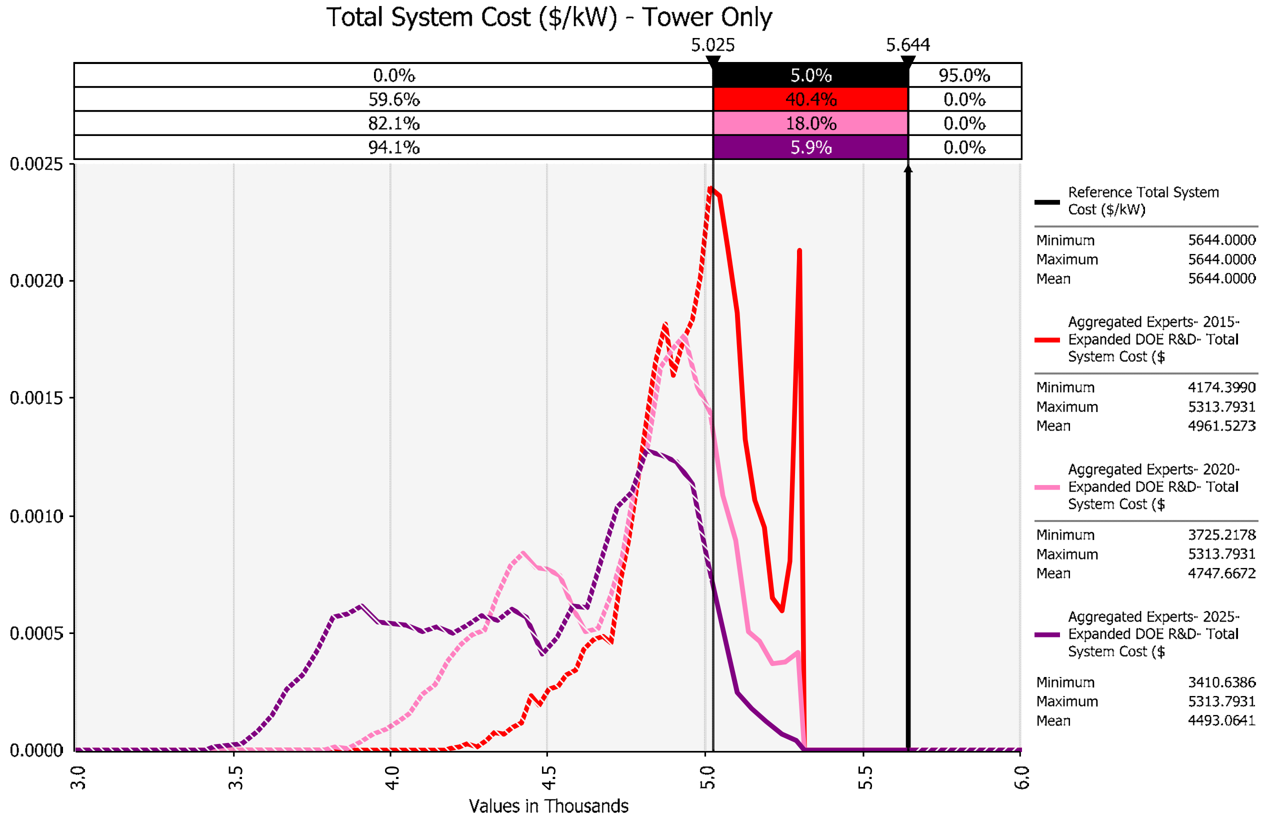
The following figures represent the aggregated total system costs provided by the experts in the three budget scenarios for CSP Utility - Tower with Storage ($0, $30M, and $60M).

The three colored lines in each of these graphs represent the aggregated expert inputs for the three time periods for CSP Utility—Tower with Storage (2015, 2020, and 2025). In each of the graphs, the 2009 reference values are represented by the black line on the right of the graphs, and the FY10 GPRA Program goal-based input value for 2015 is represented by the delimiter (i.e., thin black vertical lines) on the left of each graph. The percentages to the left side of the delimiter represent the likelihood of at least achieving the "goal-based" value. The percentages between the delimiters represent the likelihood of improving to somewhere between the "goal-based" value and reference value. Furthermore, the key to the right of each graph also lists the minimum, maximum, and mean for each aggregated distribution.

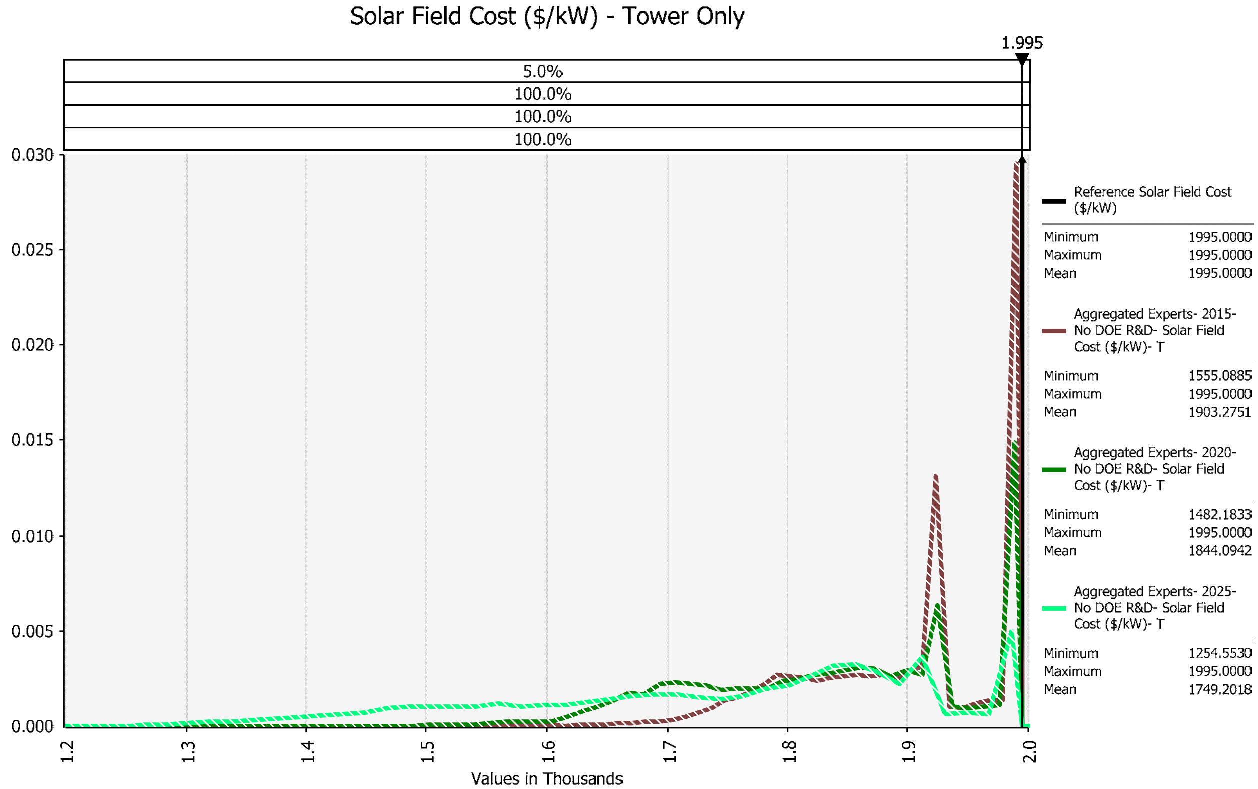
## *Total System Cost-by Funding Level*

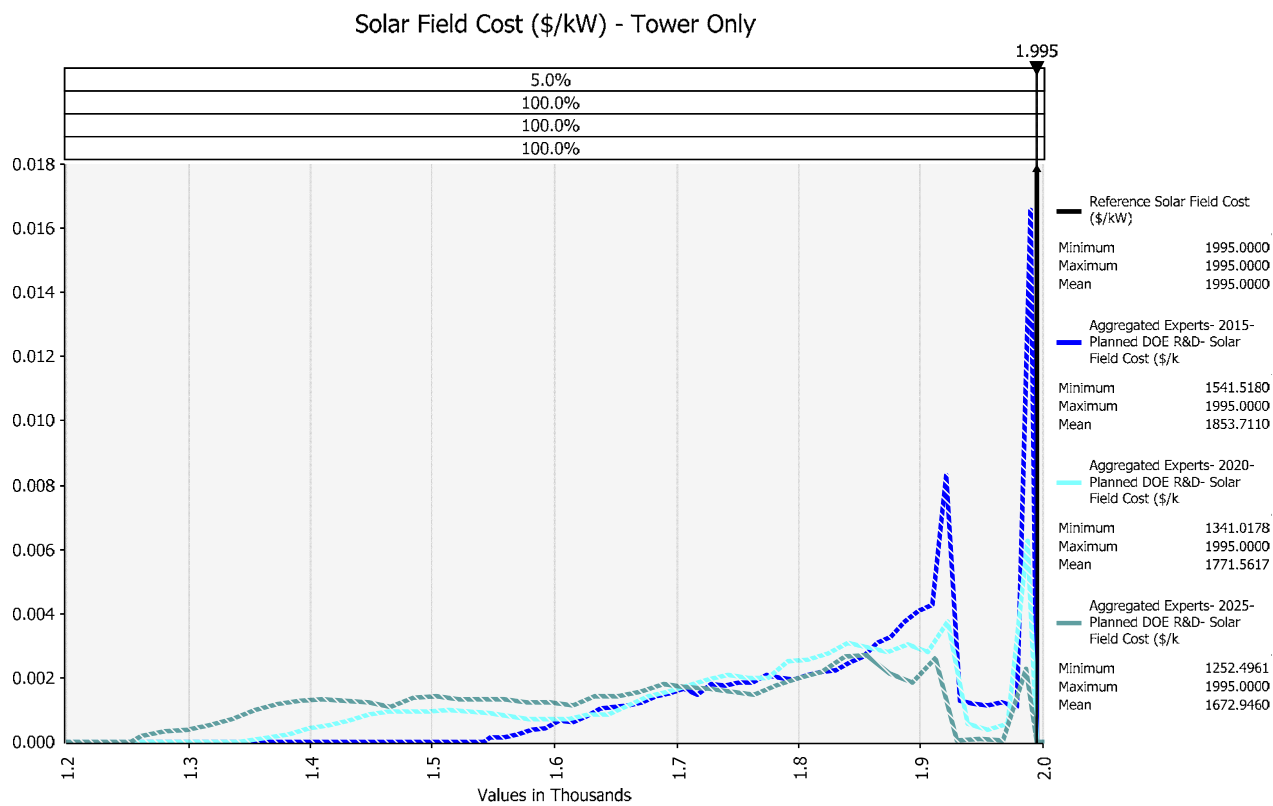


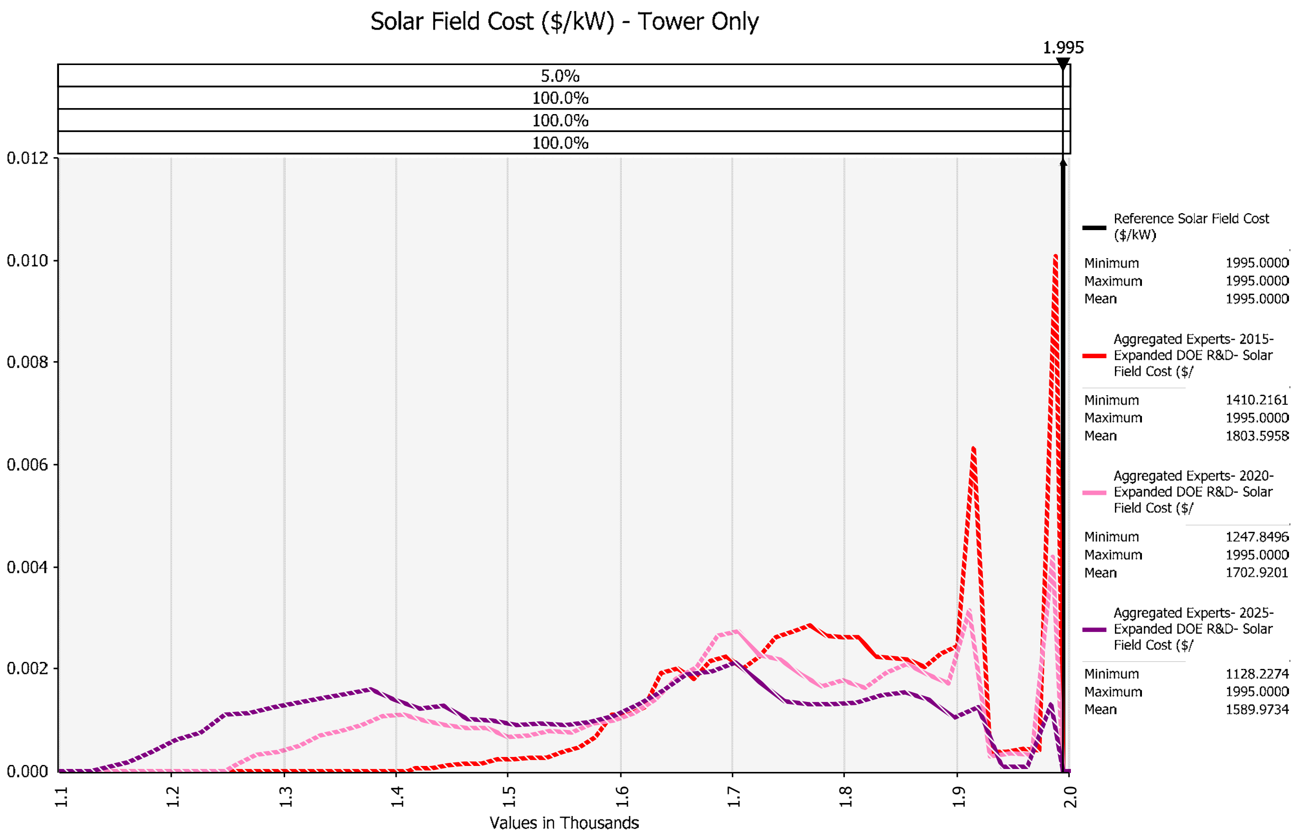




Total System Cost ($/kW) - Tower Only
5.025
5.644
0.0%
5.0%
95.0%
59.6%
40.4%
0.0%
82.1%
18.0%
0.0%
94.1%
5.9%
0.0%
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Values in Thousands
Reference Total System Cost ($/kW)
Minimum 5644.0000
Maximum 5644.0000
Mean 5644.0000
Aggregated Experts- 2015- Expanded DOE R&D- Total System Cost ($
Minimum 4174.3990
Maximum 5313.7931
Mean 4961.5273
Aggregated Experts- 2020- Expanded DOE R&D- Total System Cost ($
Minimum 3725.2178
Maximum 5313.7931
Mean 4747.6672
Aggregated Experts- 2025- Expanded DOE R&D- Total System Cost ($
Minimum 3410.6386
Maximum 5313.7931
Mean 4493.0641

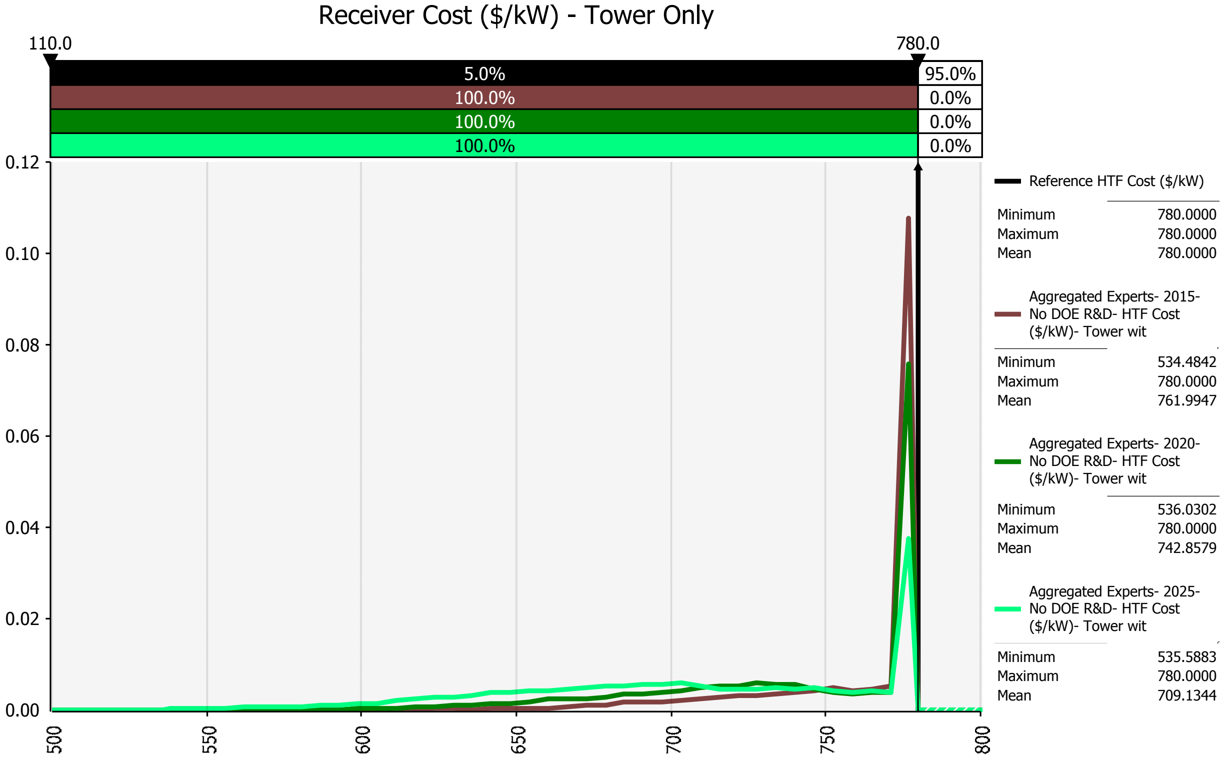
***Solar Field Cost-by Funding Level***

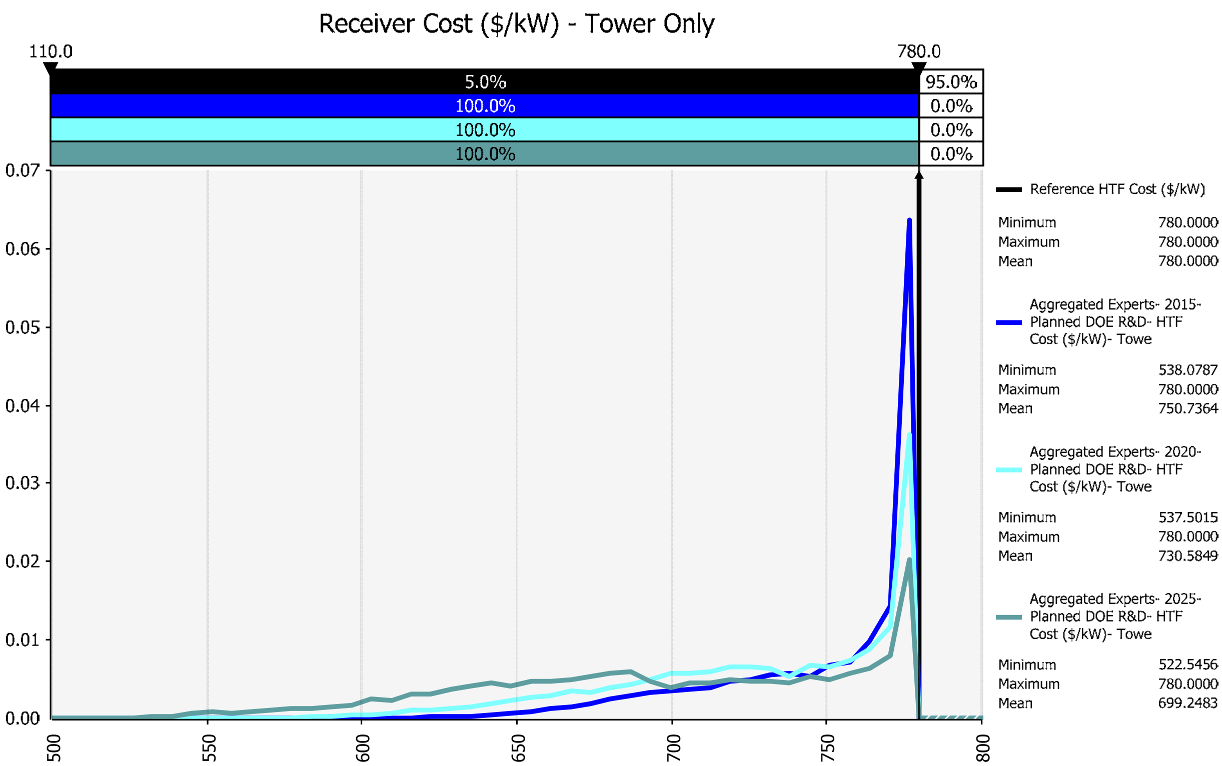


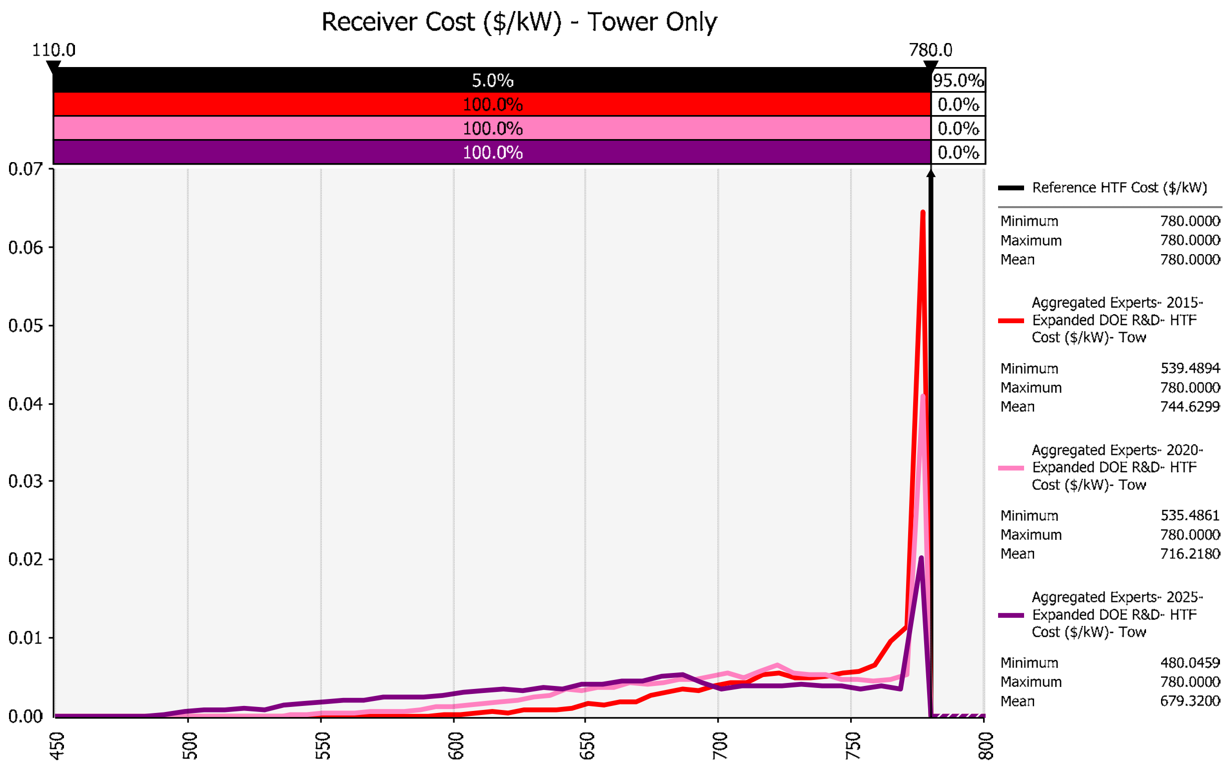




Solar Field Cost ($/kW) - Tower Only
1.995
5.0%
100.0%
100.0%
100.0%
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Values in Thousands
Reference Solar Field Cost ($/kW)
Minimum 1995.0000
Maximum 1995.0000
Mean 1995.0000
Aggregated Experts- 2015- Expanded DOE R&D- Solar Field Cost ($/
Minimum 1410.2161
Maximum 1995.0000
Mean 1803.5958
Aggregated Experts- 2020- Expanded DOE R&D- Solar Field Cost ($/
Minimum 1247.8496
Maximum 1995.0000
Mean 1702.9201
Aggregated Experts- 2025- Expanded DOE R&D- Solar Field Cost ($/
Minimum 1128.2274
Maximum 1995.0000
Mean 1589.9734

## *HTF/Receiver Cost-by Funding Level*

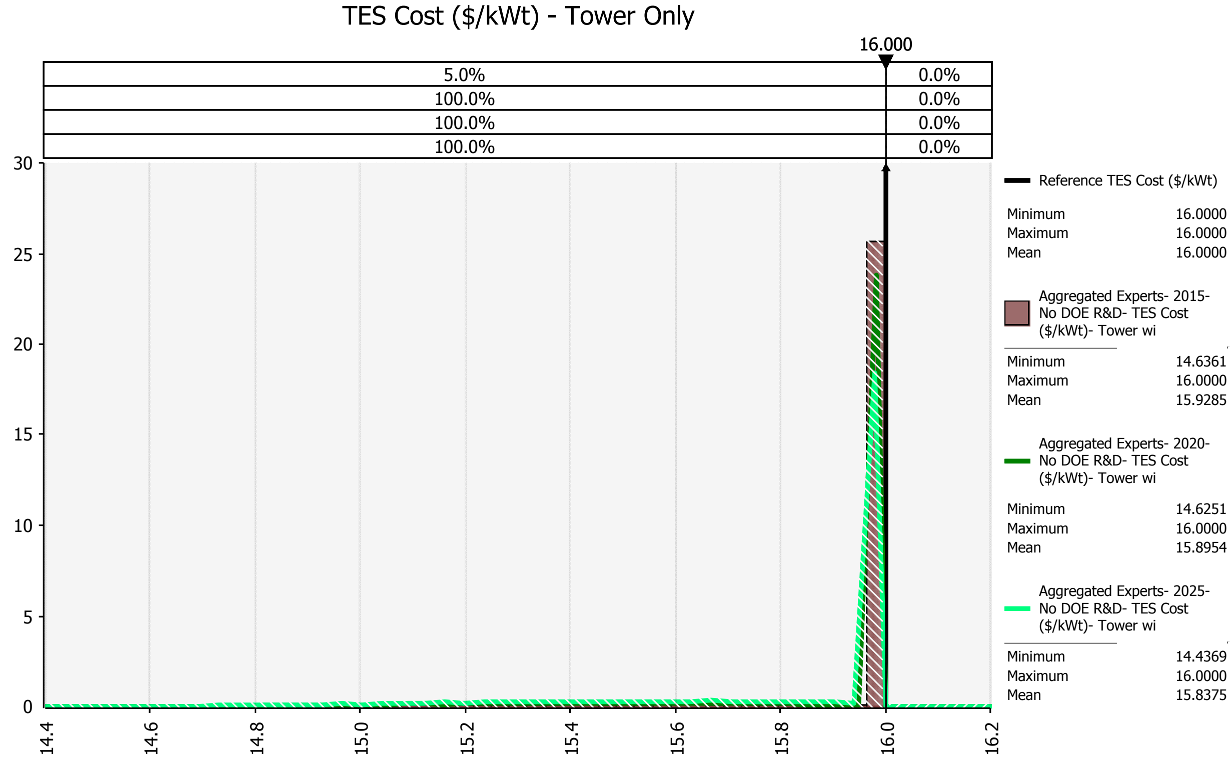


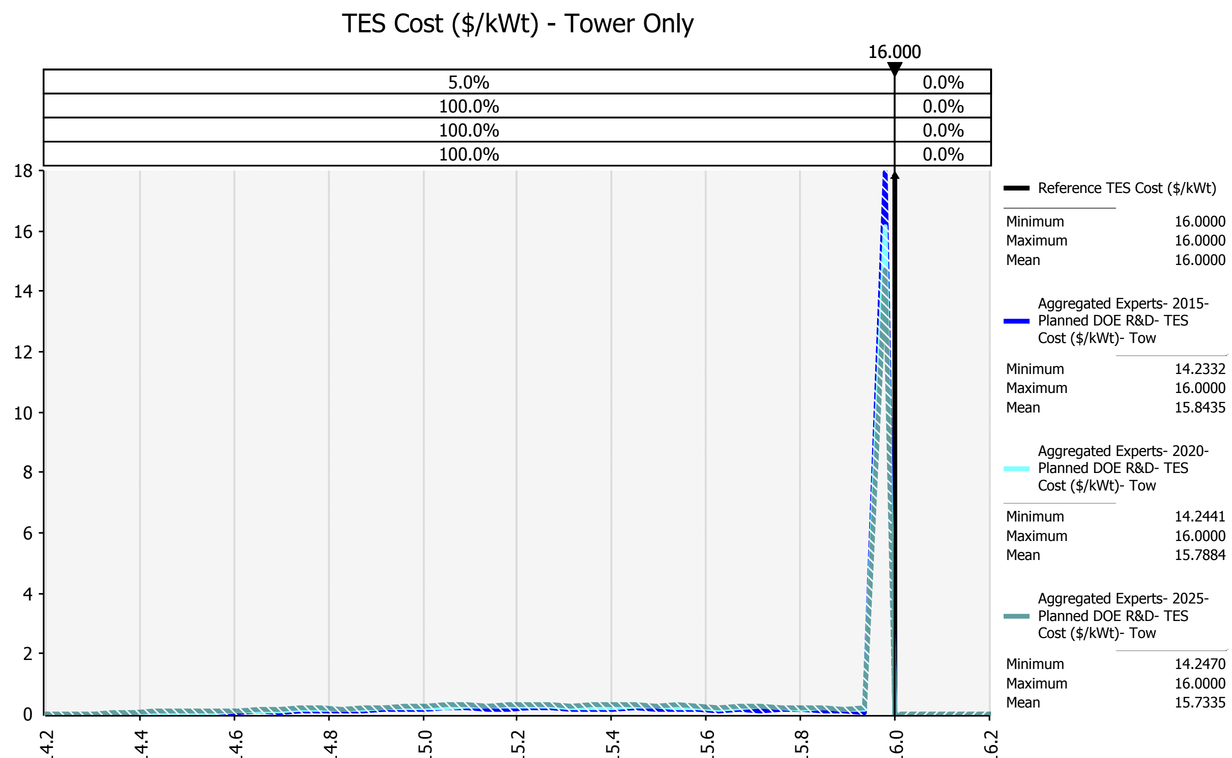



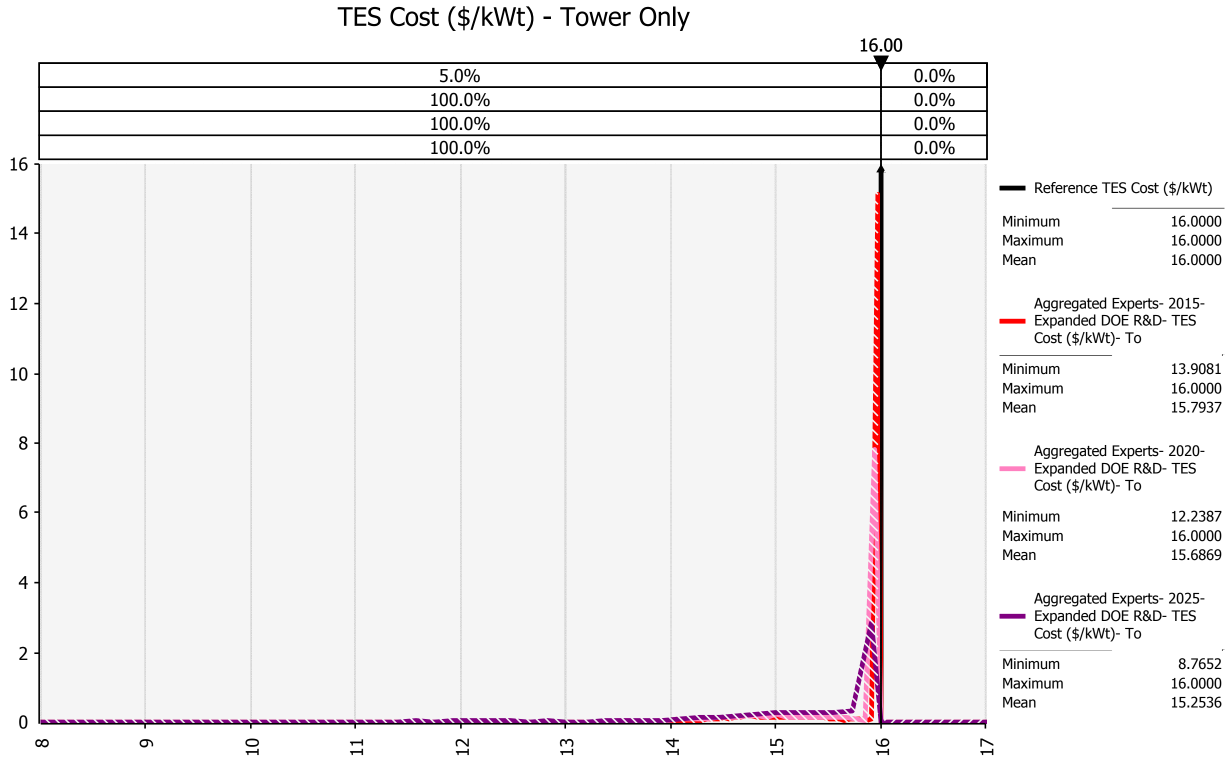


Receiver Cost ($/kW) - Tower Only
110.0
780.0
5.0%
95.0%
100.0%
0.0%
100.0%
0.0%
100.0%
0.0%
Reference HTF Cost ($/kW)
Minimum 780.0000
Maximum 780.0000
Mean 780.0000
Aggregated Experts- 2015- Expanded DOE R&D- HTF Cost ($/kW)- Tow
Minimum 539.4894
Maximum 780.0000
Mean 744.6299
Aggregated Experts- 2020- Expanded DOE R&D- HTF Cost ($/kW)- Tow
Minimum 535.4861
Maximum 780.0000
Mean 716.2180
Aggregated Experts- 2025- Expanded DOE R&D- HTF Cost ($/kW)- Tow
Minimum 480.0459
Maximum 780.0000
Mean 679.3200

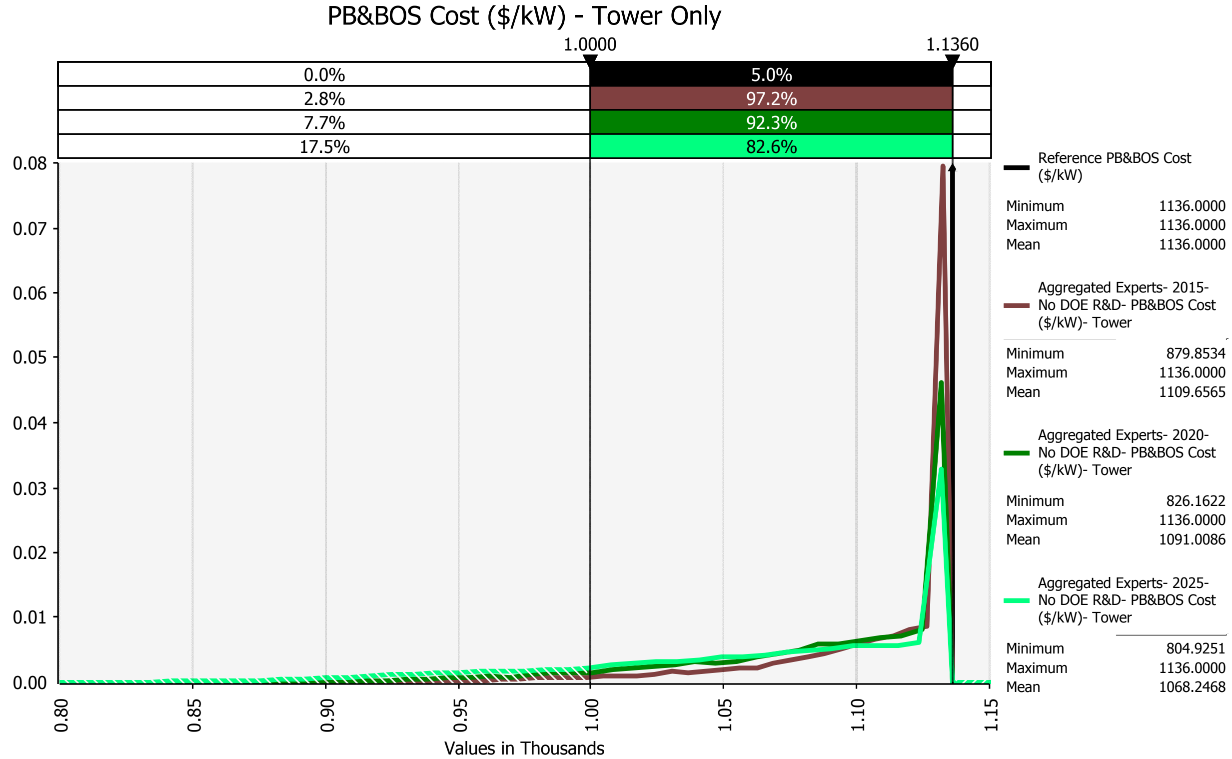
### *TES Cost-by Funding Level*

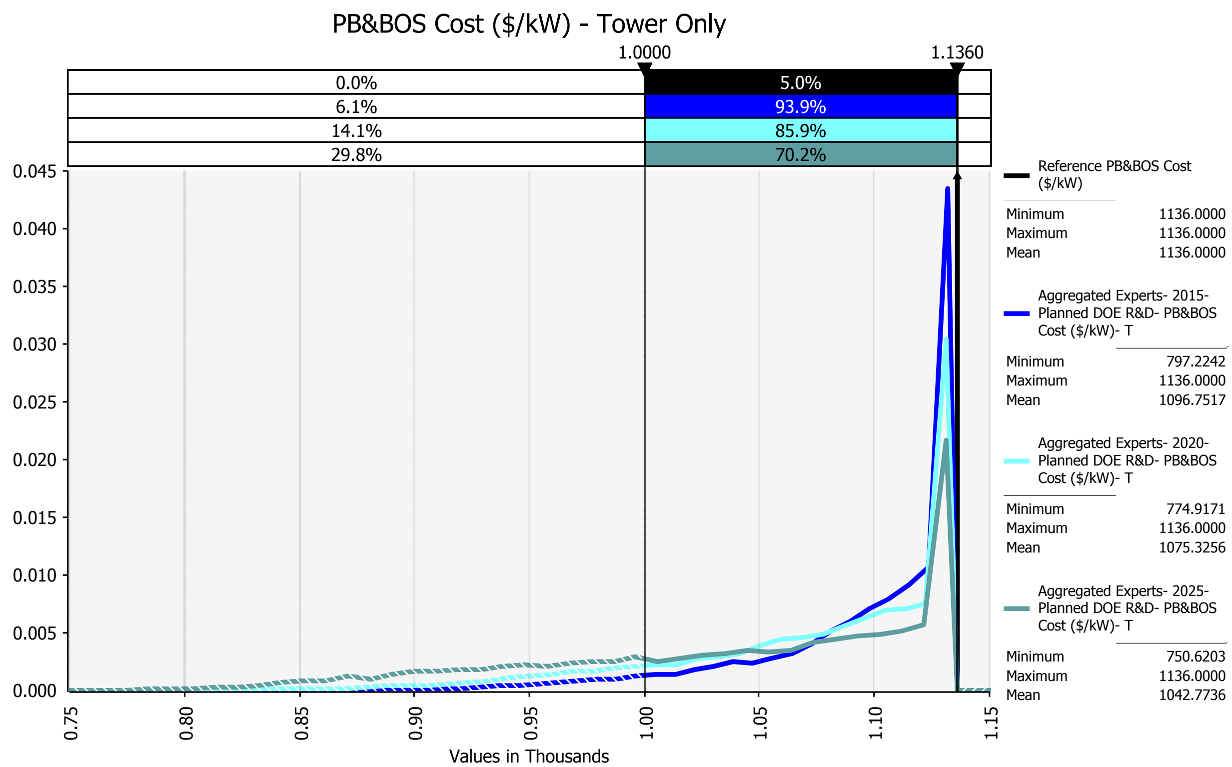


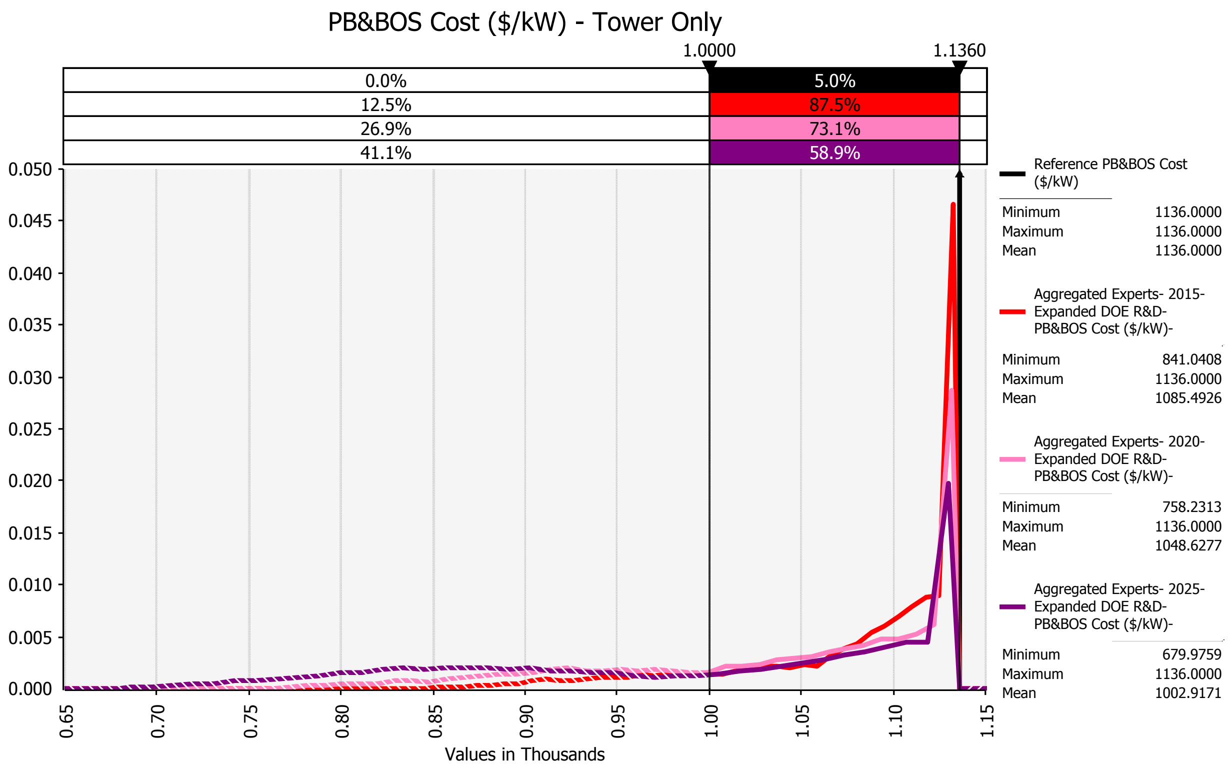




TES Cost ($/kWt) - Tower Only
16.00
5.0%
0.0%
100.0%
0.0%
100.0%
0.0%
100.0%
0.0%
16
14
12
10
8
6
4
2
0
8
9
10
11
12
13
14
15
16
17
Reference TES Cost ($/kWt)
Minimum 16.0000
Maximum 16.0000
Mean 16.0000
Aggregated Experts- 2015- Expanded DOE R&D- TES Cost ($/kWt)- To
Minimum 13.9081
Maximum 16.0000
Mean 15.7937
Aggregated Experts- 2020- Expanded DOE R&D- TES Cost ($/kWt)- To
Minimum 12.2387
Maximum 16.0000
Mean 15.6869
Aggregated Experts- 2025- Expanded DOE R&D- TES Cost ($/kWt)- To
Minimum 8.7652
Maximum 16.0000
Mean 15.2536

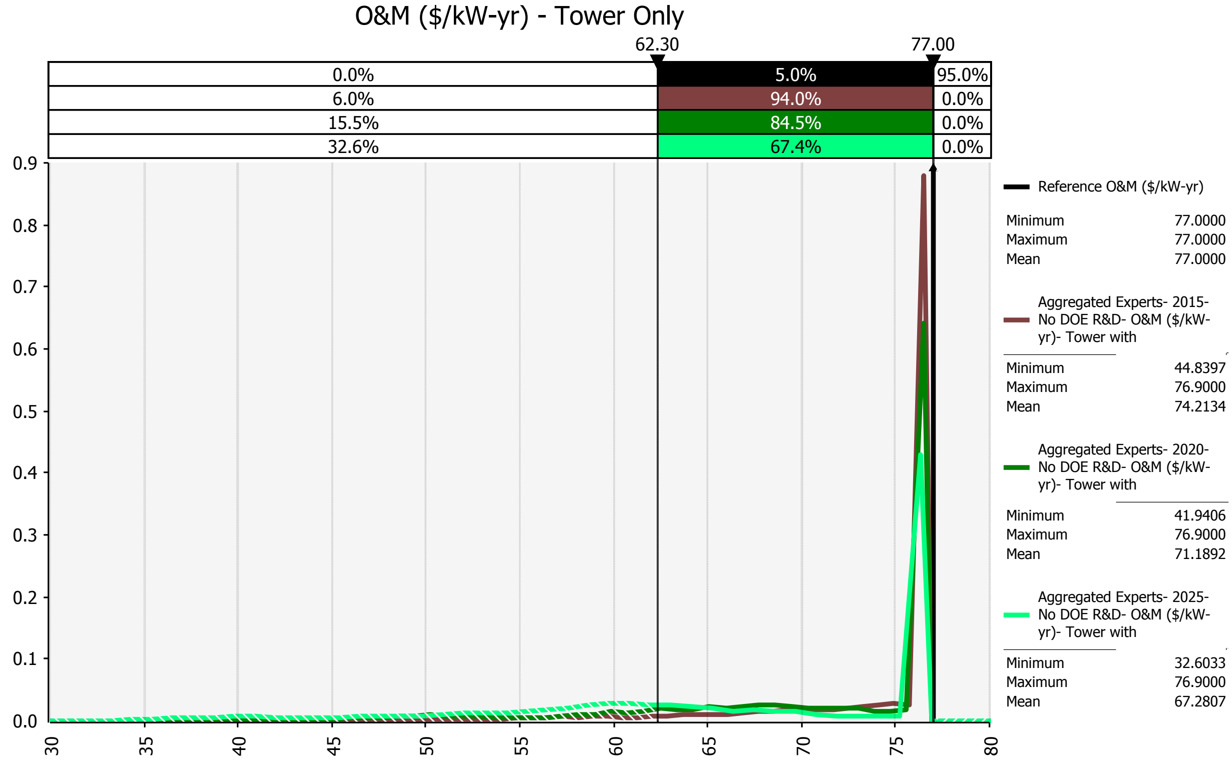
### *PB&BOS Cost-by Funding Level*

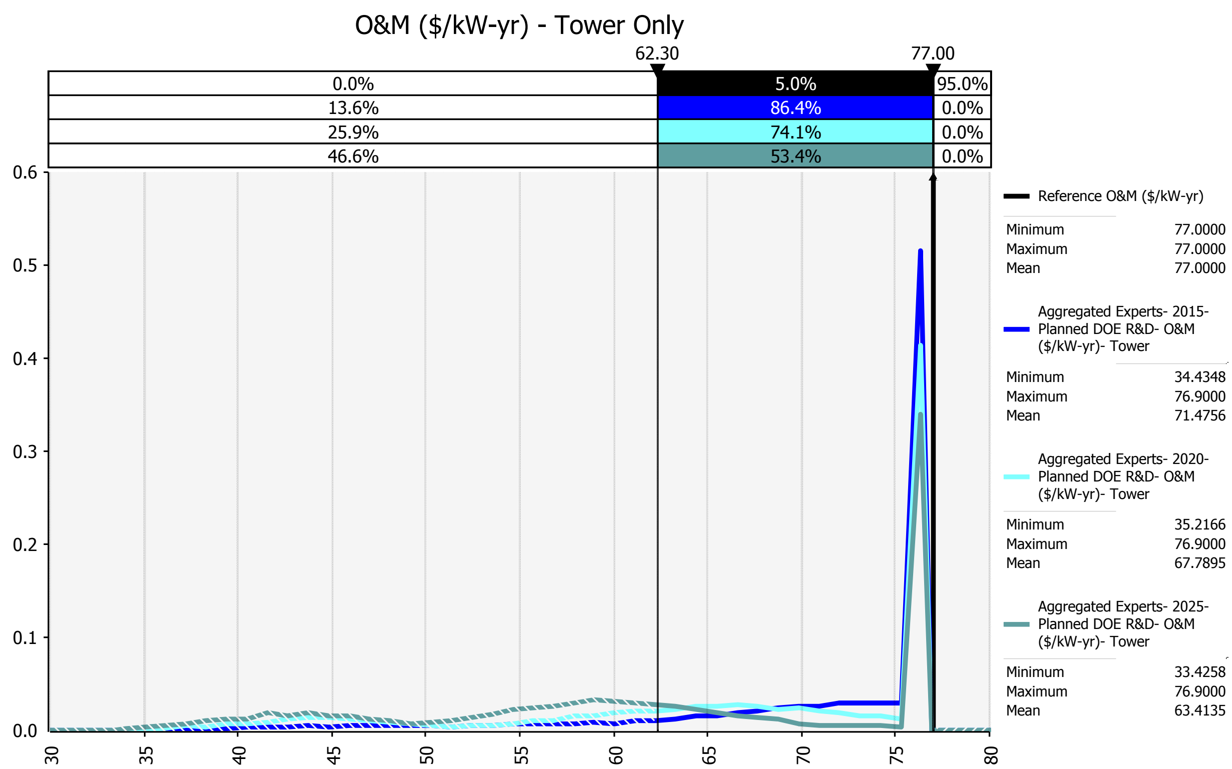


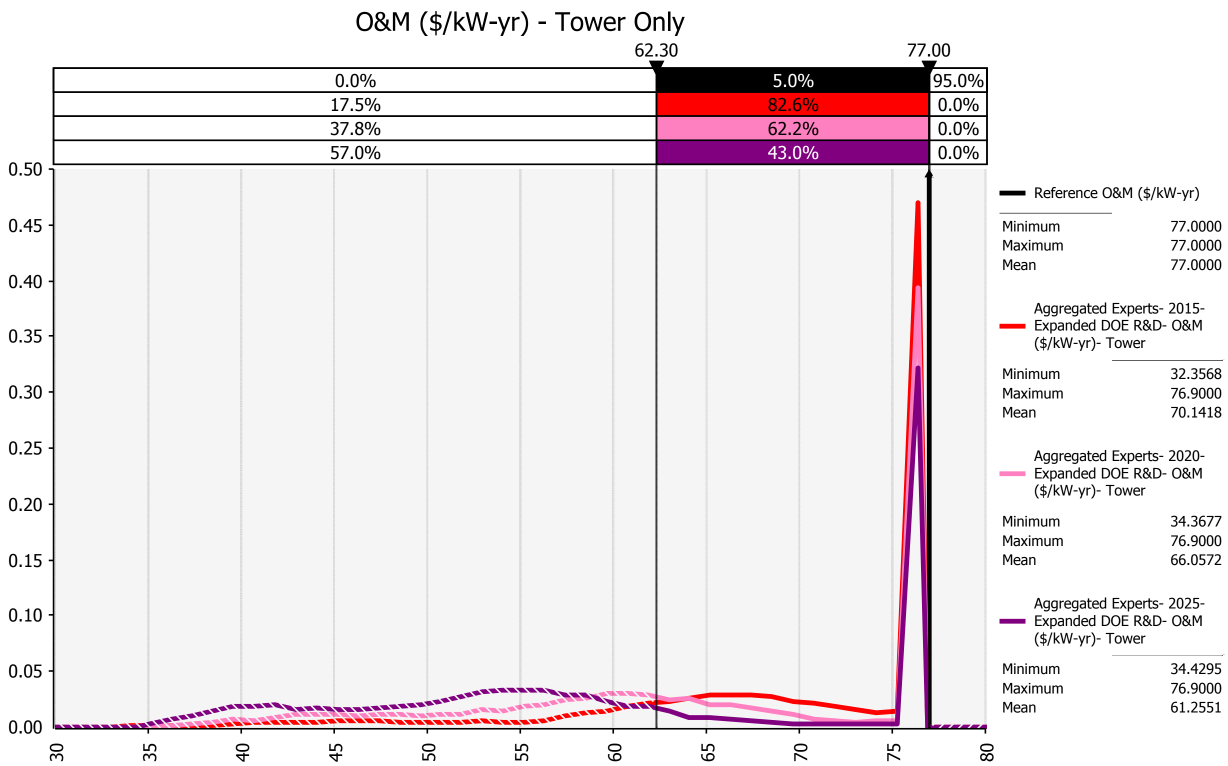




PB&BOS Cost ($/kW) - Tower Only
1.0000
1.1360
0.0%
5.0%
12.5%
87.5%
26.9%
73.1%
41.1%
58.9%
Reference PB&BOS Cost ($/kW)
Minimum 1136.0000
Maximum 1136.0000
Mean 1136.0000
Aggregated Experts- 2015- Expanded DOE R&D- PB&BOS Cost ($/kW)-
Minimum 841.0408
Maximum 1136.0000
Mean 1085.4926
Aggregated Experts- 2020- Expanded DOE R&D- PB&BOS Cost ($/kW)-
Minimum 758.2313
Maximum 1136.0000
Mean 1048.6277
Aggregated Experts- 2025- Expanded DOE R&D- PB&BOS Cost ($/kW)-
Minimum 679.9759
Maximum 1136.0000
Mean 1002.9171
Values in Thousands

## *O&M System Cost-by Funding Level*




O&M ($/kW-yr) - Tower Only
62.30
77.00
0.0%
5.0%
95.0%
17.5%
82.6%
0.0%
37.8%
62.2%
0.0%
57.0%
43.0%
0.0%
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
30
35
40
45
50
55
60
65
70
75
80
Reference O&M ($/kW-yr)
Minimum 77.0000
Maximum 77.0000
Mean 77.0000
Aggregated Experts- 2015- Expanded DOE R&D- O&M ($/kW-yr)- Tower
Minimum 32.3568
Maximum 76.9000
Mean 70.1418
Aggregated Experts- 2020- Expanded DOE R&D- O&M ($/kW-yr)- Tower
Minimum 34.3677
Maximum 76.9000
Mean 66.0572
Aggregated Experts- 2025- Expanded DOE R&D- O&M ($/kW-yr)- Tower
Minimum 34.4295
Maximum 76.9000
Mean 61.2551

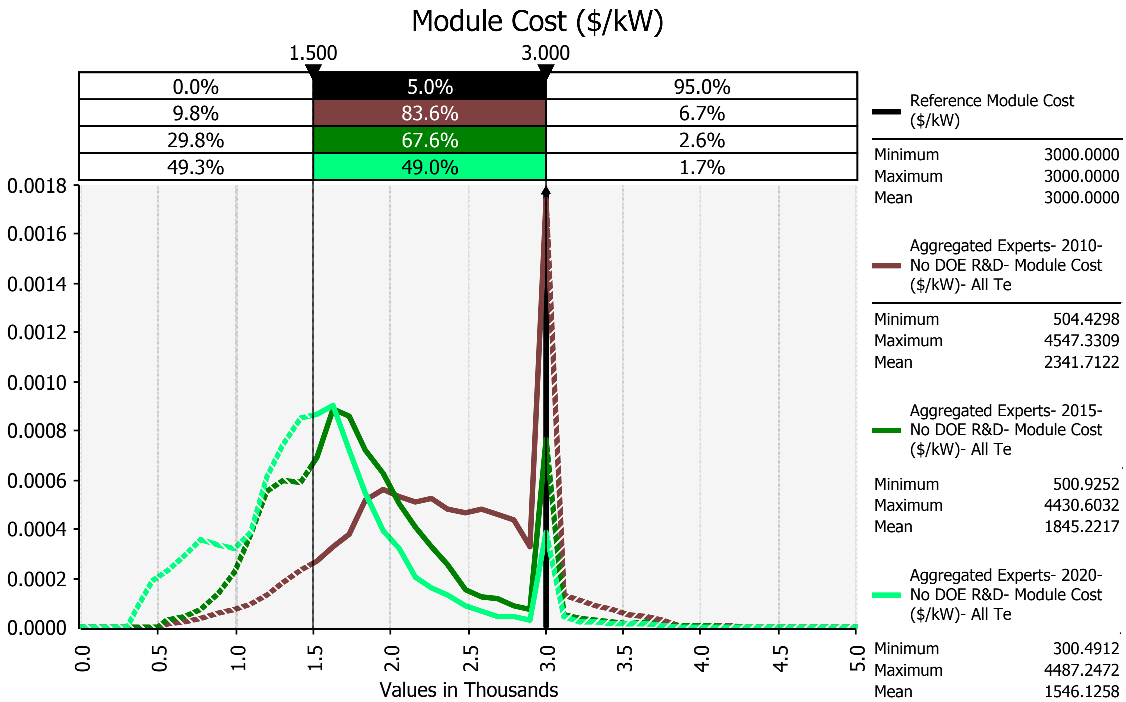
# Appendix E: Photovoltaic (PV) Risk Analysis, Summary of @Risk Results—Aggregated Probability Distributions

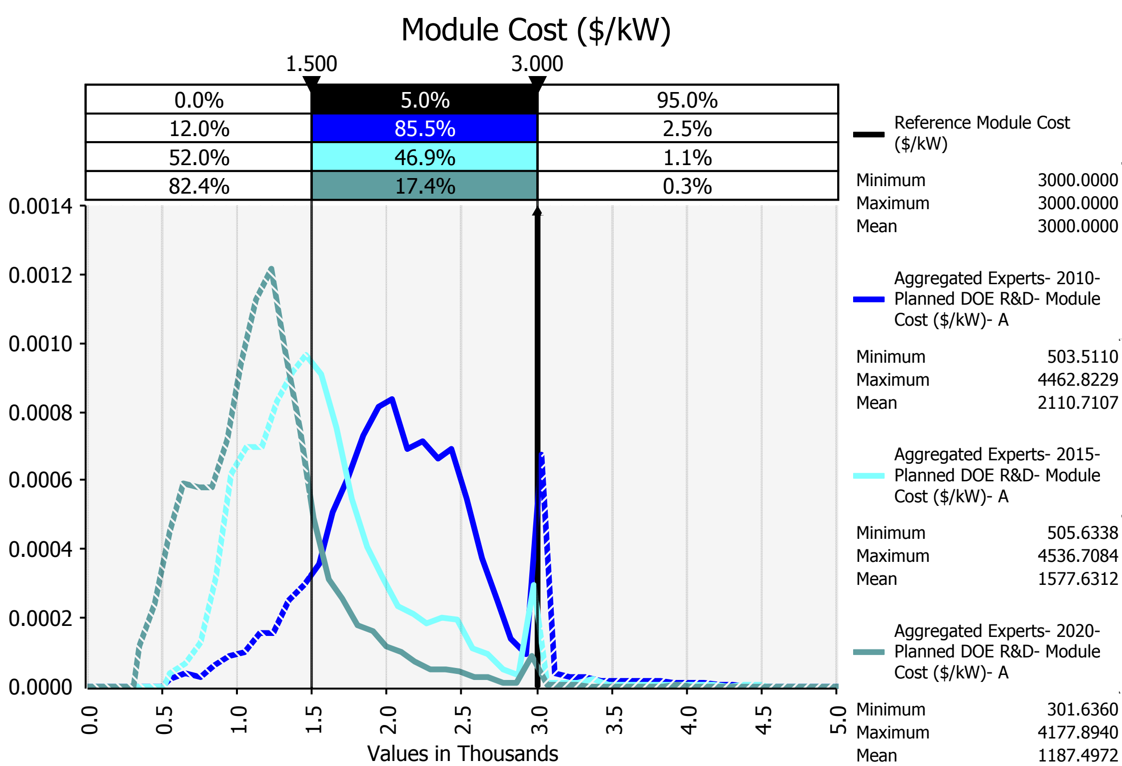
## E.1 Technical Risk and Uncertainty Analysis: Solar PV - Utility

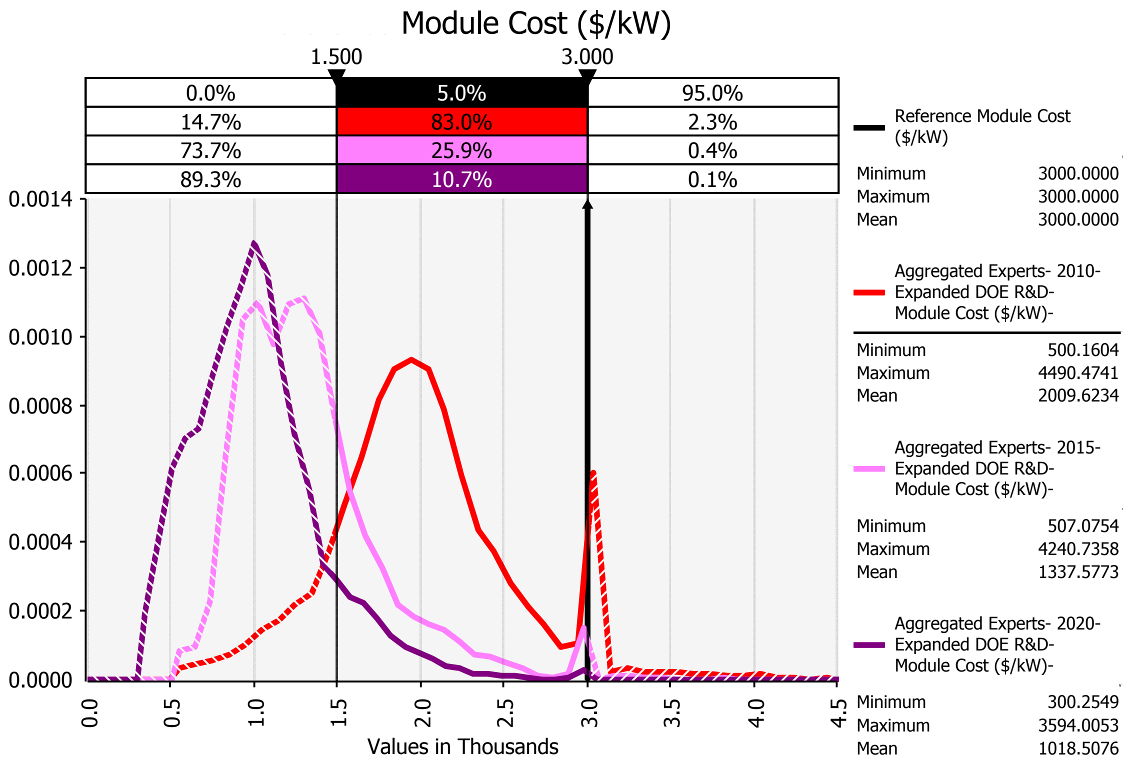
The following figures represent the aggregated module costs, inverter costs, total system cost, O&M costs, inverter lifetimes, and learning by doing (LBD) ranges provided by the experts in the three budget scenarios for PV Utility ($0, $140M, and $280M).

The three colored lines in each of these graphs represent the aggregated expert inputs for the three time periods for PV Utility (2010, 2015, and 2020). In each of the graphs, the 2009 reference values are represented by the black line on the right of the graphs, and the FY10 GPRA Program goal-based input value for 2015 is represented by the delimiter (i.e., thin black vertical lines) on the left of each graph. The percentages to the left side of the delimiter represent the likelihood of at least achieving the "goal-based" value. The percentages between the delimiters represent the likelihood of improving to somewhere between the "goal-based" value and reference value. Furthermore, the key to the right of each graph also lists the minimum, maximum, and mean for each aggregated distribution.

### *Module Cost—by Funding Level*

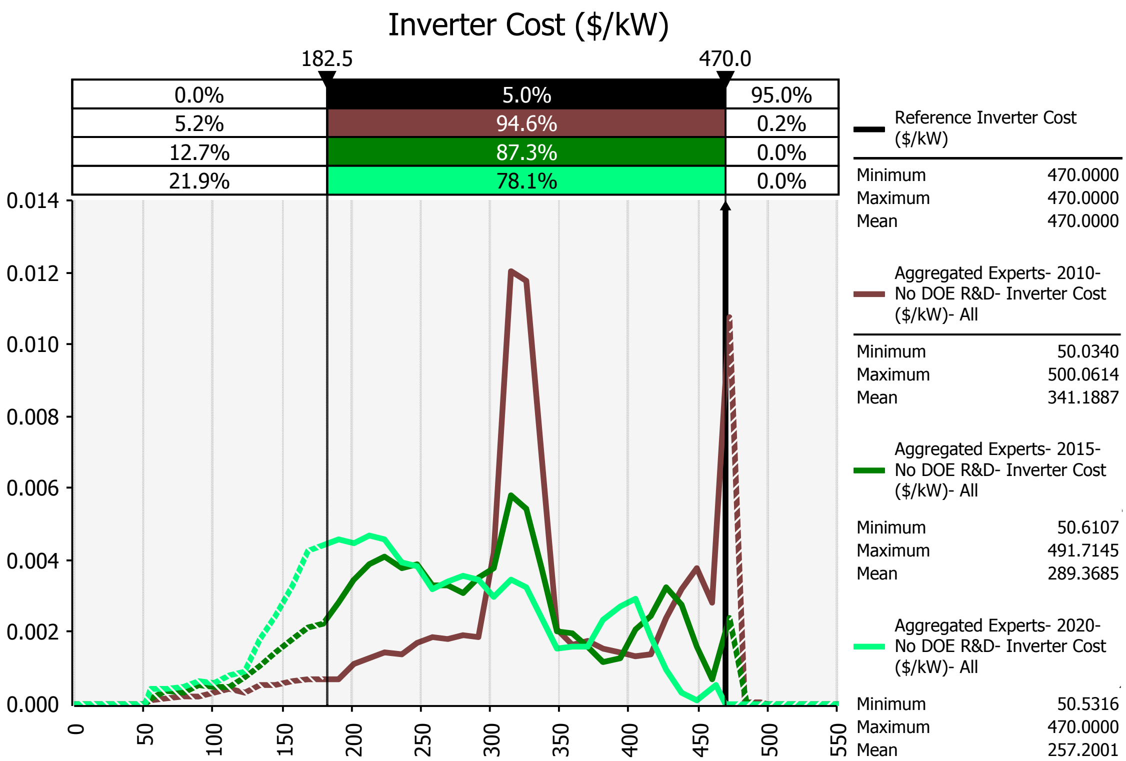


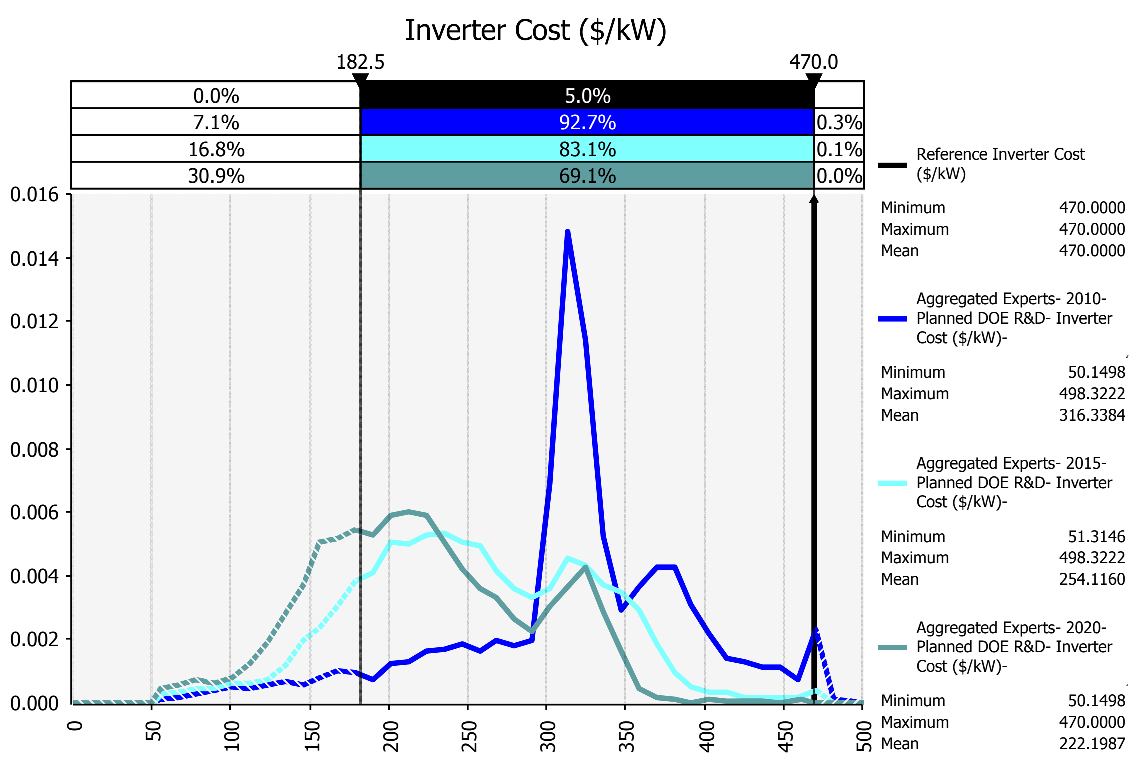



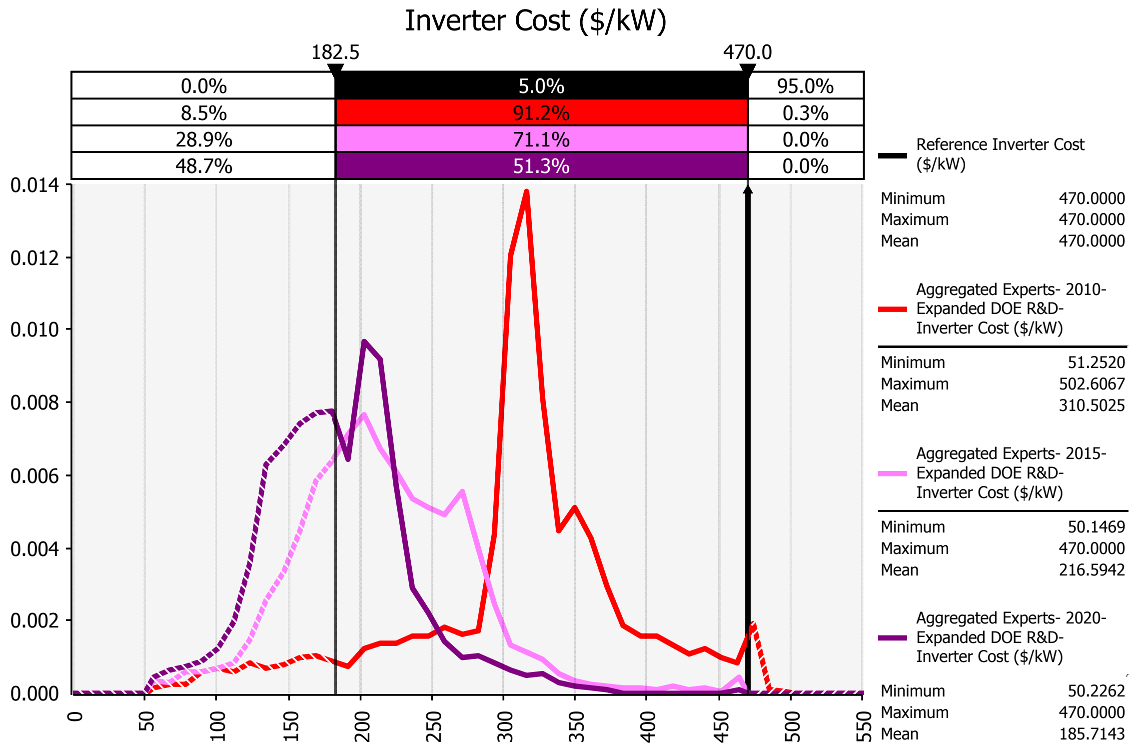


Module Cost ($/kW)
1.500
3.000
0.0%
5.0%
95.0%
14.7%
83.0%
2.3%
73.7%
25.9%
0.4%
89.3%
10.7%
0.1%
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Values in Thousands
Reference Module Cost ($/kW)
Minimum 3000.0000
Maximum 3000.0000
Mean 3000.0000
Aggregated Experts- 2010- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 500.1604
Maximum 4490.4741
Mean 2009.6234
Aggregated Experts- 2015- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 507.0754
Maximum 4240.7358
Mean 1337.5773
Aggregated Experts- 2020- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 300.2549
Maximum 3594.0053
Mean 1018.5076

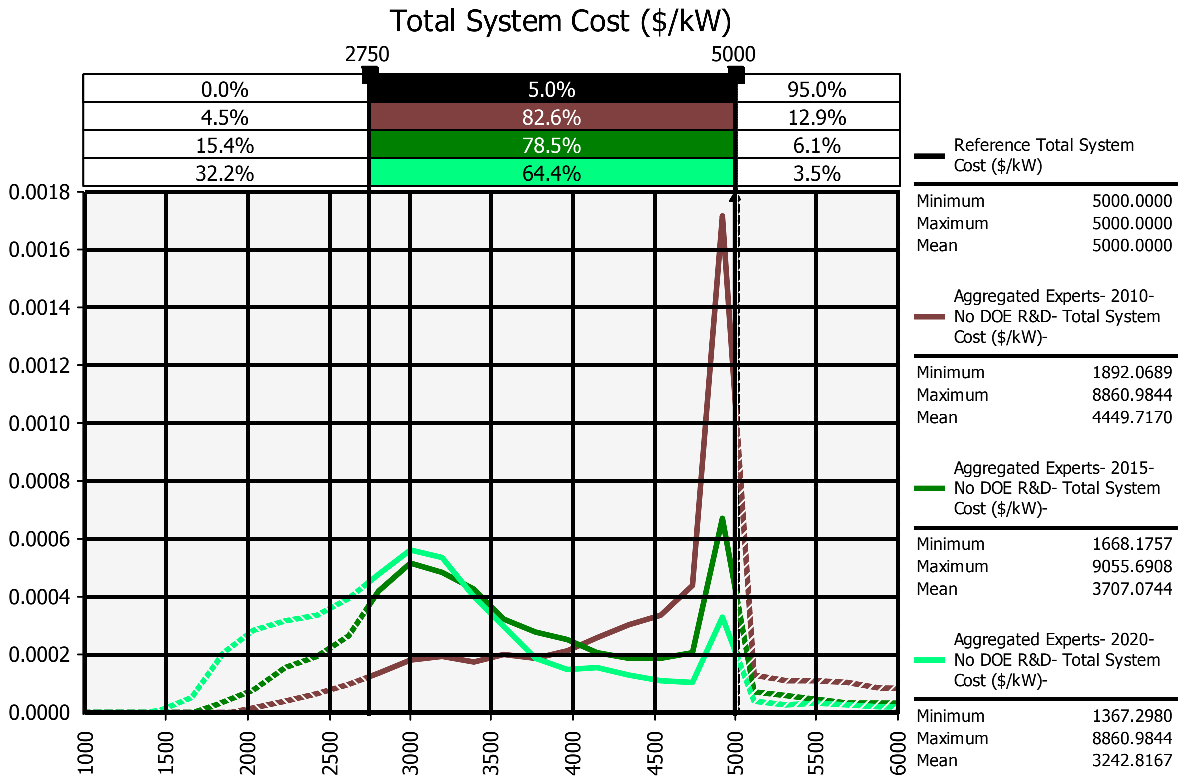
### *Inverter Cost—by Funding Level*

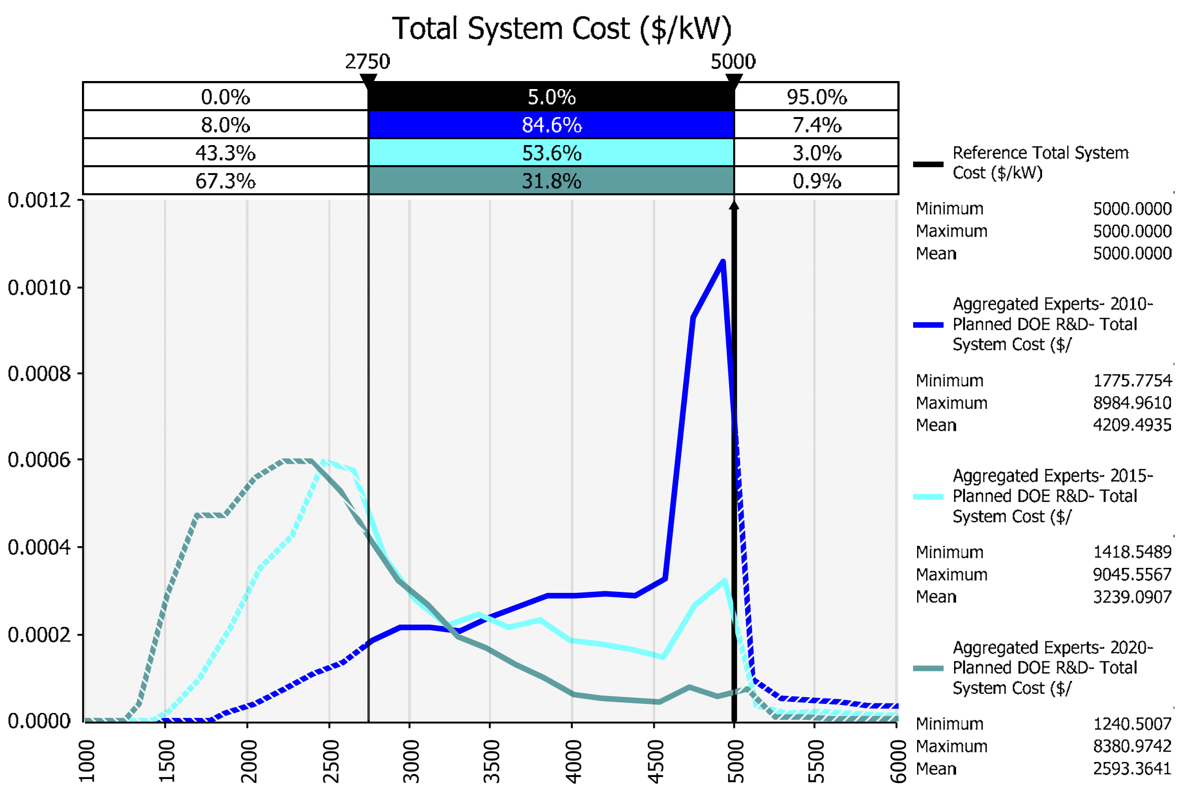


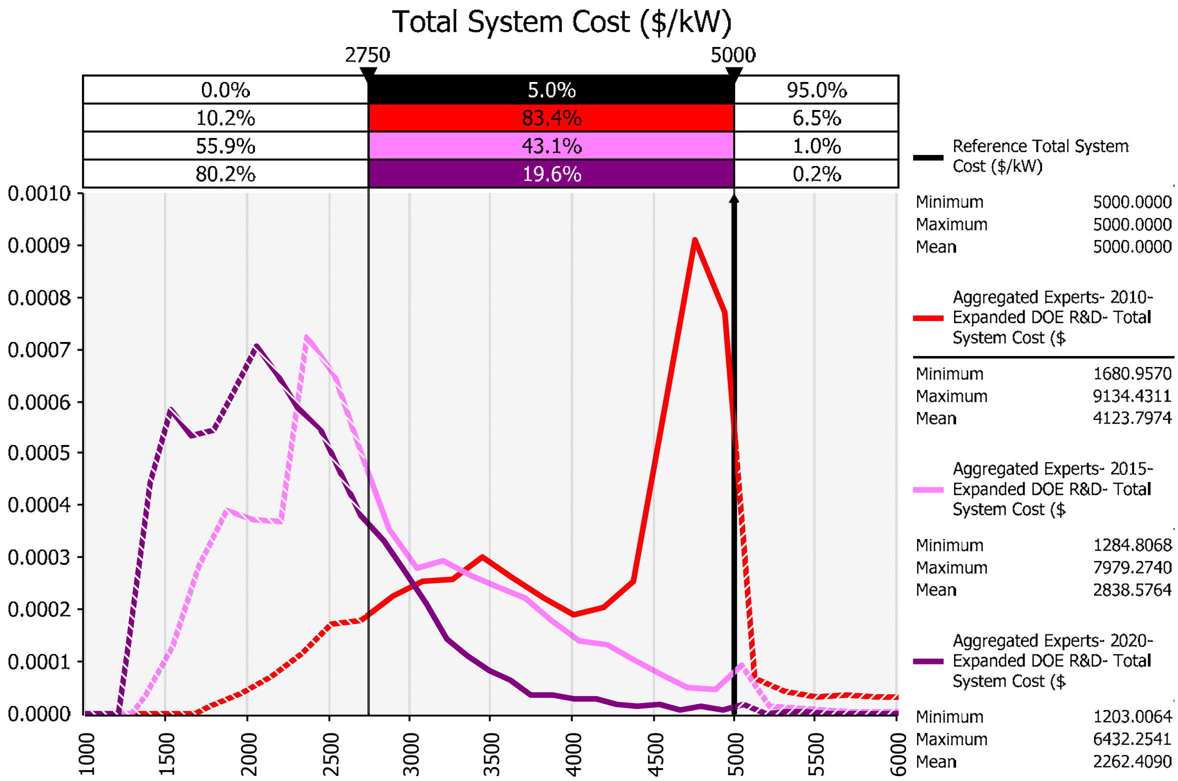




Inverter Cost ($/kW)
182.5
470.0
0.0%
5.0%
95.0%
8.5%
91.2%
0.3%
28.9%
71.1%
0.0%
48.7%
51.3%
0.0%
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
50
100
150
200
250
300
350
400
450
500
550
Reference Inverter Cost ($/kW)
Minimum 470.0000
Maximum 470.0000
Mean 470.0000
Aggregated Experts- 2010- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 51.2520
Maximum 502.6067
Mean 310.5025
Aggregated Experts- 2015- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 50.1469
Maximum 470.0000
Mean 216.5942
Aggregated Experts- 2020- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 50.2262
Maximum 470.0000
Mean 185.7143

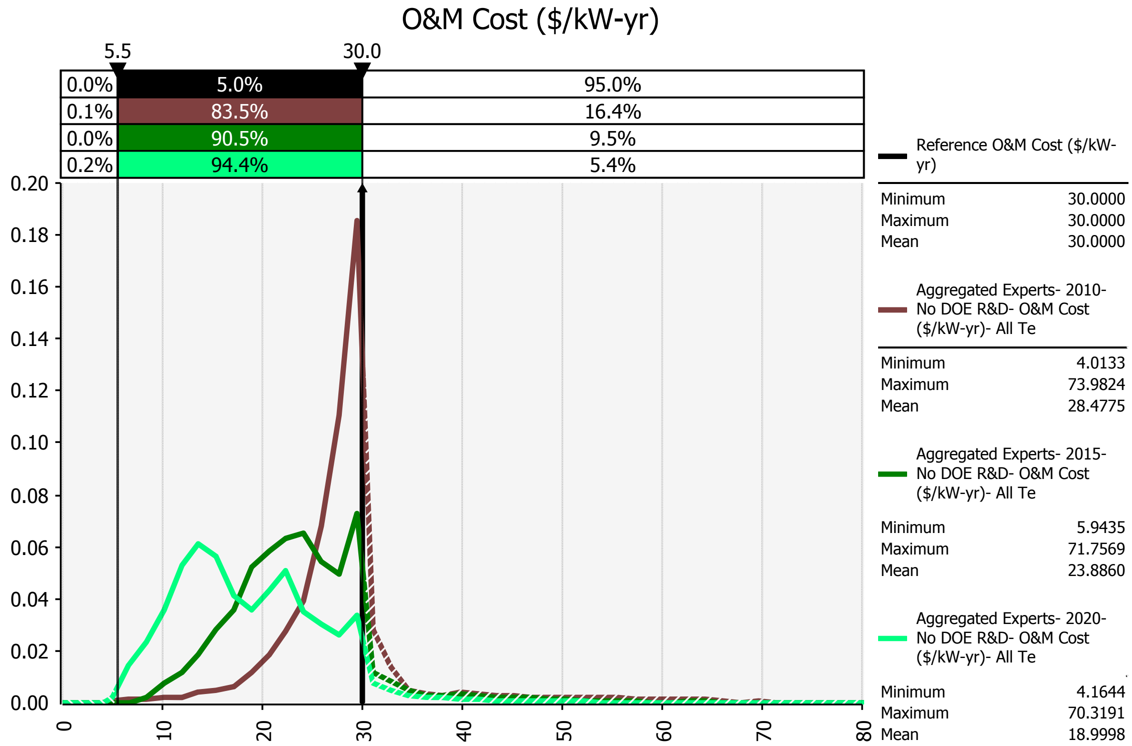
## *Total System Cost—by Funding Level*

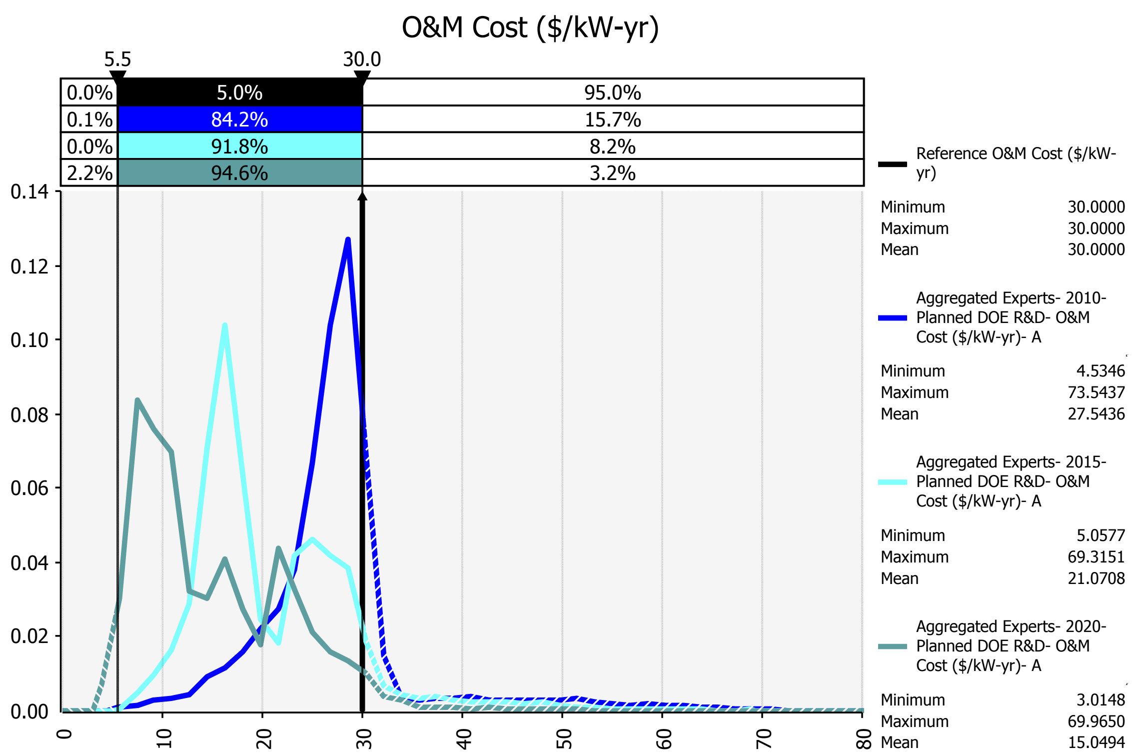


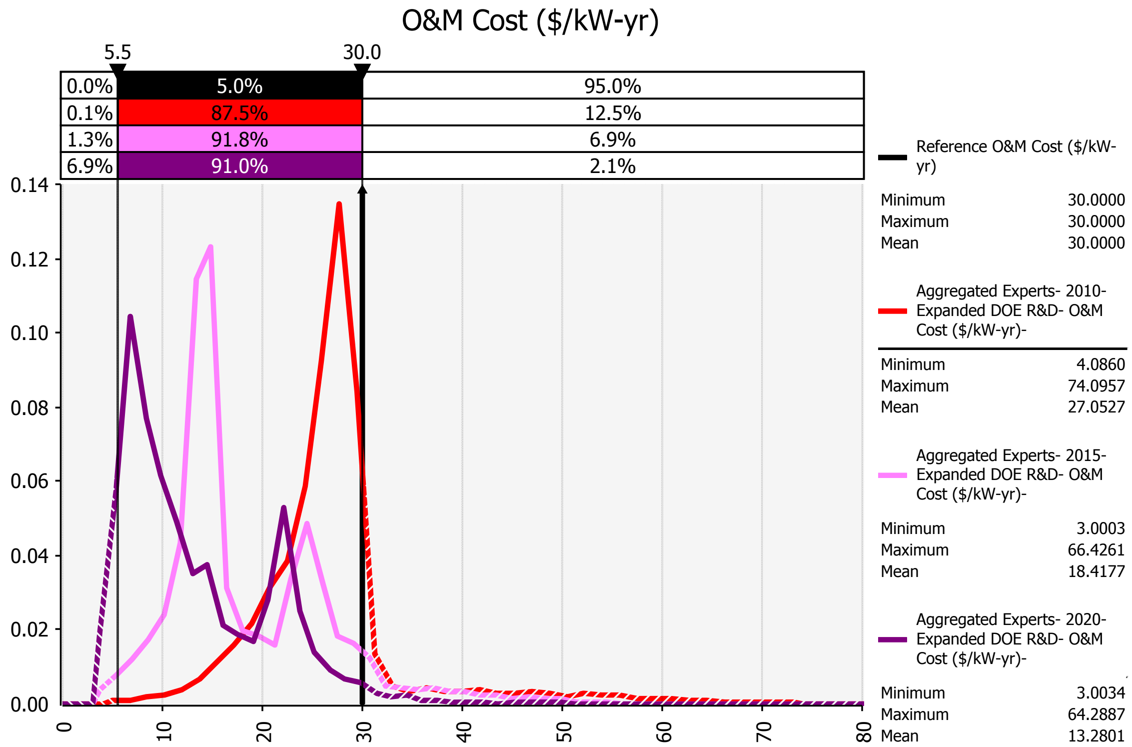




Total System Cost ($/kW)
2750
5000
0.0% | 5.0% | 95.0%
10.2% | 83.4% | 6.5%
55.9% | 43.1% | 1.0%
80.2% | 19.6% | 0.2%
0.0010
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
Reference Total System Cost ($/kW)
Minimum 5000.0000
Maximum 5000.0000
Mean 5000.0000
Aggregated Experts- 2010- Expanded DOE R&D- Total System Cost ($
Minimum 1680.9570
Maximum 9134.4311
Mean 4123.7974
Aggregated Experts- 2015- Expanded DOE R&D- Total System Cost ($
Minimum 1284.8068
Maximum 7979.2740
Mean 2838.5764
Aggregated Experts- 2020- Expanded DOE R&D- Total System Cost ($
Minimum 1203.0064
Maximum 6432.2541
Mean 2262.4090

### *O&M System Cost—by Funding Level*

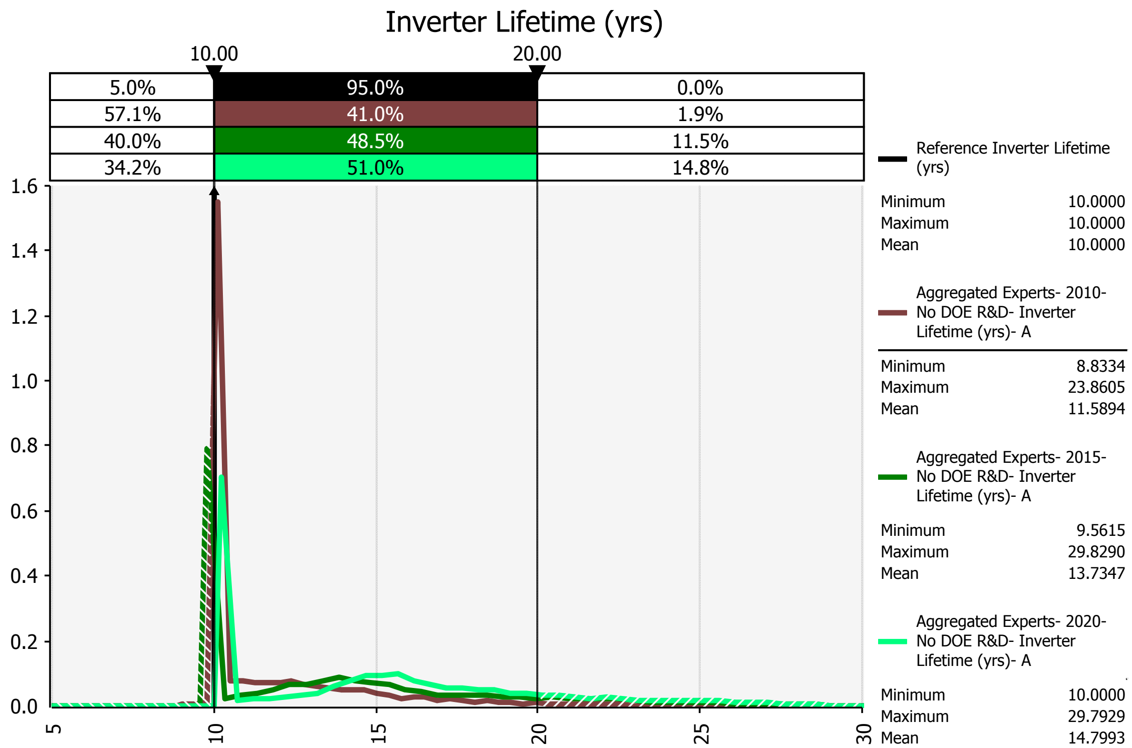


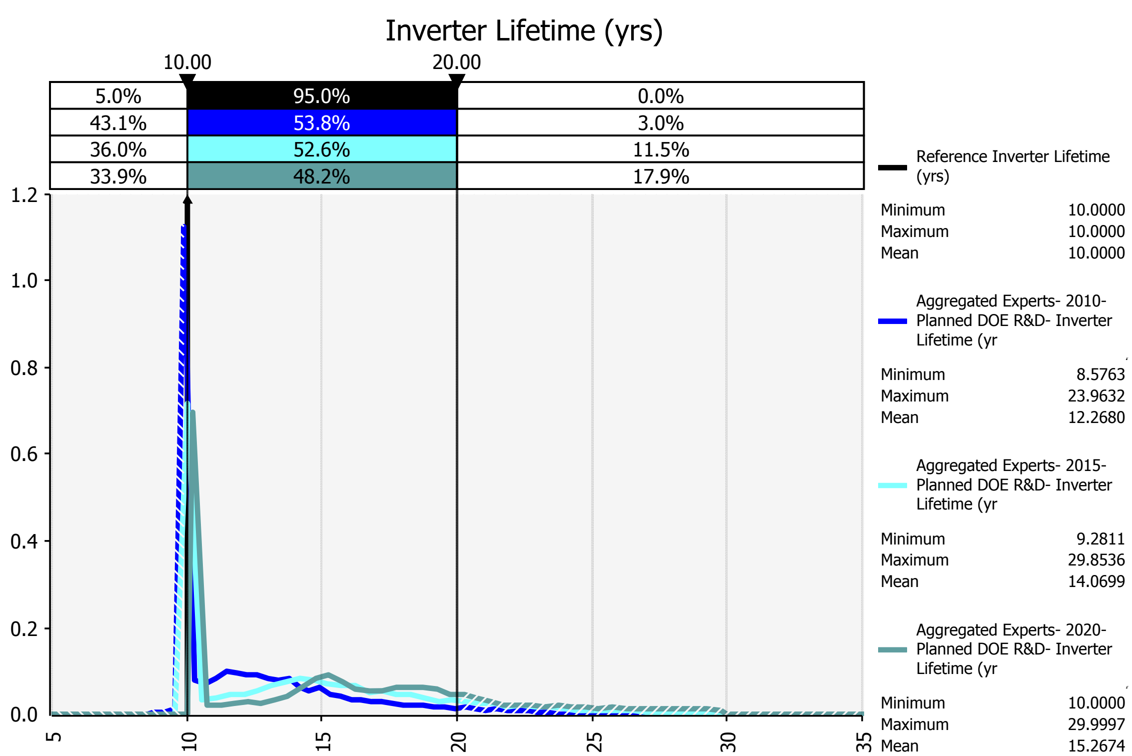



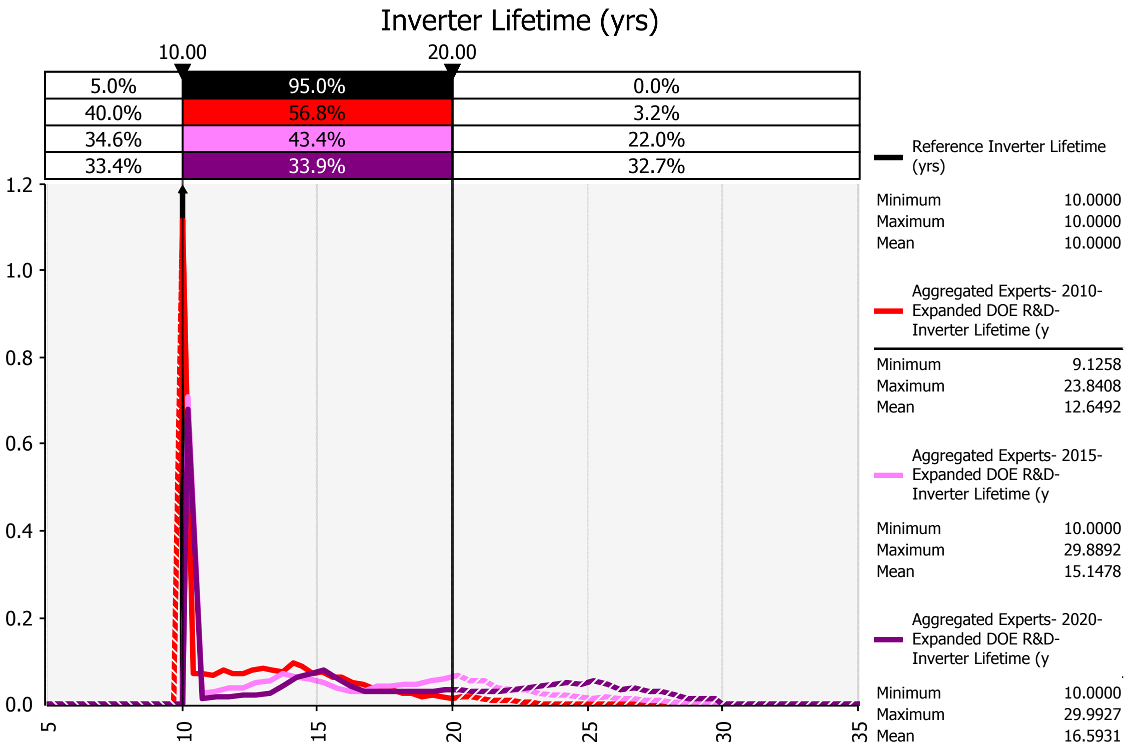


O&M Cost ($/kW-yr)
5.5
30.0
0.0%
5.0%
95.0%
0.1%
87.5%
12.5%
1.3%
91.8%
6.9%
6.9%
91.0%
2.1%
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40
50
60
70
80
Reference O&M Cost ($/kW-yr)
Minimum 30.0000
Maximum 30.0000
Mean 30.0000
Aggregated Experts- 2010- Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 4.0860
Maximum 74.0957
Mean 27.0527
Aggregated Experts- 2015- Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 3.0003
Maximum 66.4261
Mean 18.4177
Aggregated Experts- 2020- Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 3.0034
Maximum 64.2887
Mean 13.2801

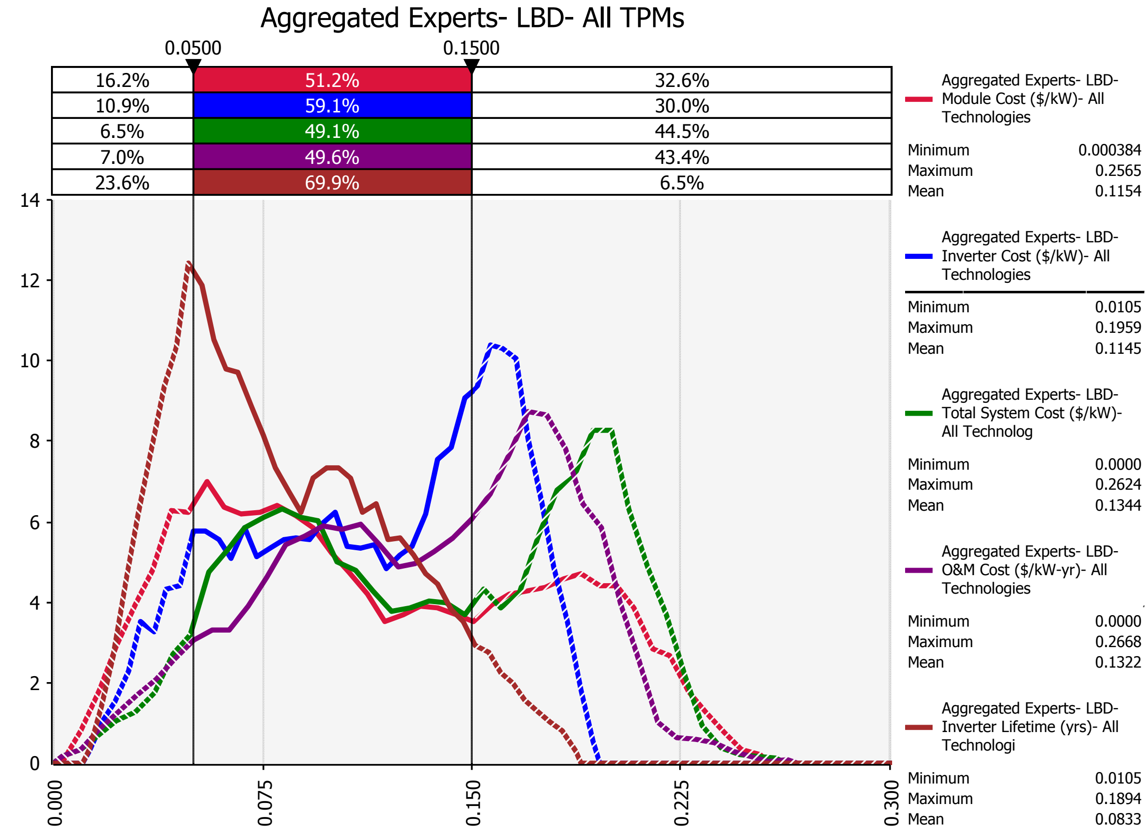
### *Inverter Life—by Funding Level*




Inverter Lifetime (yrs)
10.00
20.00
5.0% 95.0% 0.0%
40.0% 56.8% 3.2%
34.6% 43.4% 22.0%
33.4% 33.9% 32.7%
1.2
1.0
0.8
0.6
0.4
0.2
0.0
5
10
15
20
25
30
35
Reference Inverter Lifetime (yrs)
Minimum 10.0000
Maximum 10.0000
Mean 10.0000
Aggregated Experts- 2010- Expanded DOE R&D- Inverter Lifetime (y
Minimum 9.1258
Maximum 23.8408
Mean 12.6492
Aggregated Experts- 2015- Expanded DOE R&D- Inverter Lifetime (y
Minimum 10.0000
Maximum 29.8892
Mean 15.1478
Aggregated Experts- 2020- Expanded DOE R&D- Inverter Lifetime (y
Minimum 10.0000
Maximum 29.9927
Mean 16.5931

### *LBD—All TPMs*



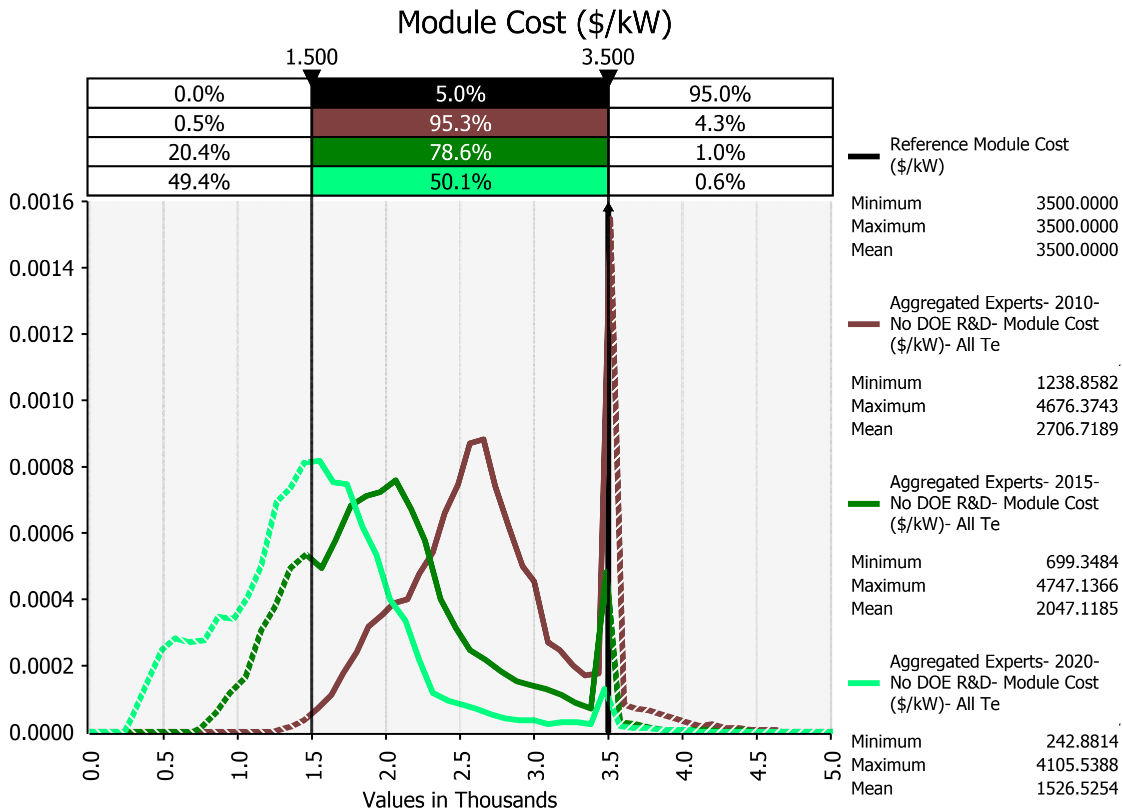
Aggregated Experts- LBD- All TPMs
0.0500
0.1500
16.2% 51.2% 32.6%
10.9% 59.1% 30.0%
6.5% 49.1% 44.5%
7.0% 49.6% 43.4%
23.6% 69.9% 6.5%
14
12
10
8
6
4
2
0
0.000
0.075
0.150
0.225
0.300
Aggregated Experts- LBD- Module Cost ($/kW)- All Technologies
Minimum 0.000384
Maximum 0.2565
Mean 0.1154
Aggregated Experts- LBD- Inverter Cost ($/kW)- All Technologies
Minimum 0.0105
Maximum 0.1959
Mean 0.1145
Aggregated Experts- LBD- Total System Cost ($/kW)- All Technolog
Minimum 0.0000
Maximum 0.2624
Mean 0.1344
Aggregated Experts- LBD- O&M Cost ($/kW-yr)- All Technologies
Minimum 0.0000
Maximum 0.2668
Mean 0.1322
Aggregated Experts- LBD- Inverter Lifetime (yrs)- All Technologi
Minimum 0.0105
Maximum 0.1894
Mean 0.0833

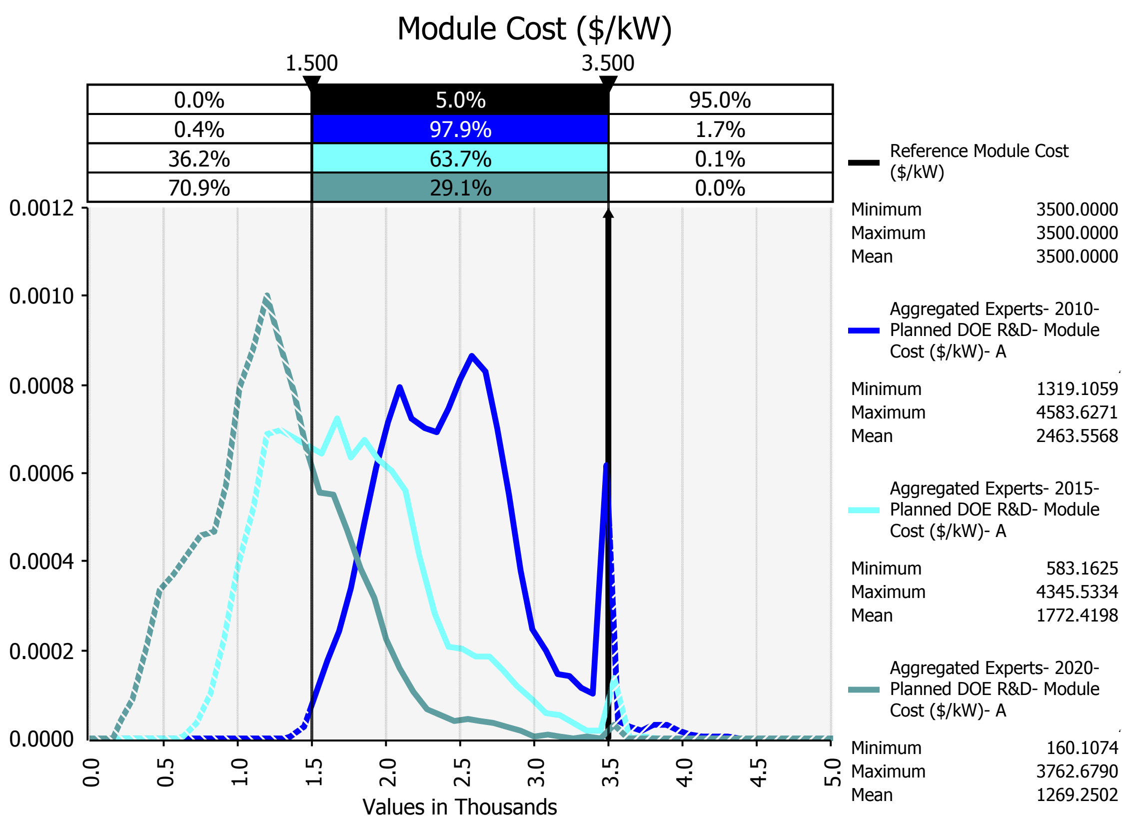
## E.2 Technical Risk and Uncertainty Analysis, Solar PV—Commercial

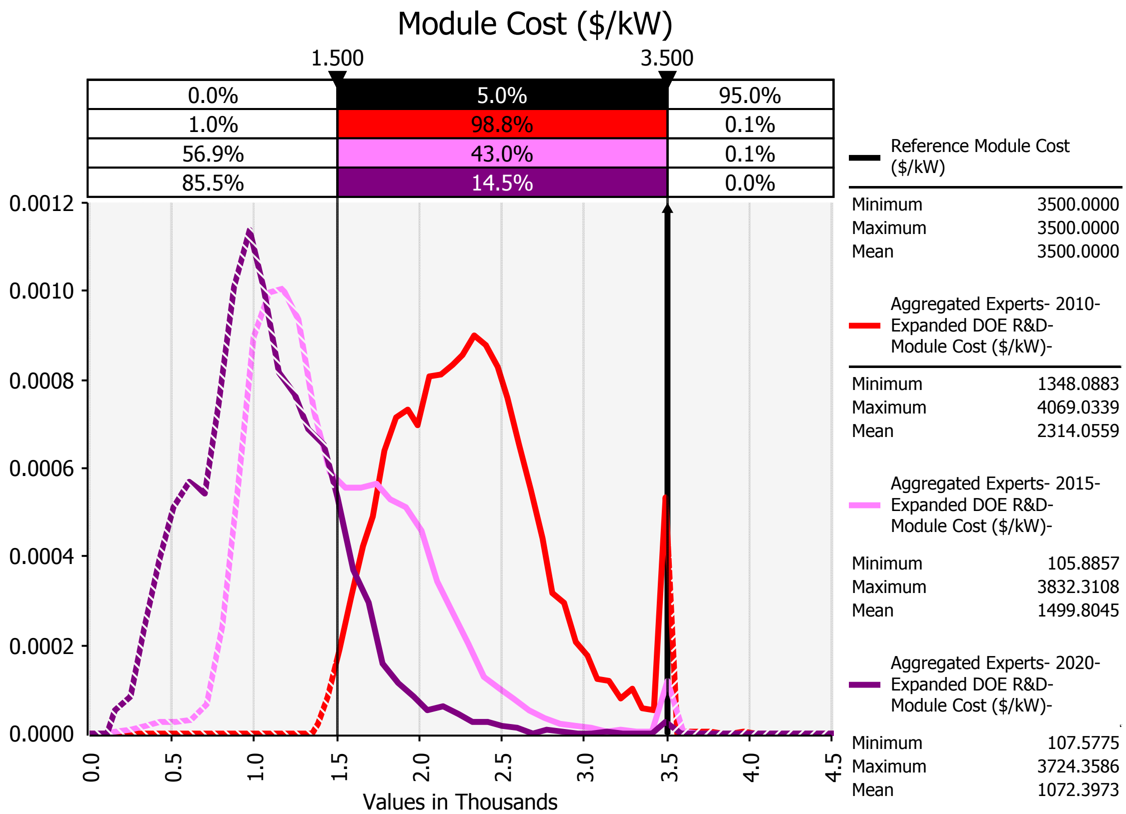
The following figures represent the aggregated module costs, inverter costs, total system cost, O&M costs, inverter lifetimes, and learning by doing (LBD) ranges provided by the experts in the three budget scenarios for PV Commercial ($0, $140M, and $280M).

The three colored lines in each of these graphs represent the aggregated expert inputs for the three time periods for PV Commercial (2010, 2015, and 2020). In each of the graphs, the 2009 reference values are represented by the black line on the right of the graphs, and the FY10 GPRA Program goal-based input value for 2015 is represented by the delimiter (i.e., thin black vertical lines) on the left of each graph. The percentages to the left side of the delimiter represent the likelihood of at least achieving the "goal-based" value. The percentages between the delimiters represent the likelihood of improving to somewhere between the "goal-based" value and reference value. Furthermore, the key to the right of each graph also lists the minimum, maximum, and mean for each aggregated distribution.

### ***Module Cost—by Funding Level***

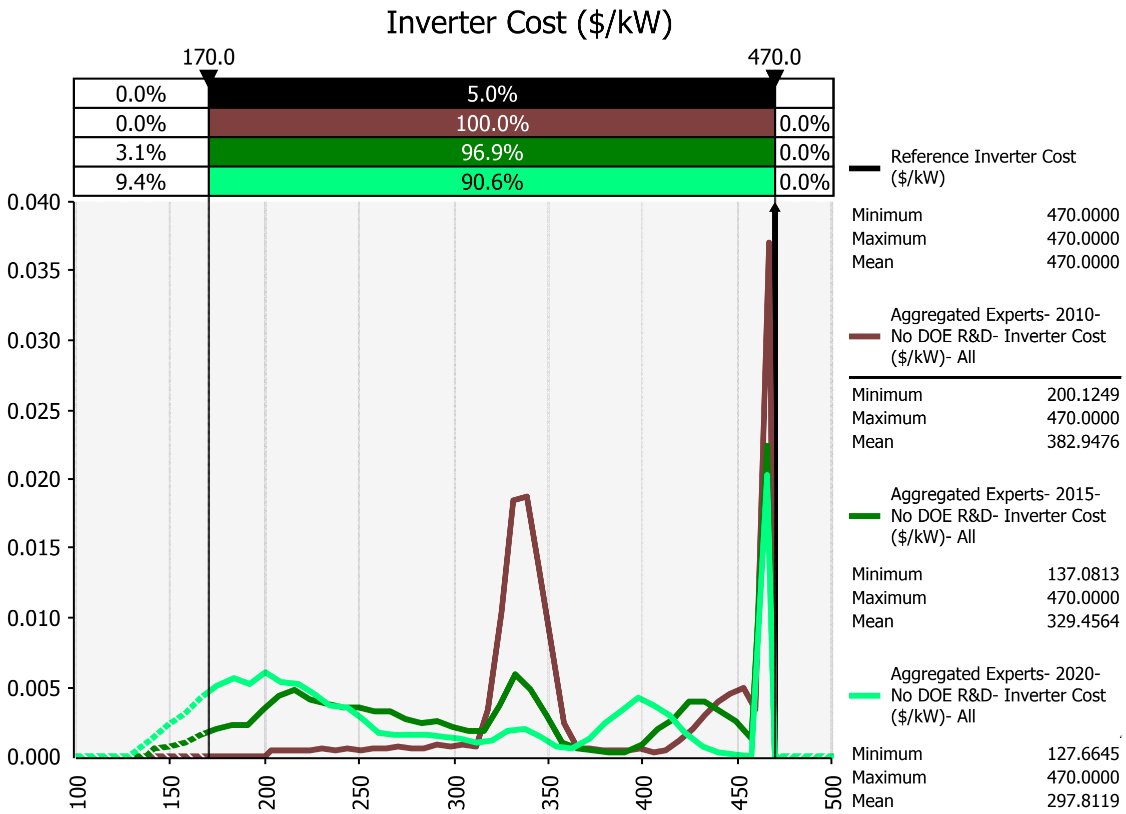


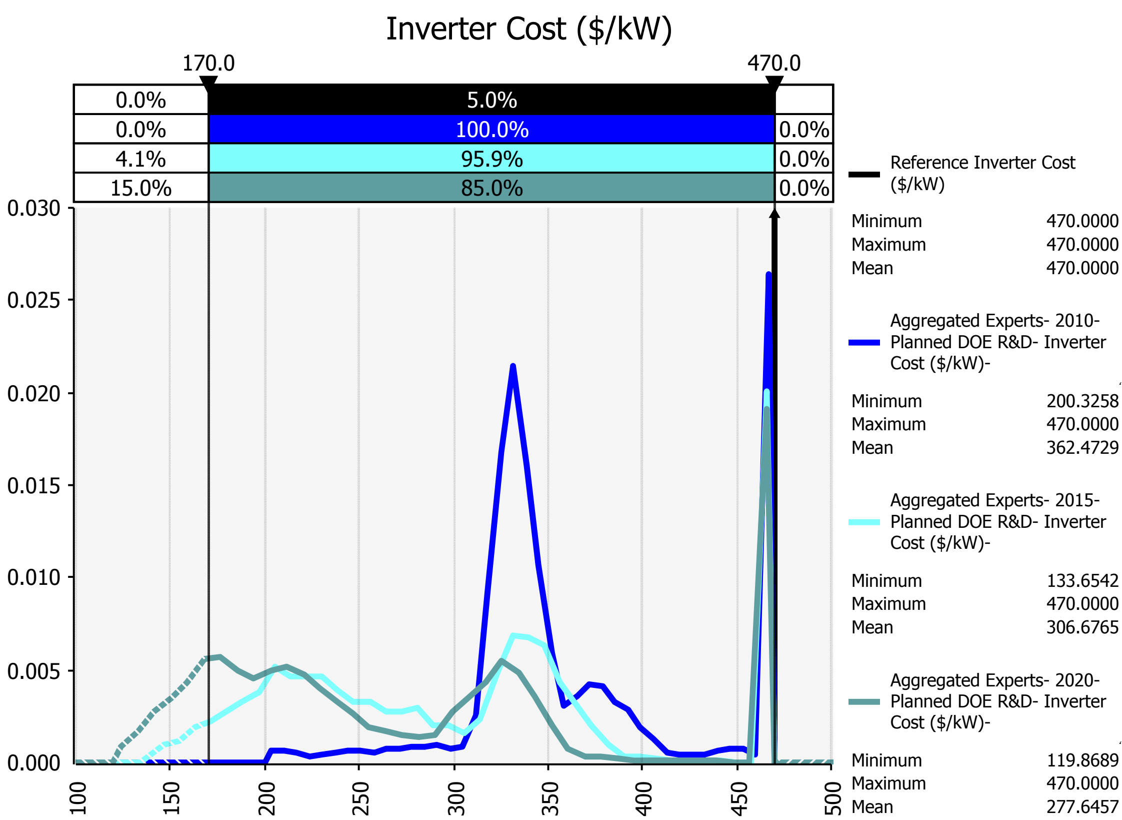



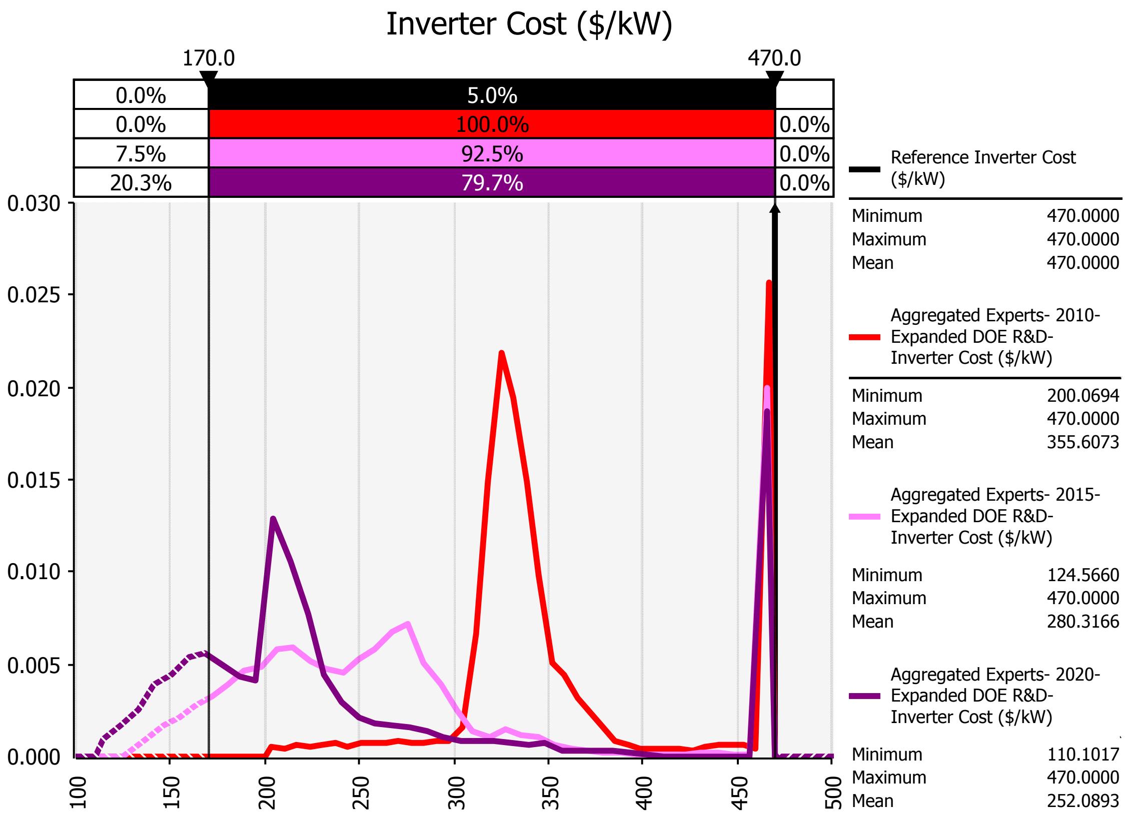


Module Cost ($/kW)
1.500
3.500
0.0%
5.0%
95.0%
1.0%
98.8%
0.1%
56.9%
43.0%
0.1%
85.5%
14.5%
0.0%
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Values in Thousands
Reference Module Cost ($/kW)
Minimum 3500.0000
Maximum 3500.0000
Mean 3500.0000
Aggregated Experts- 2010- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 1348.0883
Maximum 4069.0339
Mean 2314.0559
Aggregated Experts- 2015- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 105.8857
Maximum 3832.3108
Mean 1499.8045
Aggregated Experts- 2020- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 107.5775
Maximum 3724.3586
Mean 1072.3973

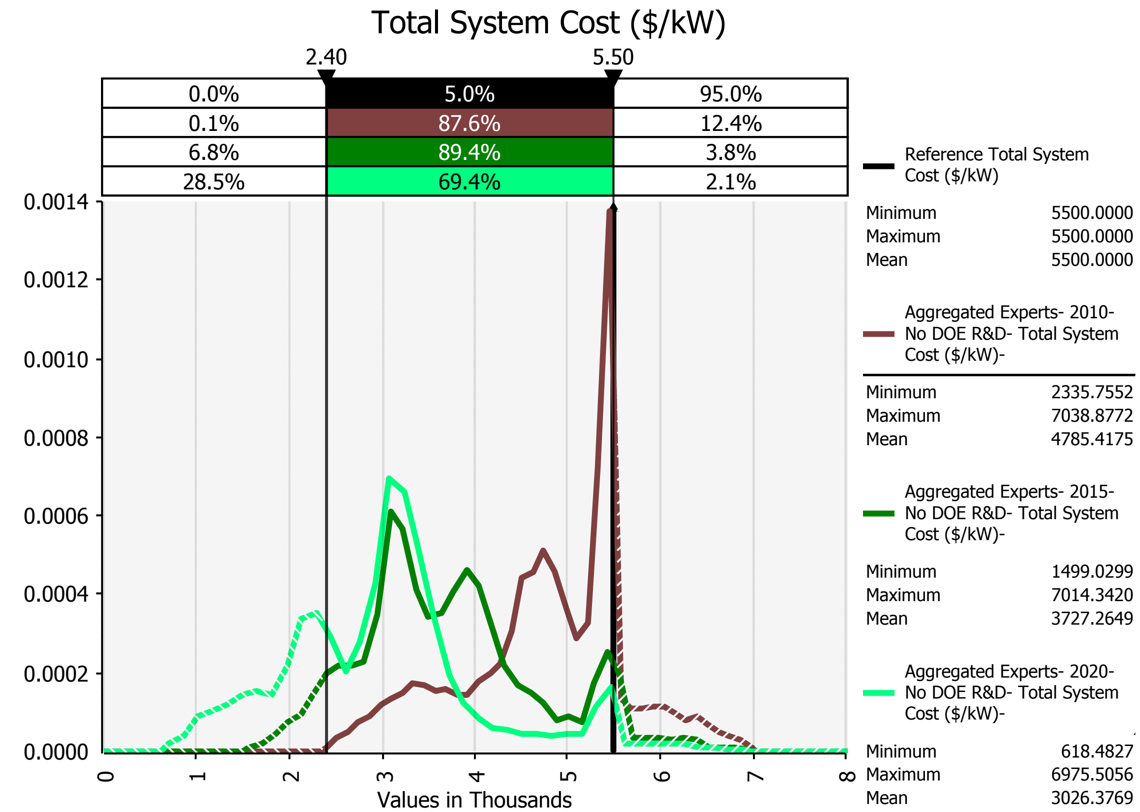
## *Inverter Cost—by Funding Level*

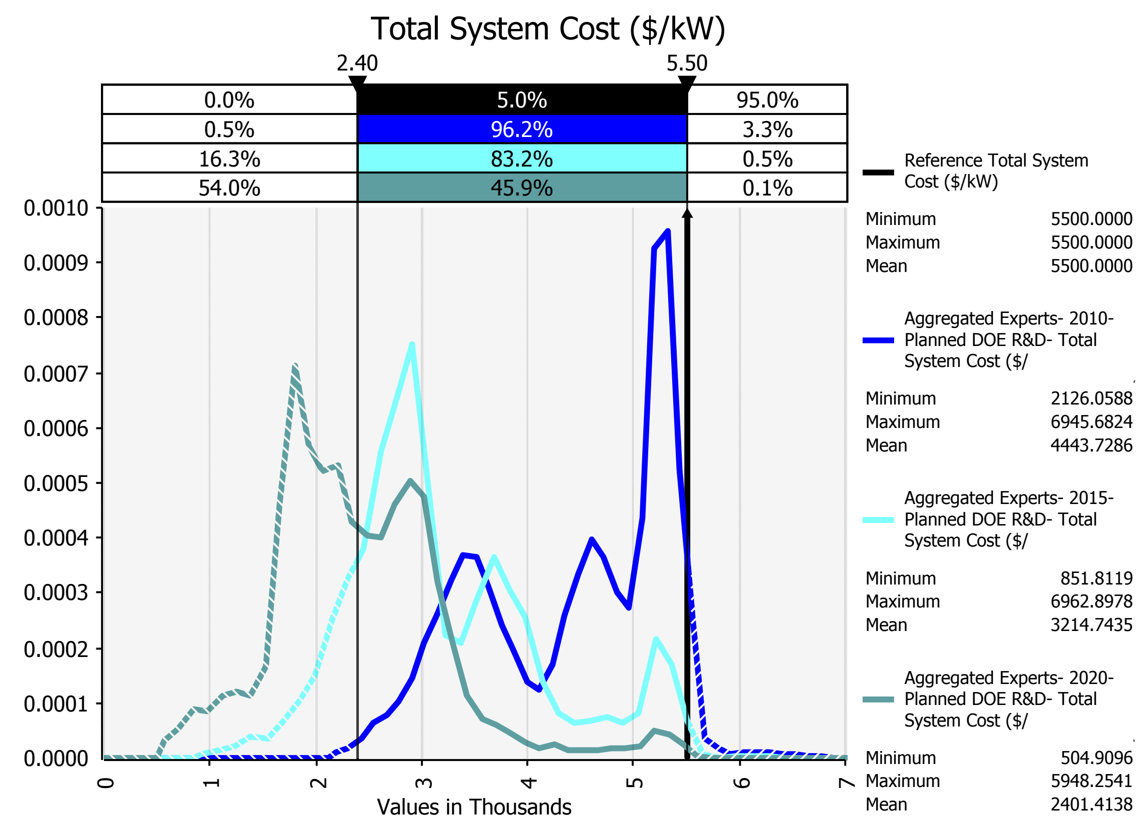


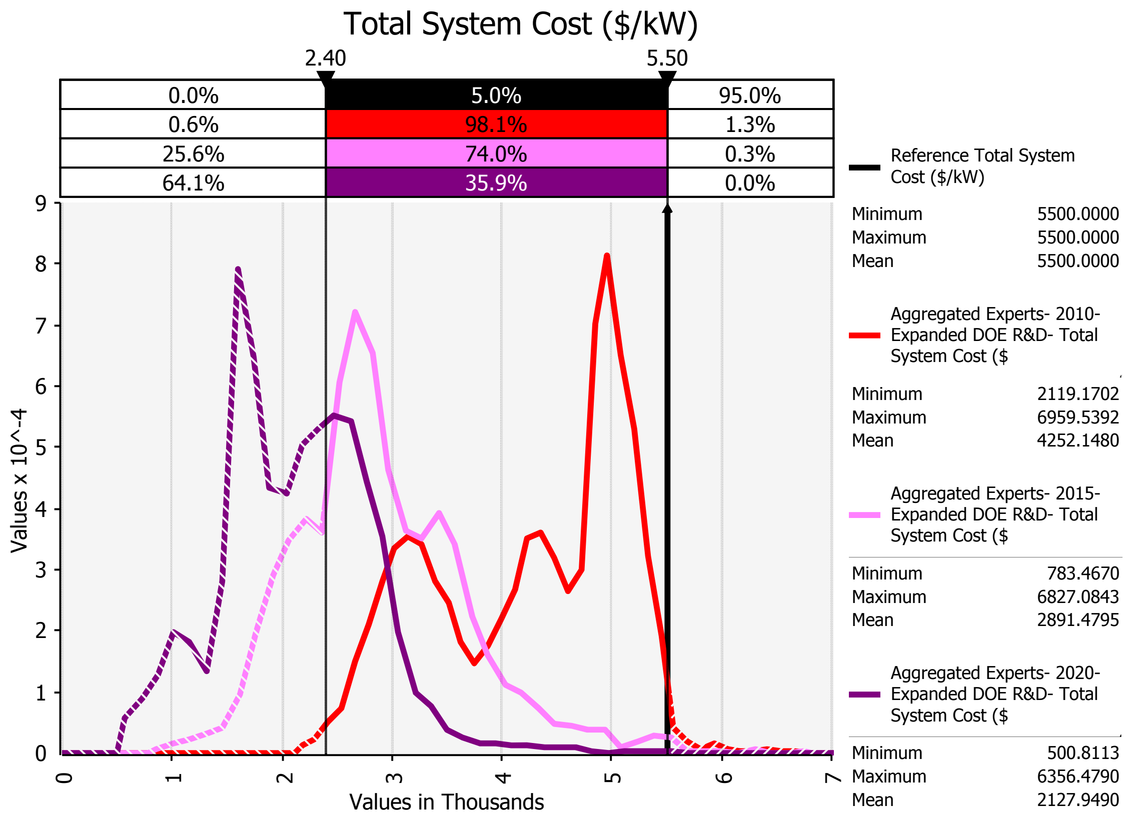




Inverter Cost ($/kW)
170.0
470.0
0.0%
5.0%
0.0%
100.0%
0.0%
7.5%
92.5%
0.0%
20.3%
79.7%
0.0%
0.030
0.025
0.020
0.015
0.010
0.005
0.000
100
150
200
250
300
350
400
450
500
Reference Inverter Cost ($/kW)
Minimum 470.0000
Maximum 470.0000
Mean 470.0000
Aggregated Experts- 2010- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 200.0694
Maximum 470.0000
Mean 355.6073
Aggregated Experts- 2015- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 124.5660
Maximum 470.0000
Mean 280.3166
Aggregated Experts- 2020- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 110.1017
Maximum 470.0000
Mean 252.0893

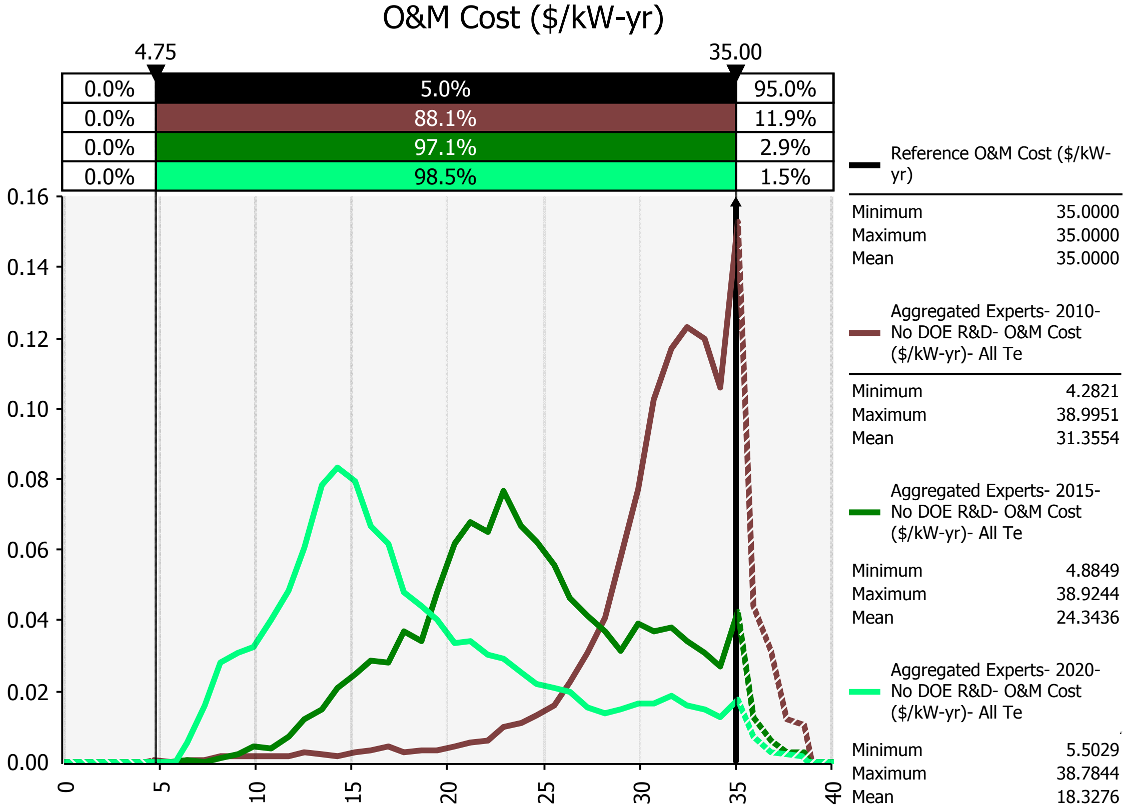
***Total System Cost—by Funding Level***

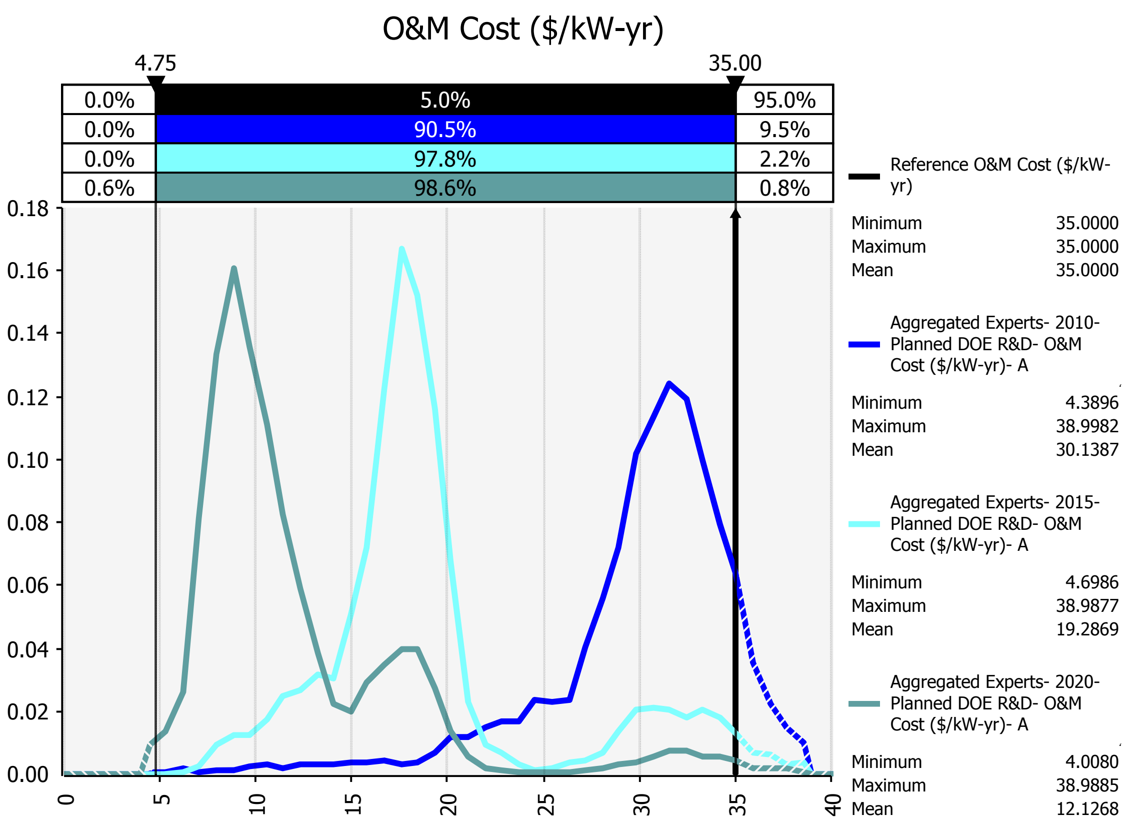


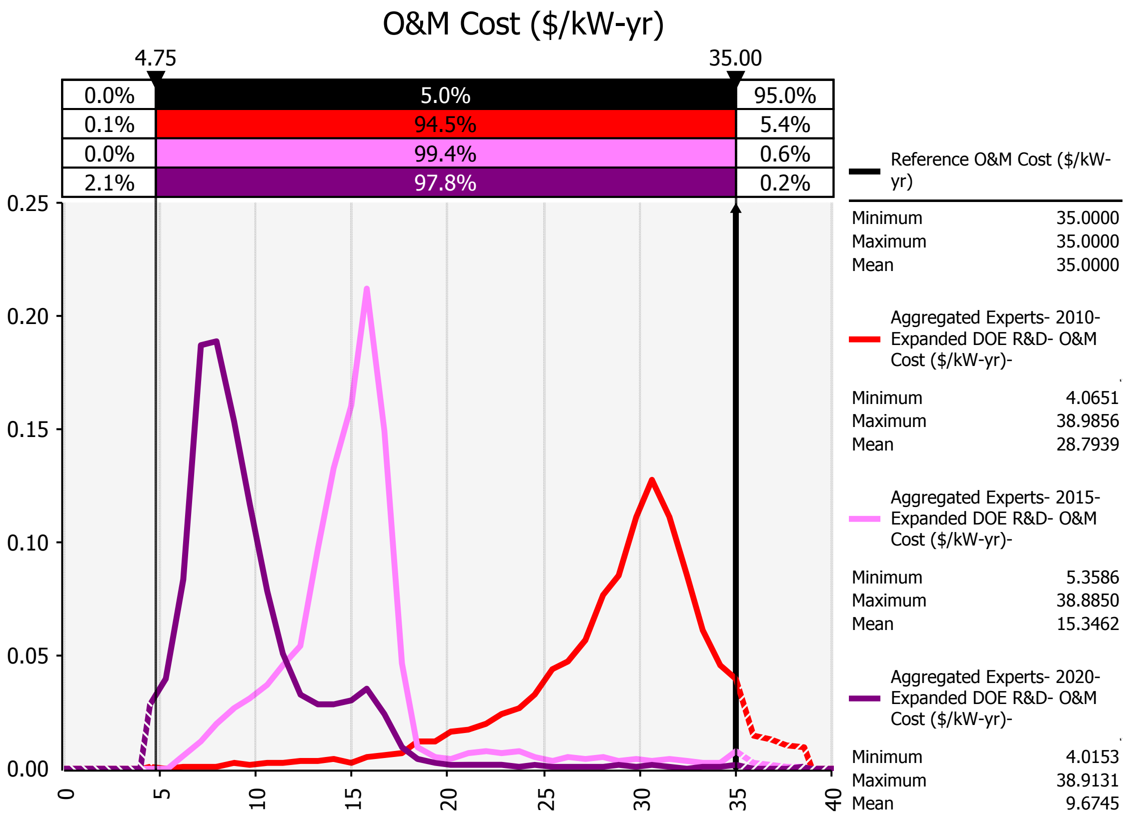




Total System Cost ($/kW)
2.40
5.50
0.0%
5.0%
95.0%
0.6%
98.1%
1.3%
25.6%
74.0%
0.3%
64.1%
35.9%
0.0%
Values x 10^-4
Values in Thousands
Reference Total System Cost ($/kW)
Minimum 5500.0000
Maximum 5500.0000
Mean 5500.0000
Aggregated Experts- 2010- Expanded DOE R&D- Total System Cost ($
Minimum 2119.1702
Maximum 6959.5392
Mean 4252.1480
Aggregated Experts- 2015- Expanded DOE R&D- Total System Cost ($
Minimum 783.4670
Maximum 6827.0843
Mean 2891.4795
Aggregated Experts- 2020- Expanded DOE R&D- Total System Cost ($
Minimum 500.8113
Maximum 6356.4790
Mean 2127.9490

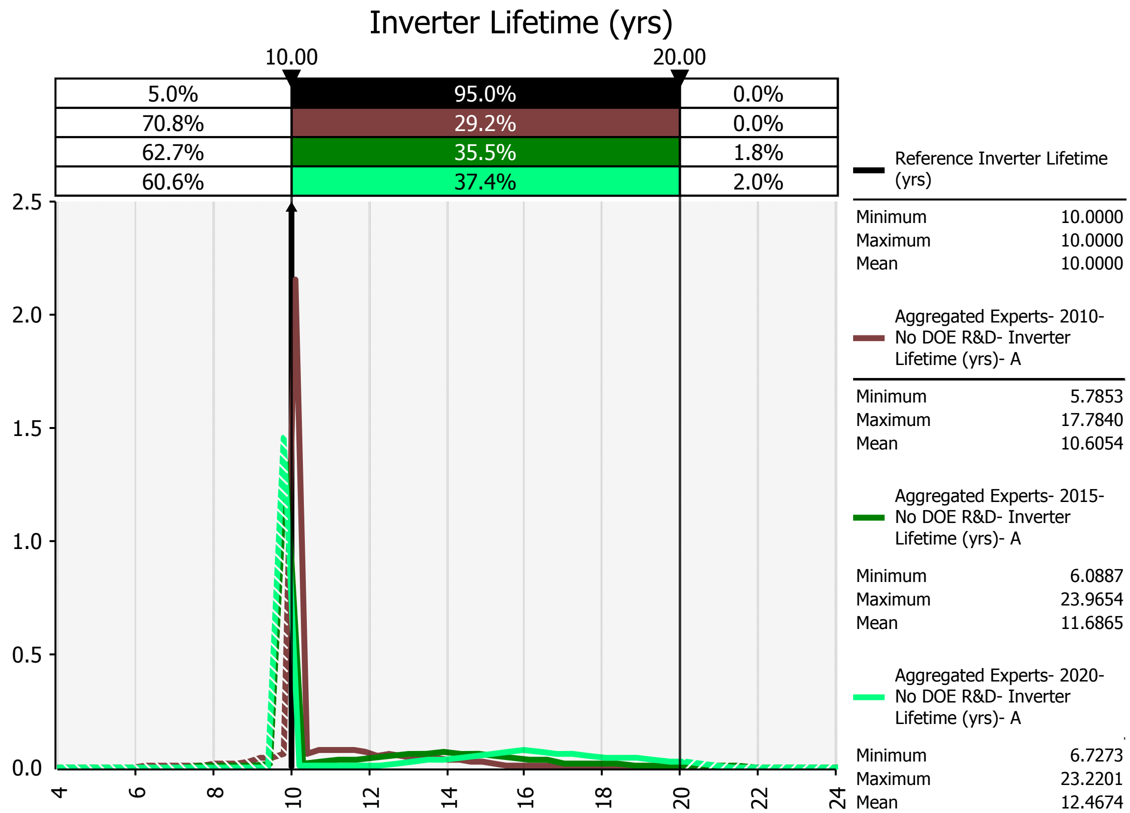
### *O&M System Cost—by Funding Level*

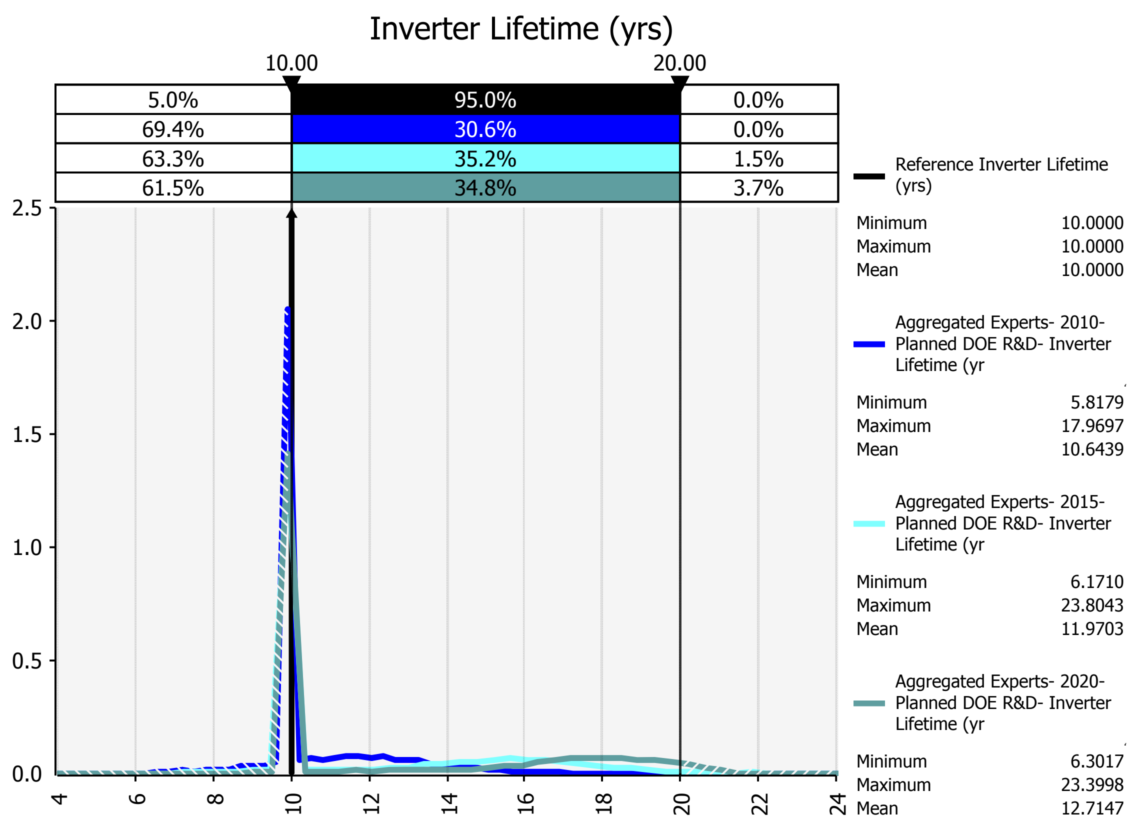


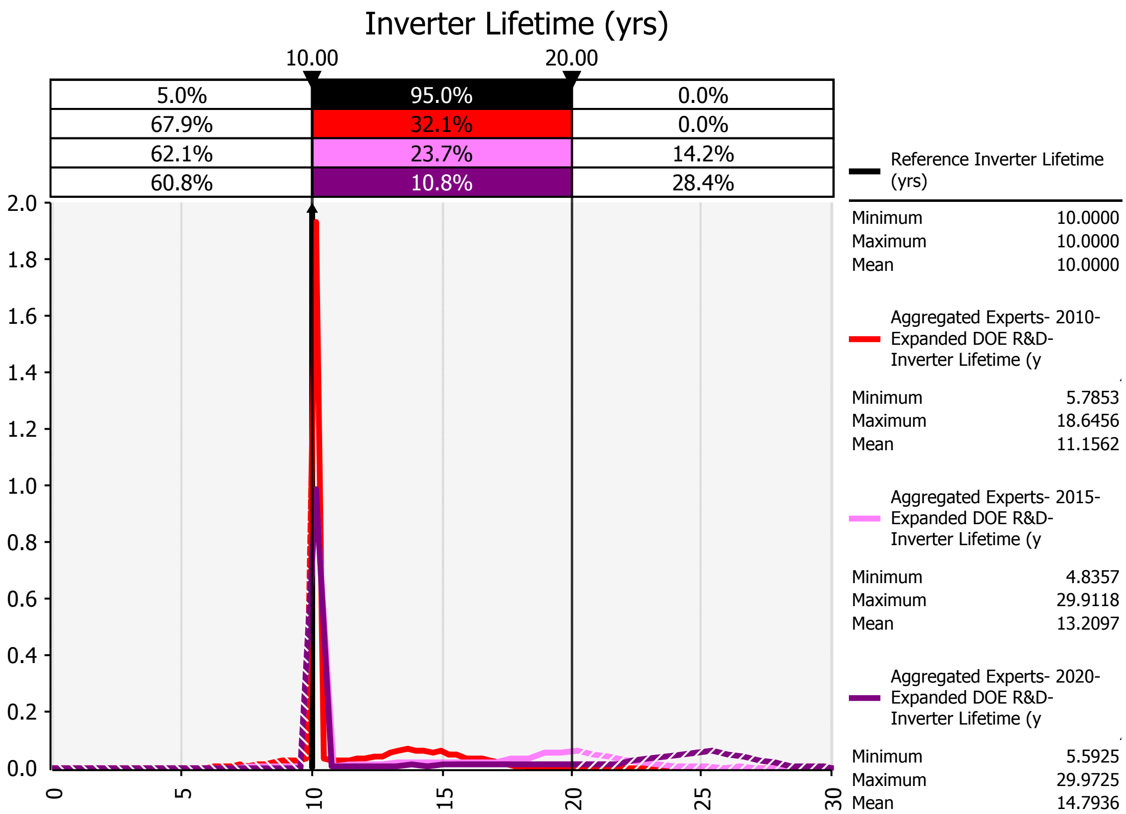




O&M Cost ($/kW-yr)
4.75
35.00
0.0%
5.0%
95.0%
0.1%
94.5%
5.4%
0.0%
99.4%
0.6%
2.1%
97.8%
0.2%
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
35
40
Reference O&M Cost ($/kW-yr)
Minimum 35.0000
Maximum 35.0000
Mean 35.0000
Aggregated Experts- 2010- Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 4.0651
Maximum 38.9856
Mean 28.7939
Aggregated Experts- 2015- Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 5.3586
Maximum 38.8850
Mean 15.3462
Aggregated Experts- 2020- Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 4.0153
Maximum 38.9131
Mean 9.6745

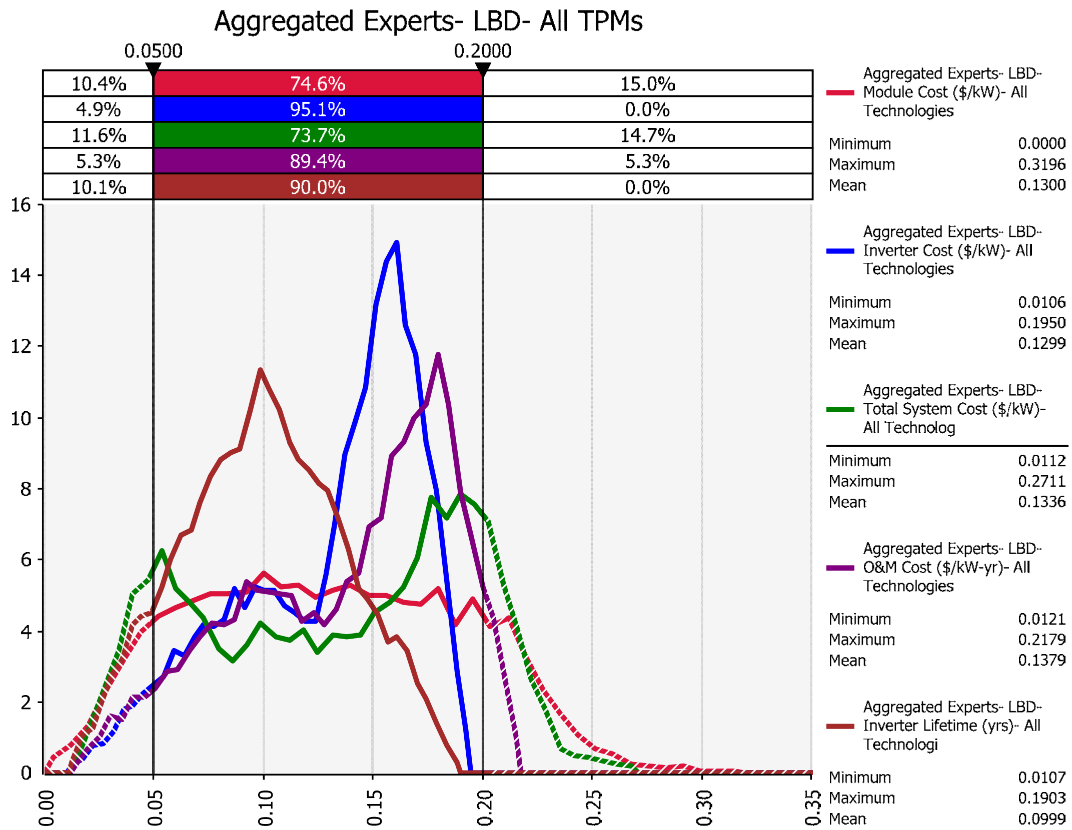
### *Inverter Life—by Funding Level*




Inverter Lifetime (yrs)
10.00
20.00
5.0%
95.0%
0.0%
67.9%
32.1%
0.0%
62.1%
23.7%
14.2%
60.8%
10.8%
28.4%
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
Reference Inverter Lifetime (yrs)
Minimum 10.0000
Maximum 10.0000
Mean 10.0000
Aggregated Experts- 2010- Expanded DOE R&D- Inverter Lifetime (y
Minimum 5.7853
Maximum 18.6456
Mean 11.1562
Aggregated Experts- 2015- Expanded DOE R&D- Inverter Lifetime (y
Minimum 4.8357
Maximum 29.9118
Mean 13.2097
Aggregated Experts- 2020- Expanded DOE R&D- Inverter Lifetime (y
Minimum 5.5925
Maximum 29.9725
Mean 14.7936

### *LBD—All TPMs*



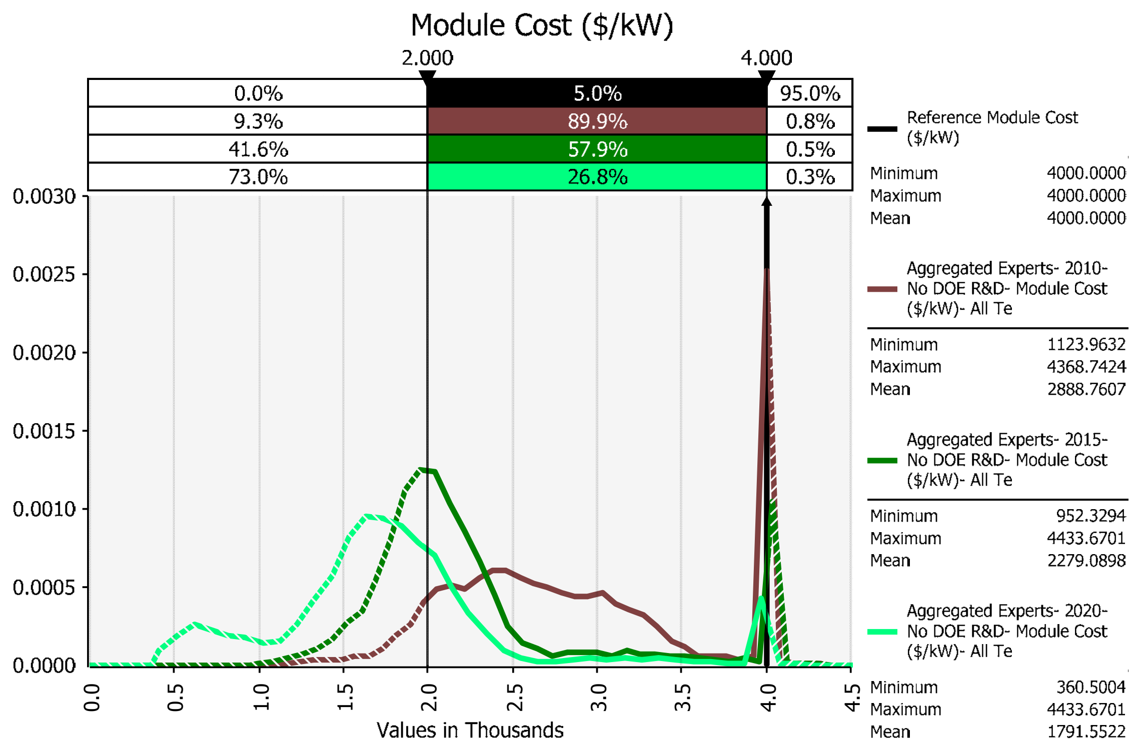
Aggregated Experts- LBD- All TPMs
0.0500
0.2000
10.4%
74.6%
15.0%
4.9%
95.1%
0.0%
11.6%
73.7%
14.7%
5.3%
89.4%
5.3%
10.1%
90.0%
0.0%
16
14
12
10
8
6
4
2
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Aggregated Experts- LBD- Module Cost ($/kW)- All Technologies
Minimum 0.0000
Maximum 0.3196
Mean 0.1300
Aggregated Experts- LBD- Inverter Cost ($/kW)- All Technologies
Minimum 0.0106
Maximum 0.1950
Mean 0.1299
Aggregated Experts- LBD- Total System Cost ($/kW)- All Technolog
Minimum 0.0112
Maximum 0.2711
Mean 0.1336
Aggregated Experts- LBD- O&M Cost ($/kW-yr)- All Technologies
Minimum 0.0121
Maximum 0.2179
Mean 0.1379
Aggregated Experts- LBD- Inverter Lifetime (yrs)- All Technologi
Minimum 0.0107
Maximum 0.1903
Mean 0.0999

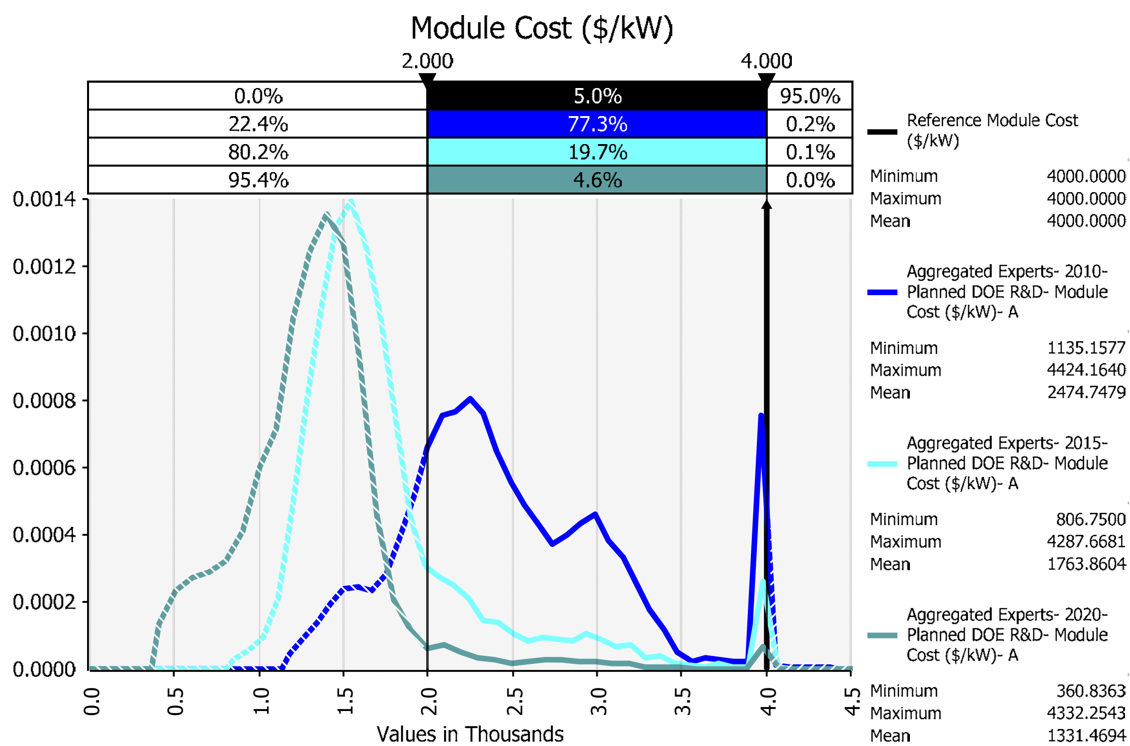
## E.3 Technical Risk and Uncertainty Analysis, Solar PV—Residential

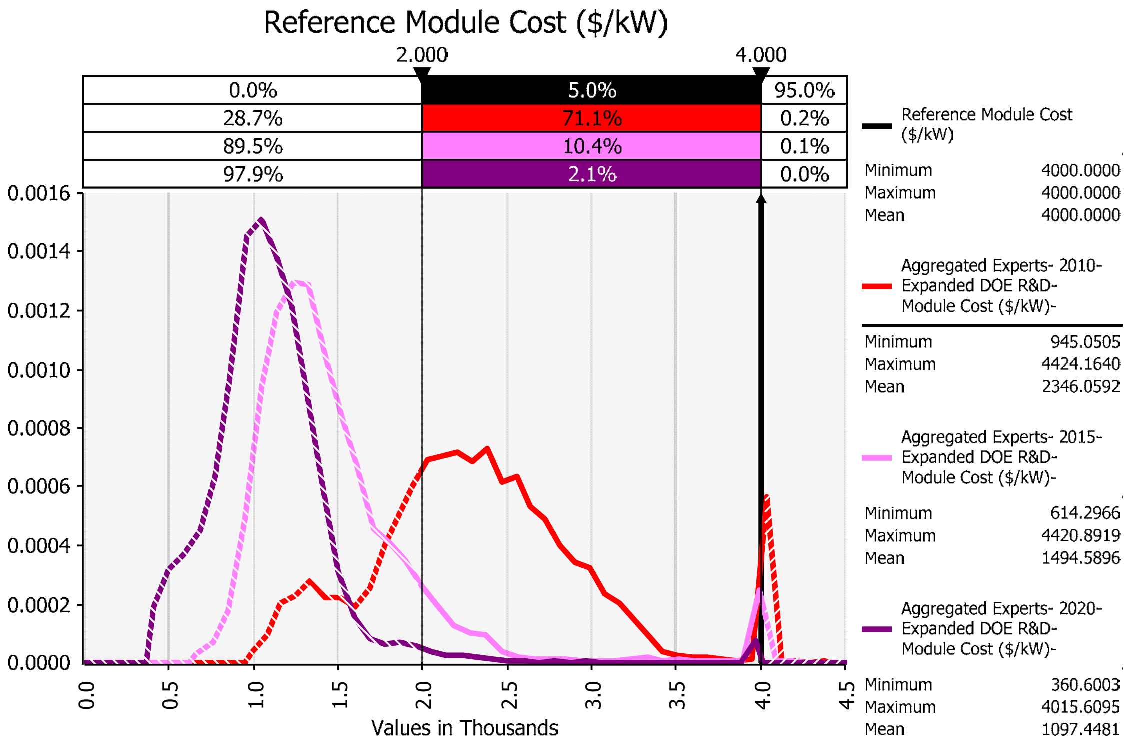
The following figures represent the aggregated module costs, inverter costs, total system cost, O&M costs, inverter lifetimes, and learning by doing (LBD) ranges provided by the experts in the three budget scenarios for PV Residential ($0, $140M, and $280M).

The three colored lines in each of these graphs represent the aggregated expert inputs for the three time periods for PV Residential (2010, 2015, and 2020). In each of the graphs, the 2009 reference values are represented by the black line on the right of the graphs, and the FY10 GPRA Program goal-based input value for 2015 is represented by the delimiter (i.e., thin black vertical lines) on the left of each graph. The percentages to the left side of the delimiter represent the likelihood of at least achieving the "goal-based" value. The percentages between the delimiters represent the likelihood of improving to somewhere between the "goal-based" value and reference value. Furthermore, the key to the right of each graph also lists the minimum, maximum, and mean for each aggregated distribution.

### *Module Cost—by Funding Level*

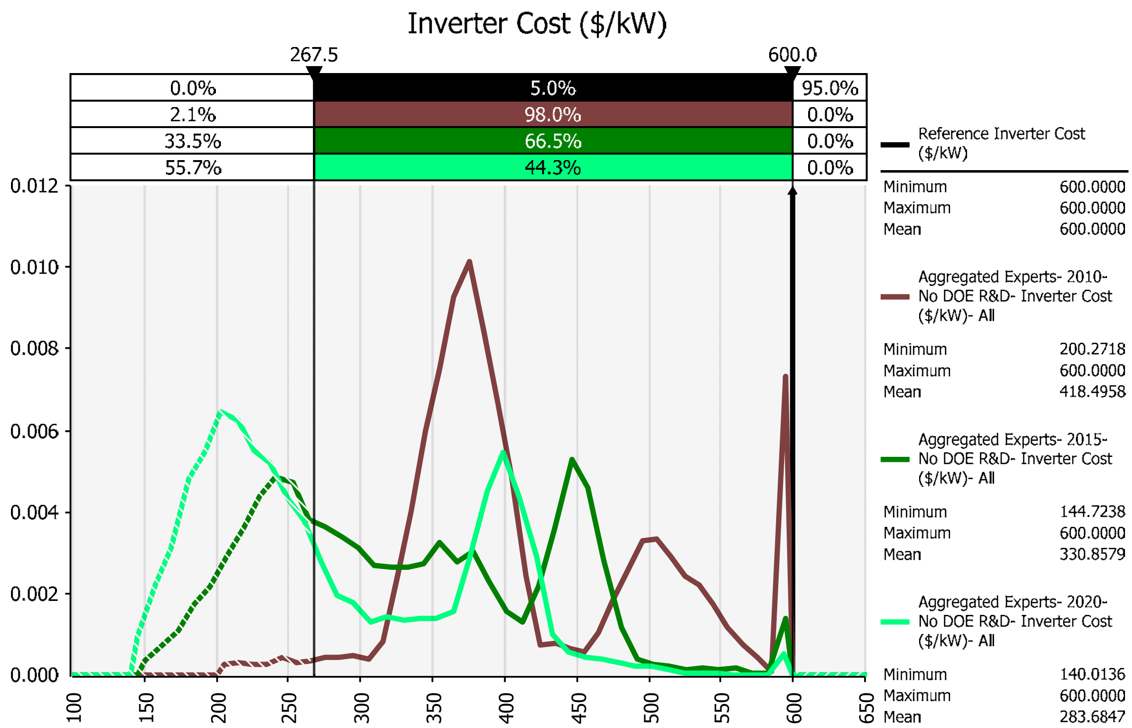


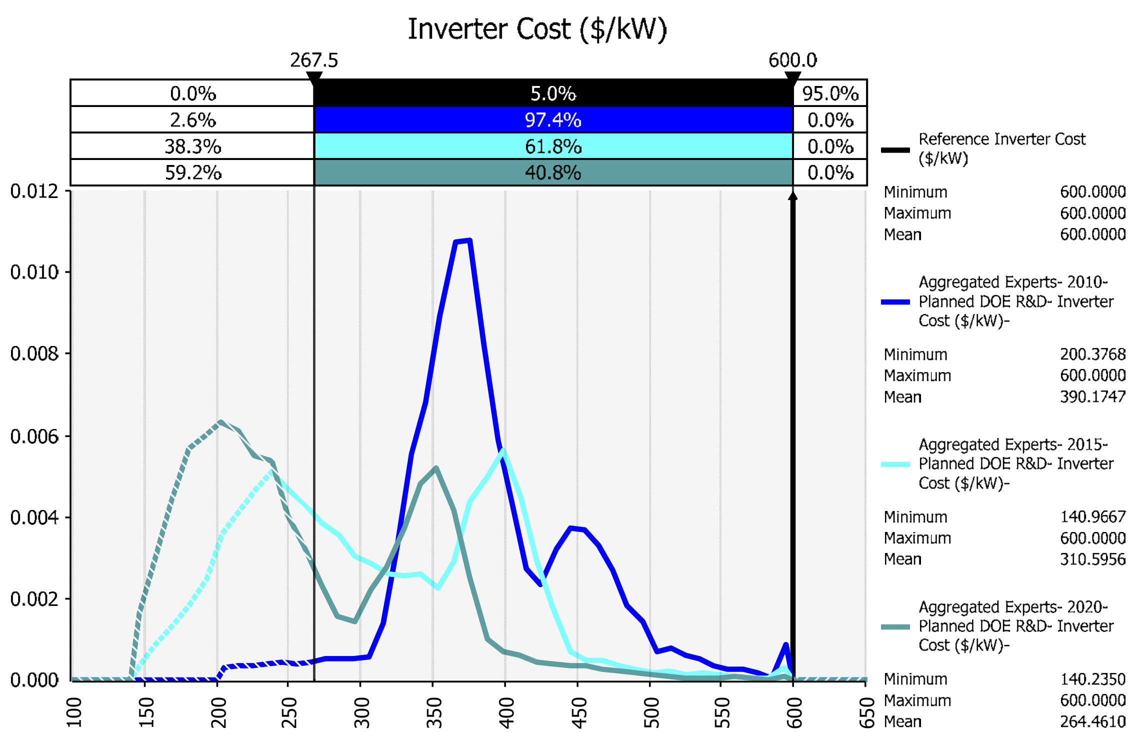



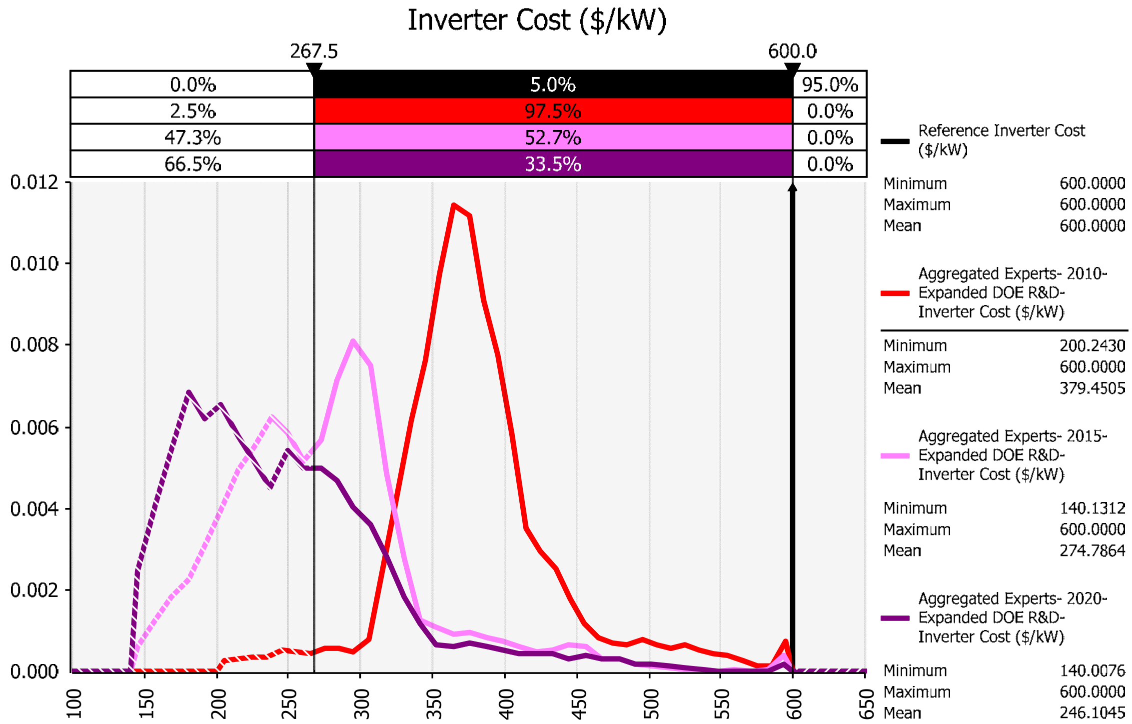


Reference Module Cost ($/kW)
2.000
4.000
0.0%
5.0%
95.0%
28.7%
71.1%
0.2%
89.5%
10.4%
0.1%
97.9%
2.1%
0.0%
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Values in Thousands
Reference Module Cost ($/kW)
Minimum 4000.0000
Maximum 4000.0000
Mean 4000.0000
Aggregated Experts- 2010- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 945.0505
Maximum 4424.1640
Mean 2346.0592
Aggregated Experts- 2015- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 614.2966
Maximum 4420.8919
Mean 1494.5896
Aggregated Experts- 2020- Expanded DOE R&D- Module Cost ($/kW)-
Minimum 360.6003
Maximum 4015.6095
Mean 1097.4481

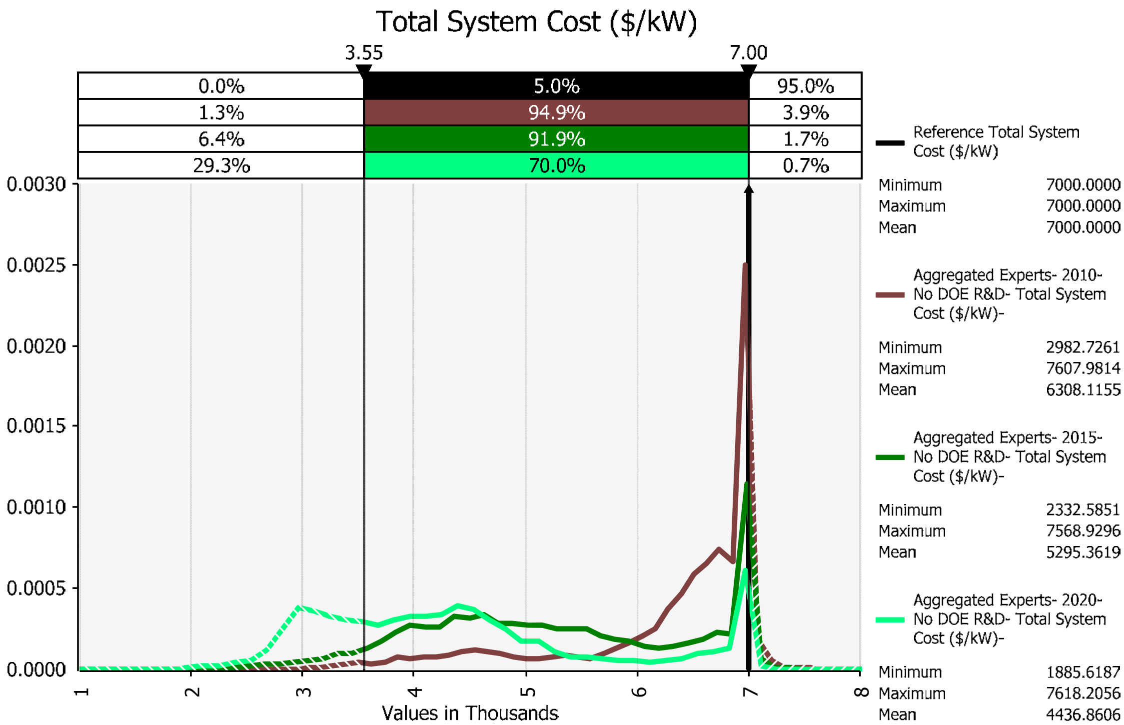
### *Inverter Cost—by Funding Level*

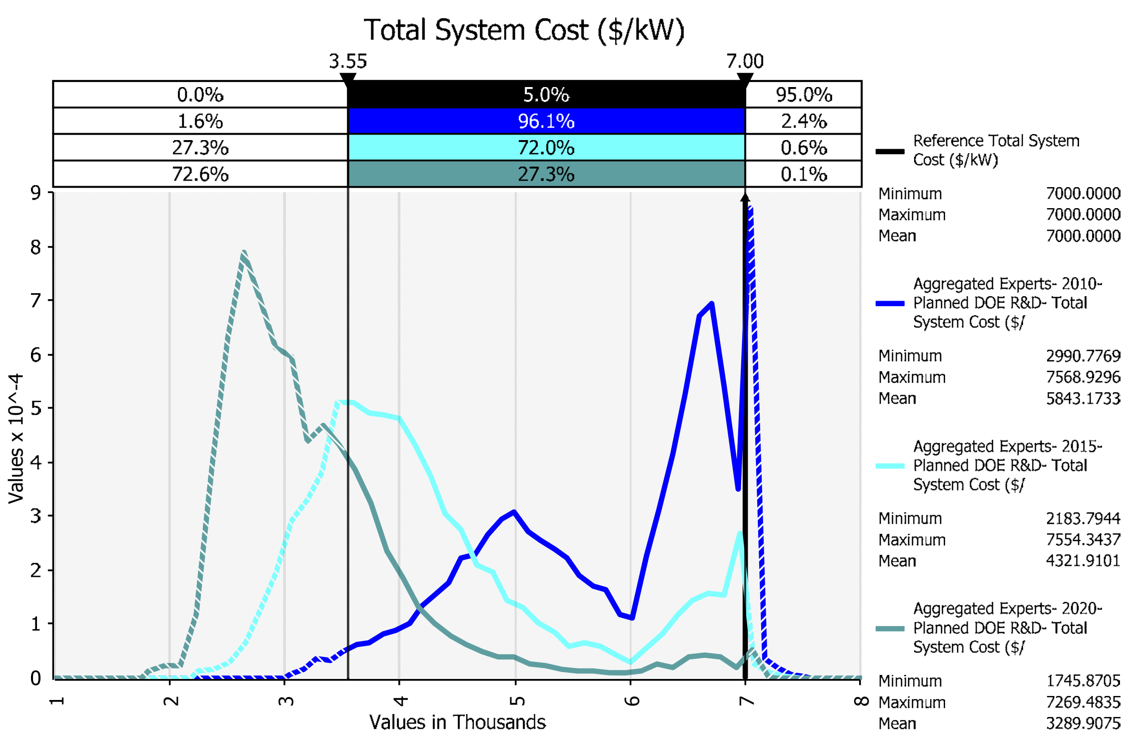


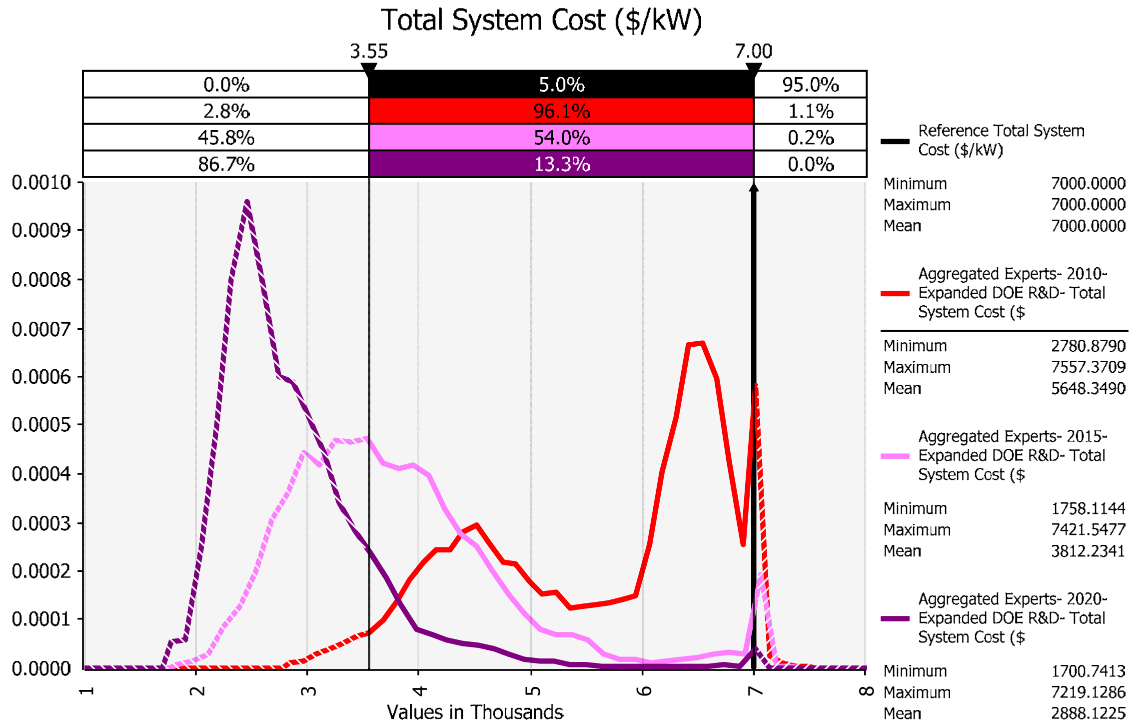




Inverter Cost ($/kW)
267.5
600.0
0.0%
5.0%
95.0%
2.5%
97.5%
0.0%
47.3%
52.7%
0.0%
66.5%
33.5%
0.0%
0.012
0.010
0.008
0.006
0.004
0.002
0.000
100
150
200
250
300
350
400
450
500
550
600
650
Reference Inverter Cost ($/kW)
Minimum 600.0000
Maximum 600.0000
Mean 600.0000
Aggregated Experts- 2010- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 200.2430
Maximum 600.0000
Mean 379.4505
Aggregated Experts- 2015- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 140.1312
Maximum 600.0000
Mean 274.7864
Aggregated Experts- 2020- Expanded DOE R&D- Inverter Cost ($/kW)
Minimum 140.0076
Maximum 600.0000
Mean 246.1045

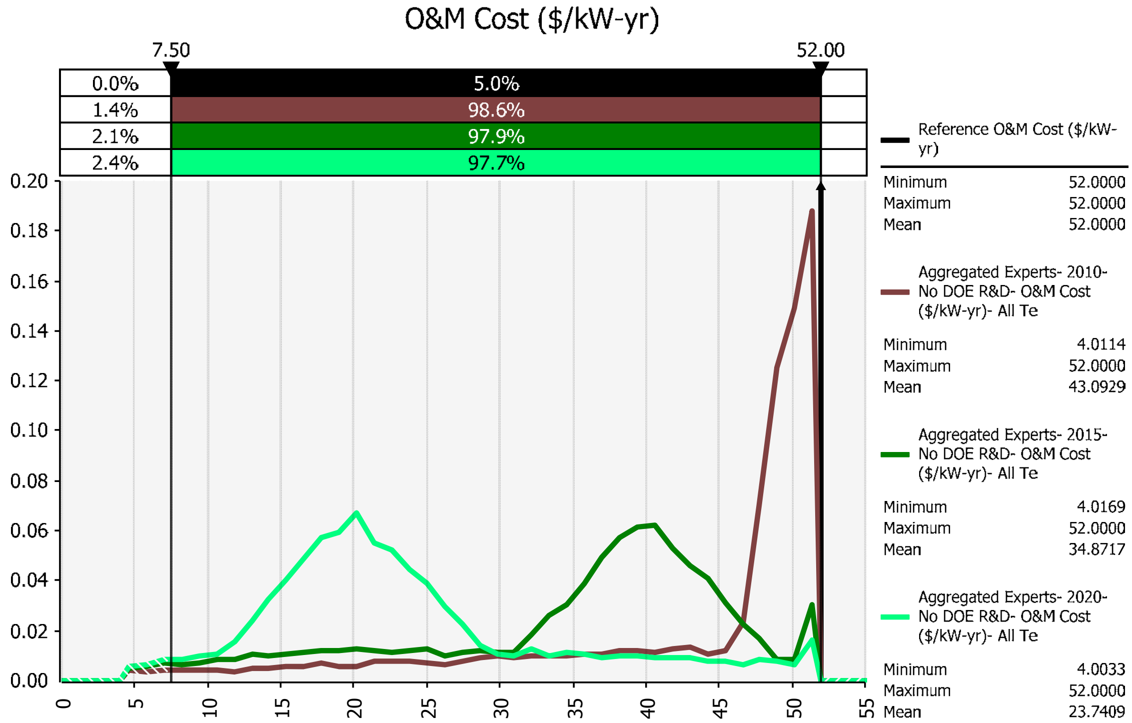
### ***Total System Cost—by Funding Level***

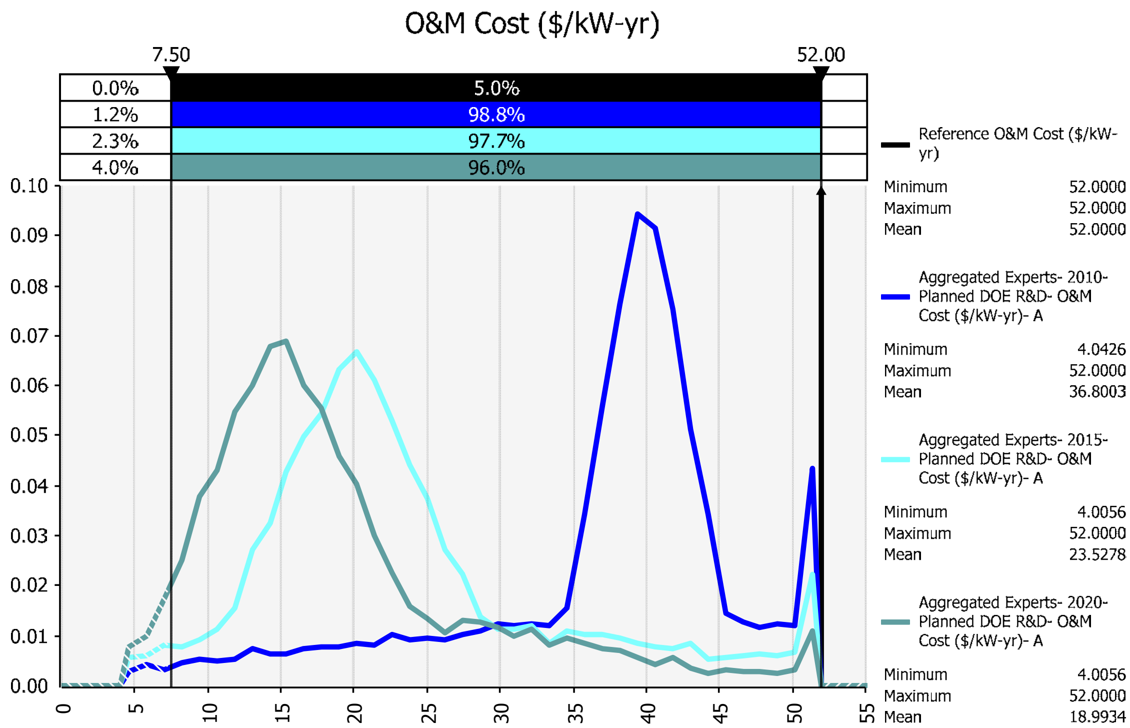


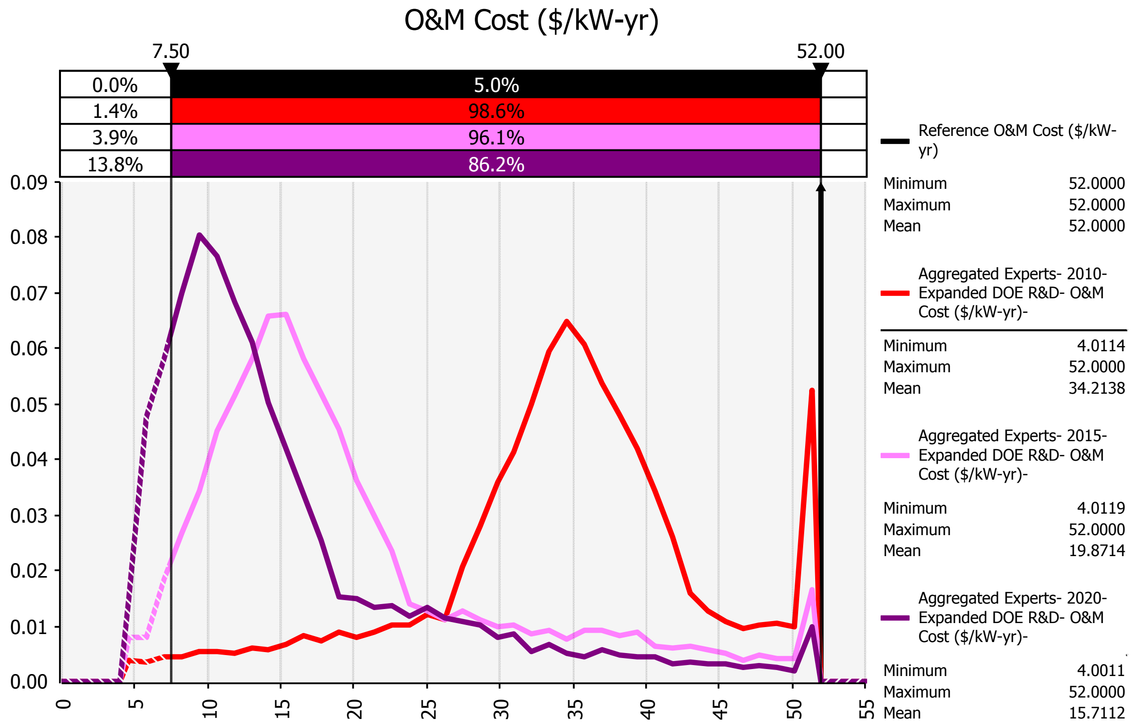




Total System Cost ($/kW)
3.55
7.00
0.0%
5.0%
95.0%
2.8%
96.1%
1.1%
45.8%
54.0%
0.2%
86.7%
13.3%
0.0%
Values in Thousands
Reference Total System Cost ($/kW)
Minimum 7000.0000
Maximum 7000.0000
Mean 7000.0000
Aggregated Experts- 2010- Expanded DOE R&D- Total System Cost ($
Minimum 2780.8790
Maximum 7557.3709
Mean 5648.3490
Aggregated Experts- 2015- Expanded DOE R&D- Total System Cost ($
Minimum 1758.1144
Maximum 7421.5477
Mean 3812.2341
Aggregated Experts- 2020- Expanded DOE R&D- Total System Cost ($
Minimum 1700.7413
Maximum 7219.1286
Mean 2888.1225

### *O&M System Cost—by Funding Level*

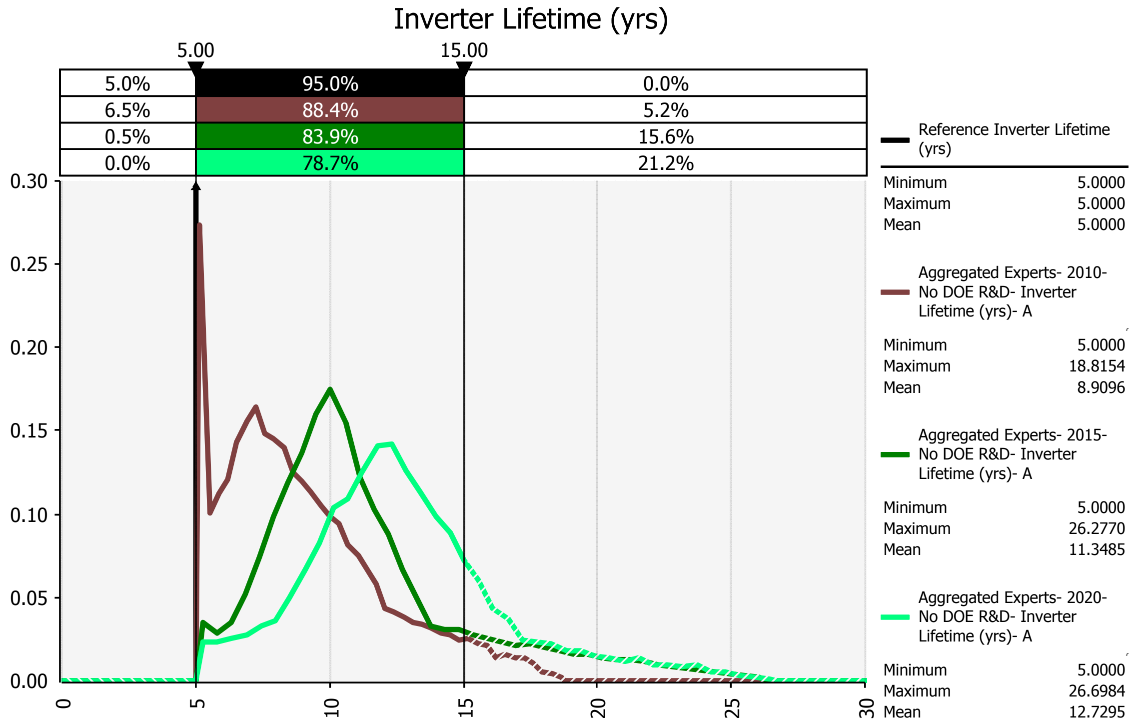


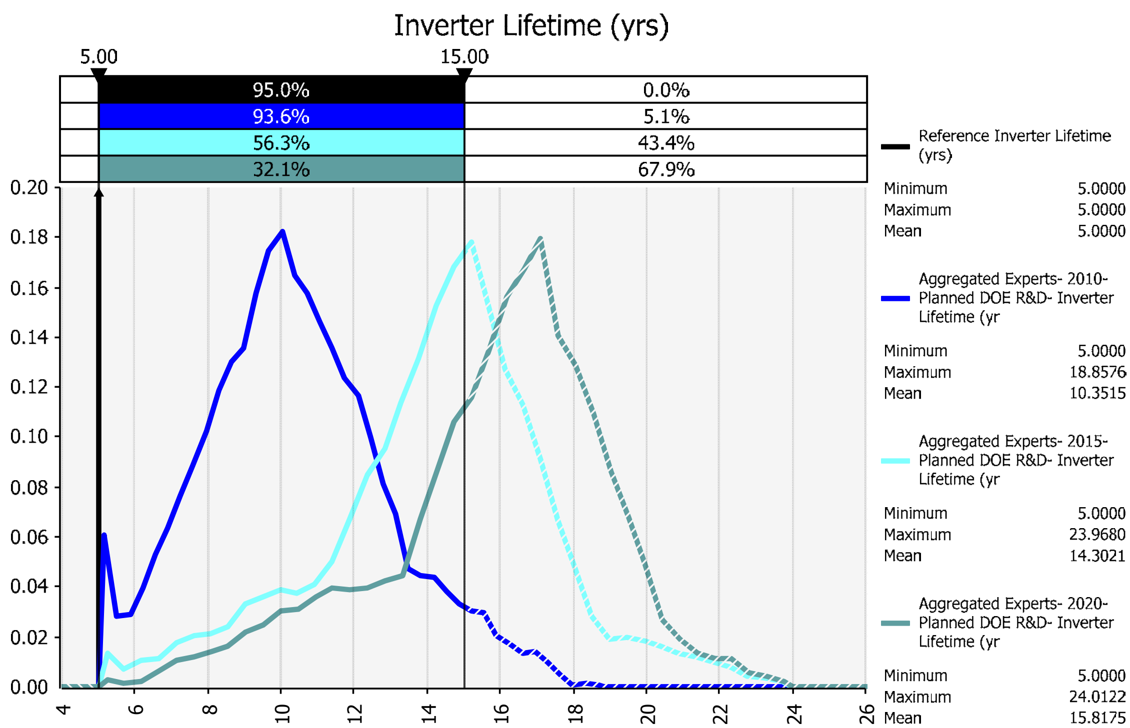



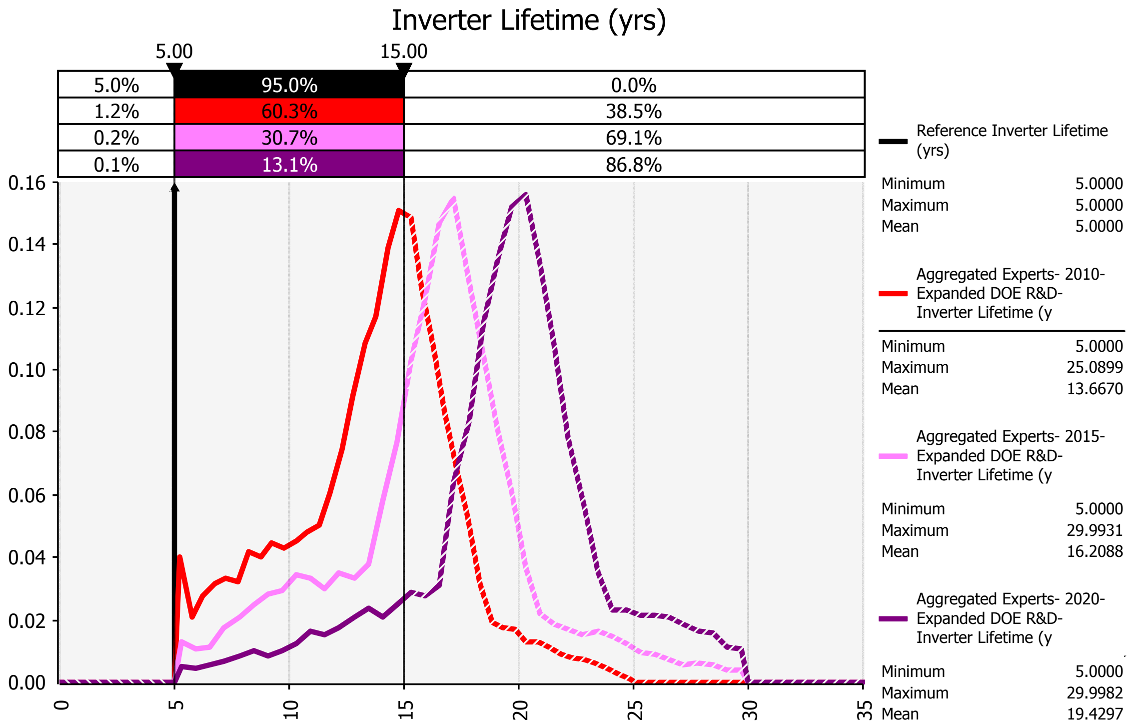


O&M Cost ($/kW-yr)
7.50
52.00
0.0%
5.0%
1.4%
98.6%
3.9%
96.1%
13.8%
86.2%
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
25
30
35
40
45
50
55
Reference O&M Cost ($/kW-yr)
Minimum 52.0000
Maximum 52.0000
Mean 52.0000
Aggregated Experts- 2010-Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 4.0114
Maximum 52.0000
Mean 34.2138
Aggregated Experts- 2015-Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 4.0119
Maximum 52.0000
Mean 19.8714
Aggregated Experts- 2020-Expanded DOE R&D- O&M Cost ($/kW-yr)-
Minimum 4.0011
Maximum 52.0000
Mean 15.7112

## *Inverter Life—by Funding Level*

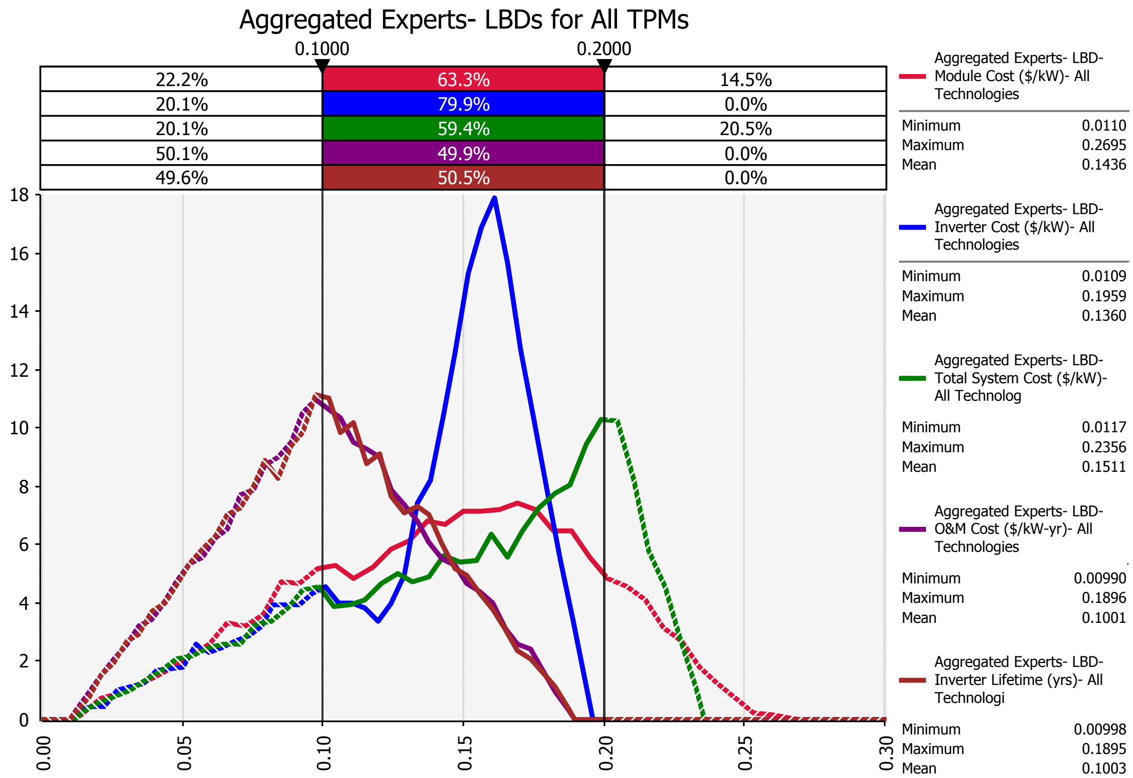




Inverter Lifetime (yrs)
5.00
15.00
5.0%
95.0%
0.0%
1.2%
60.3%
38.5%
0.2%
30.7%
69.1%
0.1%
13.1%
86.8%
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
20
25
30
35
Reference Inverter Lifetime (yrs)
Minimum 5.0000
Maximum 5.0000
Mean 5.0000
Aggregated Experts- 2010- Expanded DOE R&D- Inverter Lifetime (y
Minimum 5.0000
Maximum 25.0899
Mean 13.6670
Aggregated Experts- 2015- Expanded DOE R&D- Inverter Lifetime (y
Minimum 5.0000
Maximum 29.9931
Mean 16.2088
Aggregated Experts- 2020- Expanded DOE R&D- Inverter Lifetime (y
Minimum 5.0000
Maximum 29.9982
Mean 19.4297

*LBD—All TPMs*



Aggregated Experts- LBDs for All TPMs
0.1000
0.2000
22.2%
63.3%
14.5%
20.1%
79.9%
0.0%
20.1%
59.4%
20.5%
50.1%
49.9%
0.0%
49.6%
50.5%
0.0%
Aggregated Experts- LBD- Module Cost ($/kW)- All Technologies
Minimum 0.0110
Maximum 0.2695
Mean 0.1436
Aggregated Experts- LBD- Inverter Cost ($/kW)- All Technologies
Minimum 0.0109
Maximum 0.1959
Mean 0.1360
Aggregated Experts- LBD- Total System Cost ($/kW)- All Technolog
Minimum 0.0117
Maximum 0.2356
Mean 0.1511
Aggregated Experts- LBD- O&M Cost ($/kW-yr)- All Technologies
Minimum 0.00990
Maximum 0.1896
Mean 0.1001
Aggregated Experts- LBD- Inverter Lifetime (yrs)- All Technologi
Minimum 0.00998
Maximum 0.1895
Mean 0.1003

# Appendix F: Summary of @Risk Results—Aggregated Probability Distribution Tables

## F.1 Concentrating Solar Power—Tower with Storage

### 2009 Risk Analysis for Concentrating Solar Power (CSP) Technologies

**Technology:** **Power Tower**
**Plant Size:** **100 MW with 6 hours Thermal Energy Storage**

| **Total System Cost** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 | 5,644 |
| 2015 No DOE | 4,584 | 4,929 | 4,981 | 5,012 | 5,035 | 5,053 | 5,070 | 5,087 | 5,105 | 5,123 | 5,141 | 5,162 | 5,182 | 5,202 | 5,220 | 5,250 | 5,288 | 5,314 | 5,314 | 5,314 | 5,314 |
| 2020 No DOE | 4,342 | 4,714 | 4,790 | 4,840 | 4,876 | 4,905 | 4,930 | 4,953 | 4,977 | 5,001 | 5,024 | 5,044 | 5,067 | 5,090 | 5,113 | 5,140 | 5,171 | 5,209 | 5,261 | 5,314 | 5,314 |
| 2025 No DOE | 3,952 | 4,345 | 4,435 | 4,499 | 4,556 | 4,610 | 4,666 | 4,725 | 4,783 | 4,834 | 4,880 | 4,916 | 4,947 | 4,976 | 5,004 | 5,034 | 5,067 | 5,107 | 5,161 | 5,235 | 5,314 |
| 2015 DOE Planned | 4,436 | 4,789 | 4,842 | 4,880 | 4,917 | 4,946 | 4,971 | 4,994 | 5,016 | 5,036 | 5,054 | 5,073 | 5,091 | 5,110 | 5,129 | 5,152 | 5,181 | 5,212 | 5,264 | 5,314 | 5,314 |
| 2020 DOE Planned | 4,191 | 4,499 | 4,569 | 4,626 | 4,674 | 4,725 | 4,773 | 4,821 | 4,859 | 4,897 | 4,927 | 4,953 | 4,977 | 5,000 | 5,021 | 5,045 | 5,071 | 5,101 | 5,152 | 5,242 | 5,314 |
| 2025 DOE Planned | 3,813 | 4,195 | 4,273 | 4,334 | 4,389 | 4,437 | 4,484 | 4,530 | 4,584 | 4,647 | 4,718 | 4,786 | 4,836 | 4,876 | 4,910 | 4,937 | 4,965 | 4,998 | 5,038 | 5,099 | 5,314 |
| 2015 DOE Expanded | 4,174 | 4,574 | 4,690 | 4,765 | 4,807 | 4,840 | 4,869 | 4,898 | 4,929 | 4,956 | 4,983 | 5,007 | 5,027 | 5,048 | 5,070 | 5,095 | 5,125 | 5,167 | 5,230 | 5,297 | 5,314 |
| 2020 DOE Expanded | 3,725 | 4,188 | 4,295 | 4,373 | 4,436 | 4,500 | 4,568 | 4,658 | 4,735 | 4,787 | 4,825 | 4,860 | 4,888 | 4,918 | 4,947 | 4,977 | 5,010 | 5,047 | 5,098 | 5,186 | 5,314 |
| 2025 DOE Expanded | 3,411 | 3,765 | 3,860 | 3,943 | 4,033 | 4,129 | 4,228 | 4,318 | 4,406 | 4,507 | 4,598 | 4,672 | 4,727 | 4,771 | 4,813 | 4,853 | 4,893 | 4,933 | 4,977 | 5,039 | 5,314 |

| **Solar Field** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 |
| 2015 No DOE | 1,555 | 1,751 | 1,779 | 1,799 | 1,819 | 1,839 | 1,858 | 1,876 | 1,896 | 1,913 | 1,920 | 1,920 | 1,920 | 1,965 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 | 1,995 |
| 2020 No DOE | 1,482 | 1,651 | 1,682 | 1,706 | 1,728 | 1,753 | 1,779 | 1,801 | 1,822 | 1,840 | 1,857 | 1,873 | 1,891 | 1,909 | 1,920 | 1,925 | 1,973 | 1,995 | 1,995 | 1,995 | 1,995 |
| 2025 No DOE | 1,255 | 1,429 | 1,488 | 1,537 | 1,582 | 1,629 | 1,664 | 1,695 | 1,728 | 1,762 | 1,790 | 1,812 | 1,831 | 1,847 | 1,863 | 1,880 | 1,901 | 1,920 | 1,964 | 1,995 | 1,995 |
| 2015 DOE Planned | 1,542 | 1,643 | 1,684 | 1,717 | 1,746 | 1,772 | 1,798 | 1,821 | 1,843 | 1,862 | 1,877 | 1,891 | 1,904 | 1,915 | 1,920 | 1,930 | 1,973 | 1,995 | 1,995 | 1,995 | 1,995 |
| 2020 DOE Planned | 1,341 | 1,459 | 1,511 | 1,567 | 1,633 | 1,679 | 1,710 | 1,736 | 1,761 | 1,785 | 1,805 | 1,823 | 1,841 | 1,858 | 1,875 | 1,892 | 1,909 | 1,920 | 1,986 | 1,995 | 1,995 |
| 2025 DOE Planned | 1,252 | 1,356 | 1,398 | 1,436 | 1,479 | 1,514 | 1,552 | 1,591 | 1,633 | 1,667 | 1,696 | 1,726 | 1,758 | 1,788 | 1,814 | 1,835 | 1,854 | 1,874 | 1,899 | 1,920 | 1,995 |
| 2015 DOE Expanded | 1,410 | 1,591 | 1,632 | 1,658 | 1,684 | 1,706 | 1,729 | 1,749 | 1,767 | 1,785 | 1,804 | 1,823 | 1,846 | 1,870 | 1,892 | 1,913 | 1,920 | 1,975 | 1,995 | 1,995 | 1,995 |
| 2020 DOE Expanded | 1,248 | 1,357 | 1,406 | 1,457 | 1,524 | 1,585 | 1,629 | 1,659 | 1,683 | 1,701 | 1,721 | 1,742 | 1,766 | 1,796 | 1,826 | 1,852 | 1,876 | 1,904 | 1,920 | 1,995 | 1,995 |
| 2025 DOE Expanded | 1,128 | 1,244 | 1,287 | 1,325 | 1,359 | 1,391 | 1,429 | 1,473 | 1,525 | 1,579 | 1,623 | 1,653 | 1,680 | 1,704 | 1,731 | 1,766 | 1,806 | 1,840 | 1,874 | 1,919 | 1,995 |

| **HTF/Receiver** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 |
| 2015 No DOE | 534 | 691 | 714 | 730 | 744 | 755 | 767 | 776 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 |
| 2020 No DOE | 536 | 652 | 674 | 690 | 703 | 714 | 723 | 732 | 741 | 751 | 765 | 778 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 | 780 |
| 2025 No DOE | 536 | 604 | 626 | 642 | 654 | 666 | 677 | 686 | 695 | 703 | 712 | 723 | 734 | 745 | 757 | 769 | 780 | 780 | 780 | 780 | 780 |
| 2015 DOE Planned | 538 | 678 | 695 | 709 | 720 | 731 | 739 | 749 | 756 | 763 | 767 | 771 | 774 | 777 | 779 | 780 | 780 | 780 | 780 | 780 | 780 |
| 2020 DOE Planned | 538 | 643 | 663 | 678 | 690 | 700 | 709 | 717 | 724 | 732 | 741 | 748 | 756 | 763 | 768 | 772 | 776 | 780 | 780 | 780 | 780 |
| 2025 DOE Planned | 523 | 591 | 615 | 630 | 642 | 653 | 664 | 674 | 683 | 692 | 704 | 715 | 725 | 736 | 746 | 756 | 765 | 771 | 777 | 780 | 780 |
| 2015 DOE Expanded | 539 | 658 | 681 | 696 | 708 | 719 | 728 | 738 | 748 | 756 | 764 | 769 | 773 | 777 | 780 | 780 | 780 | 780 | 780 | 780 | 780 |
| 2020 DOE Expanded | 535 | 610 | 635 | 650 | 664 | 676 | 687 | 697 | 707 | 716 | 724 | 733 | 742 | 753 | 764 | 774 | 780 | 780 | 780 | 780 | 780 |
| 2025 DOE Expanded | 480 | 545 | 570 | 591 | 609 | 623 | 638 | 651 | 663 | 674 | 684 | 694 | 708 | 720 | 733 | 746 | 760 | 773 | 780 | 780 | 780 |

| **TES** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2015 No DOE | 14.6 | 15.4 | 15.7 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2020 No DOE | 14.6 | 15.2 | 15.5 | 15.7 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2025 No DOE | 14.4 | 15.1 | 15.3 | 15.5 | 15.7 | 15.8 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2015 DOE Planned | 14.2 | 15.0 | 15.2 | 15.5 | 15.9 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2020 DOE Planned | 14.2 | 14.9 | 15.1 | 15.3 | 15.5 | 15.8 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2025 DOE Planned | 14.2 | 14.8 | 15.0 | 15.2 | 15.3 | 15.5 | 15.7 | 15.9 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2015 DOE Expanded | 13.9 | 14.6 | 15.0 | 15.3 | 15.8 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2020 DOE Expanded | 12.2 | 14.3 | 14.7 | 15.0 | 15.3 | 15.7 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| 2025 DOE Expanded | 8.8 | 12.2 | 14.1 | 14.5 | 14.8 | 15.0 | 15.1 | 15.3 | 15.5 | 15.7 | 15.9 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |

| **PB&BOS** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2015 No DOE | 879.9 | 1,021.2 | 1,052.1 | 1,072.1 | 1,085.8 | 1,096.1 | 1,104.9 | 1,112.1 | 1,119.0 | 1,124.8 | 1,130.5 | 1,135.4 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2020 No DOE | 826.2 | 981.7 | 1,012.6 | 1,033.4 | 1,049.5 | 1,064.0 | 1,075.3 | 1,085.2 | 1,093.9 | 1,101.8 | 1,109.2 | 1,116.3 | 1,123.0 | 1,129.3 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2025 No DOE | 804.9 | 927.7 | 962.0 | 988.2 | 1,009.7 | 1,026.3 | 1,041.4 | 1,054.4 | 1,066.8 | 1,077.8 | 1,087.9 | 1,097.5 | 1,106.5 | 1,115.1 | 1,123.4 | 1,131.7 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2015 DOE Planned | 797.2 | 990.5 | 1,026.3 | 1,048.2 | 1,065.5 | 1,078.1 | 1,087.4 | 1,095.3 | 1,102.4 | 1,108.6 | 1,114.6 | 1,119.8 | 1,124.7 | 1,129.2 | 1,133.5 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2020 DOE Planned | 774.9 | 945.5 | 978.5 | 1,004.2 | 1,025.0 | 1,042.1 | 1,055.3 | 1,066.4 | 1,077.0 | 1,086.7 | 1,095.2 | 1,102.4 | 1,109.7 | 1,116.8 | 1,123.7 | 1,130.2 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2025 DOE Planned | 750.6 | 876.3 | 912.2 | 938.6 | 961.7 | 982.1 | 1,000.9 | 1,019.9 | 1,036.5 | 1,050.7 | 1,065.2 | 1,078.0 | 1,089.4 | 1,099.9 | 1,109.6 | 1,119.1 | 1,127.6 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2015 DOE Expanded | 841.0 | 940.8 | 980.9 | 1,016.5 | 1,040.4 | 1,063.4 | 1,077.1 | 1,087.9 | 1,096.5 | 1,104.0 | 1,110.8 | 1,116.5 | 1,122.4 | 1,127.9 | 1,133.5 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2020 DOE Expanded | 758.2 | 863.8 | 902.3 | 929.1 | 959.1 | 987.8 | 1,015.3 | 1,036.4 | 1,053.2 | 1,068.5 | 1,081.2 | 1,092.8 | 1,103.1 | 1,112.6 | 1,122.1 | 1,130.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |
| 2025 DOE Expanded | 680.0 | 776.6 | 813.2 | 840.3 | 865.4 | 890.7 | 918.7 | 949.7 | 990.7 | 1,024.8 | 1,048.5 | 1,067.5 | 1,082.4 | 1,096.1 | 1,107.9 | 1,118.8 | 1,129.6 | 1,136.0 | 1,136.0 | 1,136.0 | 1,136.0 |

| **O&M** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 | 77.0 |
| 2015 No DOE | 44.8 | 60.8 | 66.2 | 69.6 | 72.2 | 74.4 | 76.3 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| 2020 No DOE | 41.9 | 51.4 | 58.4 | 62.1 | 64.7 | 66.9 | 68.9 | 71.2 | 73.7 | 76.7 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| 2025 No DOE | 32.6 | 43.4 | 50.6 | 54.7 | 57.5 | 59.6 | 61.3 | 63.2 | 65.3 | 68.2 | 72.6 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| 2015 DOE Planned | 34.4 | 49.7 | 58.2 | 63.5 | 66.7 | 69.0 | 71.0 | 72.8 | 74.4 | 76.1 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| 2020 DOE Planned | 35.2 | 43.3 | 47.3 | 55.5 | 59.3 | 61.8 | 64.1 | 66.0 | 67.8 | 70.0 | 72.4 | 75.8 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| 2025 DOE Planned | 33.4 | 40.6 | 43.6 | 46.5 | 51.7 | 54.8 | 56.7 | 58.5 | 60.0 | 61.8 | 63.6 | 65.9 | 69.5 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| 2015 DOE Expanded | 32.4 | 48.0 | 57.7 | 61.2 | 63.4 | 65.3 | 67.0 | 68.8 | 71.0 | 73.8 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| 2020 DOE Expanded | 34.4 | 43.5 | 47.9 | 52.5 | 55.6 | 57.9 | 59.7 | 61.3 | 63.1 | 65.2 | 67.9 | 73.6 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| 2025 DOE Expanded | 34.4 | 39.7 | 42.3 | 45.3 | 48.4 | 50.8 | 52.7 | 54.2 | 55.7 | 57.1 | 58.9 | 61.3 | 65.1 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |

| LBD | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Solar Field | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| HTF/Receiver | 0.00 | 0.03 | 0.05 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | 0.10 | 0.12 | 0.14 | 0.16 | 0.18 | 0.24 | 0.47 | 0.57 | 0.64 | 0.74 | 0.95 |
| TES | 0.00 | 0.05 | 0.07 | 0.09 | 0.10 | 0.11 | 0.14 | 0.23 | 0.25 | 0.27 | 0.29 | 0.30 | 0.31 | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 | 0.44 | 0.57 | 0.97 |
| PB&BOS | 0.00 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.10 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.19 | 0.20 | 0.20 | 0.22 | 0.24 | 0.29 |
| O&M | 0.00 | 0.04 | 0.05 | 0.06 | 0.06 | 0.07 | 0.08 | 0.08 | 0.12 | 0.16 | 0.28 | 0.54 | 0.59 | 0.61 | 0.64 | 0.67 | 0.69 | 0.71 | 0.74 | 0.78 | 0.93 |

## F.2 Concentrating Solar Power—Trough with Storage

### 2009 Risk Analysis for Concentrating Solar Power (CSP) Technologies

**Technology:** **Trough**
**Plant Size:** **100 MW with 6 hours Thermal Energy Storage**

| **Total System Cost** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 | 6,443 |
| 2015 No DOE | 5,044 | 5,500 | 5,571 | 5,641 | 5,738 | 5,916 | 6,028 | 6,103 | 6,156 | 6,207 | 6,250 | 6,296 | 6,348 | 6,409 | 6,431 | 6,444 | 6,444 | 6,444 | 6,444 | 6,444 | 6,444 |
| 2020 No DOE | 4,321 | 4,991 | 5,069 | 5,151 | 5,264 | 5,401 | 5,508 | 5,589 | 5,679 | 5,776 | 5,870 | 5,956 | 6,040 | 6,103 | 6,165 | 6,218 | 6,272 | 6,335 | 6,405 | 6,444 | 6,444 |
| 2025 No DOE | 3,678 | 4,370 | 4,571 | 4,655 | 4,722 | 4,805 | 4,918 | 5,035 | 5,149 | 5,277 | 5,428 | 5,552 | 5,666 | 5,775 | 5,879 | 5,959 | 6,043 | 6,130 | 6,220 | 6,329 | 6,444 |
| 2015 DOE Planned | 4,820 | 5,299 | 5,368 | 5,427 | 5,499 | 5,596 | 5,723 | 5,822 | 5,904 | 5,975 | 6,051 | 6,119 | 6,190 | 6,254 | 6,317 | 6,390 | 6,442 | 6,444 | 6,444 | 6,444 | 6,444 |
| 2020 DOE Planned | 4,128 | 4,756 | 4,856 | 4,911 | 4,969 | 5,030 | 5,099 | 5,171 | 5,272 | 5,364 | 5,456 | 5,561 | 5,669 | 5,765 | 5,858 | 5,951 | 6,062 | 6,151 | 6,240 | 6,333 | 6,444 |
| 2025 DOE Planned | 3,413 | 3,975 | 4,137 | 4,280 | 4,404 | 4,536 | 4,610 | 4,657 | 4,703 | 4,777 | 4,890 | 4,997 | 5,134 | 5,272 | 5,382 | 5,483 | 5,576 | 5,675 | 5,820 | 6,073 | 6,444 |
| 2015 DOE Expanded | 4,234 | 5,103 | 5,189 | 5,250 | 5,303 | 5,360 | 5,437 | 5,530 | 5,625 | 5,728 | 5,825 | 5,934 | 6,058 | 6,150 | 6,217 | 6,268 | 6,315 | 6,357 | 6,394 | 6,433 | 6,444 |
| 2020 DOE Expanded | 3,477 | 4,286 | 4,451 | 4,579 | 4,694 | 4,774 | 4,828 | 4,874 | 4,927 | 4,992 | 5,072 | 5,209 | 5,395 | 5,548 | 5,670 | 5,794 | 5,922 | 6,044 | 6,167 | 6,290 | 6,444 |
| 2025 DOE Expanded | 2,870 | 3,555 | 3,697 | 3,814 | 3,925 | 4,038 | 4,160 | 4,281 | 4,406 | 4,535 | 4,597 | 4,645 | 4,720 | 4,885 | 5,057 | 5,259 | 5,395 | 5,514 | 5,650 | 5,906 | 6,444 |

| **Solar Field** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 |
| 2015 No DOE | 2,177 | 2,315 | 2,376 | 2,449 | 2,664 | 2,786 | 2,852 | 2,901 | 2,950 | 2,992 | 3,033 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 |
| 2020 No DOE | 1,791 | 1,923 | 2,015 | 2,203 | 2,331 | 2,424 | 2,519 | 2,603 | 2,658 | 2,702 | 2,753 | 2,804 | 2,853 | 2,907 | 2,981 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 |
| 2025 No DOE | 1,523 | 1,650 | 1,748 | 1,900 | 1,995 | 2,096 | 2,196 | 2,284 | 2,364 | 2,450 | 2,523 | 2,587 | 2,644 | 2,697 | 2,770 | 2,872 | 3,036 | 3,052 | 3,052 | 3,052 | 3,052 |
| 2015 DOE Planned | 1,951 | 2,154 | 2,217 | 2,275 | 2,395 | 2,580 | 2,661 | 2,736 | 2,798 | 2,860 | 2,913 | 2,963 | 3,027 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 |
| 2020 DOE Planned | 1,689 | 1,807 | 1,880 | 1,970 | 2,107 | 2,199 | 2,276 | 2,356 | 2,436 | 2,504 | 2,556 | 2,606 | 2,655 | 2,707 | 2,772 | 2,849 | 2,936 | 3,052 | 3,052 | 3,052 | 3,052 |
| 2025 DOE Planned | 1,466 | 1,594 | 1,640 | 1,717 | 1,811 | 1,888 | 1,958 | 2,035 | 2,116 | 2,199 | 2,285 | 2,377 | 2,436 | 2,482 | 2,527 | 2,587 | 2,666 | 2,776 | 2,963 | 3,052 | 3,052 |
| 2015 DOE Expanded | 1,500 | 2,027 | 2,093 | 2,153 | 2,266 | 2,421 | 2,514 | 2,577 | 2,631 | 2,683 | 2,739 | 2,799 | 2,860 | 2,922 | 2,979 | 3,035 | 3,052 | 3,052 | 3,052 | 3,052 | 3,052 |
| 2020 DOE Expanded | 1,500 | 1,740 | 1,792 | 1,852 | 1,923 | 2,015 | 2,108 | 2,198 | 2,277 | 2,344 | 2,415 | 2,473 | 2,531 | 2,594 | 2,662 | 2,749 | 2,891 | 3,052 | 3,052 | 3,052 | 3,052 |
| 2025 DOE Expanded | 1,347 | 1,532 | 1,571 | 1,609 | 1,668 | 1,735 | 1,795 | 1,850 | 1,910 | 1,974 | 2,038 | 2,117 | 2,201 | 2,306 | 2,411 | 2,474 | 2,551 | 2,664 | 2,892 | 3,052 | 3,052 |

| **HTF/Receiver** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| 2015 No DOE | 110 | 124 | 129 | 133 | 136 | 138 | 141 | 143 | 145 | 147 | 149 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| 2020 No DOE | 87 | 107 | 114 | 120 | 125 | 129 | 132 | 136 | 139 | 141 | 144 | 147 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| 2025 No DOE | 78 | 94 | 99 | 103 | 107 | 110 | 113 | 116 | 120 | 123 | 127 | 130 | 133 | 136 | 140 | 144 | 147 | 150 | 150 | 150 | 150 |
| 2015 DOE Planned | 82 | 112 | 120 | 125 | 130 | 133 | 135 | 138 | 141 | 143 | 145 | 147 | 149 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| 2020 DOE Planned | 65 | 93 | 98 | 102 | 105 | 108 | 111 | 114 | 117 | 120 | 123 | 127 | 130 | 134 | 138 | 142 | 146 | 150 | 150 | 150 | 150 |
| 2025 DOE Planned | 48 | 67 | 75 | 82 | 88 | 93 | 98 | 102 | 105 | 109 | 112 | 116 | 120 | 123 | 127 | 131 | 137 | 143 | 150 | 150 | 150 |
| 2015 DOE Expanded | 69 | 97 | 107 | 115 | 121 | 126 | 130 | 134 | 137 | 140 | 143 | 145 | 148 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| 2020 DOE Expanded | 48 | 68 | 75 | 81 | 87 | 91 | 96 | 100 | 105 | 109 | 112 | 116 | 119 | 124 | 129 | 135 | 142 | 149 | 150 | 150 | 150 |
| 2025 DOE Expanded | 32 | 42 | 46 | 51 | 72 | 80 | 85 | 89 | 94 | 97 | 101 | 104 | 107 | 110 | 114 | 119 | 125 | 133 | 146 | 150 | 150 |

| TES | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| 2015 No DOE | 27.2 | 38.7 | 40.2 | 41.2 | 42.1 | 42.9 | 43.6 | 44.2 | 44.8 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| 2020 No DOE | 18.5 | 29.5 | 33.8 | 35.9 | 37.5 | 38.8 | 39.9 | 41.0 | 42.3 | 43.9 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| 2025 No DOE | 11.4 | 23.0 | 24.7 | 26.0 | 27.0 | 28.1 | 29.3 | 30.9 | 32.9 | 34.6 | 36.4 | 38.3 | 40.3 | 42.7 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| 2015 DOE Planned | 28.2 | 36.8 | 38.2 | 39.3 | 40.2 | 41.1 | 42.0 | 42.9 | 43.7 | 44.6 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| 2020 DOE Planned | 11.5 | 24.4 | 29.7 | 31.6 | 32.9 | 33.9 | 34.9 | 35.9 | 37.0 | 38.1 | 39.3 | 40.5 | 41.9 | 43.2 | 44.5 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| 2025 DOE Planned | 10.0 | 14.5 | 17.0 | 18.3 | 19.2 | 20.0 | 20.8 | 21.8 | 23.4 | 26.1 | 28.7 | 31.4 | 34.1 | 36.5 | 38.4 | 40.3 | 42.2 | 44.3 | 45.0 | 45.0 | 45.0 |
| 2015 DOE Expanded | 27.8 | 33.7 | 35.6 | 37.1 | 38.3 | 39.6 | 40.7 | 41.9 | 43.1 | 44.0 | 44.9 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| 2020 DOE Expanded | 10.5 | 19.0 | 23.8 | 26.1 | 27.3 | 28.4 | 29.3 | 30.3 | 31.4 | 32.8 | 34.5 | 36.6 | 38.4 | 40.3 | 42.6 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| 2025 DOE Expanded | 10.0 | 13.0 | 14.4 | 15.1 | 15.7 | 16.2 | 16.9 | 17.7 | 19.0 | 20.6 | 22.5 | 24.9 | 27.7 | 30.1 | 32.6 | 34.6 | 36.7 | 39.3 | 43.4 | 45.0 | 45.0 |

| PB&BOS | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2015 No DOE | 809.1 | 922.1 | 971.4 | 1,002.4 | 1,026.1 | 1,046.3 | 1,063.8 | 1,080.9 | 1,098.4 | 1,116.6 | 1,118.7 | 1,118.7 | 1,118.7 | 1,118.7 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2020 No DOE | 706.5 | 836.1 | 881.8 | 915.1 | 939.9 | 963.3 | 985.5 | 1,005.1 | 1,026.8 | 1,049.0 | 1,074.8 | 1,102.5 | 1,118.7 | 1,118.7 | 1,118.7 | 1,118.7 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2025 No DOE | 635.5 | 772.1 | 812.6 | 847.9 | 876.5 | 900.7 | 923.5 | 945.7 | 969.1 | 994.5 | 1,019.9 | 1,050.0 | 1,088.2 | 1,118.7 | 1,118.7 | 1,118.7 | 1,118.7 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2015 DOE Planned | 718.6 | 883.3 | 922.2 | 951.5 | 975.4 | 997.9 | 1,017.0 | 1,036.1 | 1,052.3 | 1,068.8 | 1,085.7 | 1,103.0 | 1,118.7 | 1,118.7 | 1,118.7 | 1,118.7 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2020 DOE Planned | 650.3 | 801.4 | 845.2 | 880.6 | 905.3 | 927.8 | 948.0 | 967.5 | 986.2 | 1,007.0 | 1,027.2 | 1,052.6 | 1,082.9 | 1,118.5 | 1,118.7 | 1,118.7 | 1,118.7 | 1,118.7 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2025 DOE Planned | 451.1 | 705.2 | 764.0 | 803.6 | 836.3 | 862.9 | 886.7 | 908.2 | 929.2 | 950.7 | 968.3 | 984.4 | 997.9 | 1,009.3 | 1,020.9 | 1,033.6 | 1,053.2 | 1,096.5 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2015 DOE Expanded | 526.4 | 785.5 | 876.3 | 917.4 | 947.1 | 973.6 | 997.6 | 1,019.8 | 1,038.8 | 1,058.2 | 1,077.8 | 1,097.7 | 1,118.7 | 1,118.7 | 1,118.7 | 1,118.7 | 1,118.7 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2020 DOE Expanded | 357.8 | 618.9 | 742.3 | 800.4 | 842.6 | 871.7 | 896.6 | 919.5 | 942.1 | 965.3 | 989.9 | 1,011.4 | 1,029.4 | 1,045.8 | 1,060.2 | 1,079.2 | 1,103.3 | 1,119.0 | 1,119.0 | 1,119.0 | 1,119.0 |
| 2025 DOE Expanded | 157.8 | 476.9 | 630.0 | 709.0 | 752.6 | 788.3 | 816.4 | 842.8 | 867.8 | 889.7 | 914.5 | 936.9 | 960.2 | 982.5 | 1,005.3 | 1,029.5 | 1,057.3 | 1,096.6 | 1,119.0 | 1,119.0 | 1,119.0 |

| O&M | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 |
| 2015 No DOE | 45.7 | 58.1 | 61.6 | 64.3 | 66.5 | 68.4 | 70.1 | 71.7 | 73.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 |
| 2020 No DOE | 31.4 | 49.8 | 54.5 | 57.1 | 59.1 | 60.9 | 62.3 | 63.6 | 64.8 | 66.0 | 67.0 | 68.1 | 69.5 | 71.1 | 73.4 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 |
| 2025 No DOE | 17.7 | 40.5 | 47.0 | 50.2 | 52.7 | 54.7 | 56.3 | 57.8 | 59.1 | 60.2 | 61.5 | 62.8 | 64.4 | 66.2 | 68.5 | 71.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 |
| 2015 DOE Planned | 43.7 | 56.2 | 59.1 | 60.9 | 62.4 | 63.8 | 64.9 | 66.1 | 67.3 | 68.6 | 70.1 | 71.9 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 |
| 2020 DOE Planned | 10.6 | 37.6 | 43.8 | 48.3 | 51.9 | 54.9 | 57.1 | 58.8 | 60.1 | 61.3 | 62.4 | 63.4 | 64.4 | 65.4 | 66.5 | 67.8 | 69.7 | 73.3 | 74.0 | 74.0 | 74.0 |
| 2025 DOE Planned | 10.4 | 27.6 | 36.7 | 39.8 | 42.5 | 45.2 | 47.6 | 50.1 | 52.3 | 54.1 | 55.5 | 56.8 | 58.0 | 59.4 | 60.6 | 62.1 | 63.9 | 65.8 | 69.1 | 74.0 | 74.0 |
| 2015 DOE Expanded | 30.0 | 50.0 | 54.6 | 57.7 | 59.7 | 61.3 | 62.6 | 63.6 | 64.8 | 65.9 | 67.2 | 69.0 | 71.5 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 | 74.0 |
| 2020 DOE Expanded | 10.6 | 33.0 | 40.9 | 44.9 | 47.8 | 50.1 | 52.3 | 54.1 | 55.4 | 56.7 | 57.8 | 58.9 | 60.0 | 61.1 | 62.3 | 63.8 | 65.7 | 69.2 | 74.0 | 74.0 | 74.0 |
| 2025 DOE Expanded | 10.5 | 26.1 | 35.3 | 38.3 | 40.4 | 42.1 | 43.8 | 45.3 | 46.6 | 48.0 | 49.3 | 50.6 | 51.8 | 53.1 | 54.6 | 56.4 | 59.1 | 62.5 | 66.8 | 74.0 | 74.0 |

| LBD | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Solar Field | 0.00 | 0.06 | 0.07 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.12 | 0.14 | 0.16 | 0.19 | 0.22 | 0.22 | 0.24 | 0.26 | 0.28 | 0.30 | 0.32 | 0.33 |
| HTF/Receiver | 0.00 | 0.03 | 0.05 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | 0.10 | 0.12 | 0.14 | 0.16 | 0.18 | 0.24 | 0.25 | 0.27 | 0.30 | 0.32 | 0.35 |
| TES | 0.00 | 0.05 | 0.07 | 0.09 | 0.10 | 0.11 | 0.15 | 0.23 | 0.25 | 0.27 | 0.29 | 0.30 | 0.31 | 0.33 | 0.34 | 0.36 | 0.38 | 0.40 | 0.44 | 0.44 | 0.46 |
| PB&BOS | 0.00 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.10 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.19 | 0.20 | 0.20 | 0.22 | 0.24 | 0.29 |
| O&M | 0.00 | 0.04 | 0.05 | 0.06 | 0.06 | 0.07 | 0.08 | 0.09 | 0.12 | 0.16 | 0.28 | 0.17 | 0.18 | 0.19 | 0.19 | 0.20 | 0.20 | 0.22 | 0.24 | 0.25 | 0.27 |

## *F.3 Photovoltaic —Utility*

### 2009 Risk Analysis for Photovoltaic (PV) Technologies

**Technology:** **Crystalline Silicon / Thin Film / CPV in a Utility Market Application**
**Plant Size:** **10 MW**

| Module Cost (2009$/kW) | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 |
| 2010 No DOE | 522 | 1,269 | 1,498 | 1,660 | 1,781 | 1,887 | 1,976 | 2,067 | 2,162 | 2,265 | 2,365 | 2,470 | 2,577 | 2,682 | 2,800 | 2,944 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 |
| 2015 No DOE | 504 | 1,022 | 1,159 | 1,251 | 1,337 | 1,426 | 1,505 | 1,575 | 1,637 | 1,691 | 1,748 | 1,809 | 1,873 | 1,947 | 2,029 | 2,139 | 2,287 | 2,504 | 2,978 | 3,000 | 3,000 |
| 2020 No DOE | 300 | 593 | 772 | 912 | 1,070 | 1,183 | 1,264 | 1,335 | 1,394 | 1,453 | 1,504 | 1,559 | 1,614 | 1,671 | 1,735 | 1,810 | 1,903 | 2,038 | 2,274 | 3,000 | 3,000 |
| 2010 DOE Planned | 502 | 1,218 | 1,431 | 1,579 | 1,686 | 1,770 | 1,841 | 1,912 | 1,972 | 2,029 | 2,088 | 2,159 | 2,231 | 2,304 | 2,380 | 2,451 | 2,539 | 2,654 | 2,847 | 3,000 | 3,000 |
| 2015 DOE Planned | 500 | 883 | 983 | 1,051 | 1,125 | 1,196 | 1,261 | 1,320 | 1,376 | 1,430 | 1,481 | 1,531 | 1,583 | 1,642 | 1,713 | 1,802 | 1,921 | 2,110 | 2,350 | 2,709 | 3,000 |
| 2020 DOE Planned | 300 | 535 | 628 | 711 | 798 | 880 | 954 | 1,014 | 1,067 | 1,117 | 1,160 | 1,204 | 1,250 | 1,291 | 1,339 | 1,401 | 1,471 | 1,569 | 1,734 | 2,036 | 3,000 |
| 2010 DOE Expanded | 501 | 1,131 | 1,376 | 1,517 | 1,615 | 1,688 | 1,744 | 1,804 | 1,858 | 1,911 | 1,961 | 2,017 | 2,072 | 2,136 | 2,207 | 2,288 | 2,392 | 2,541 | 2,799 | 3,000 | 3,000 |
| 2015 DOE Expanded | 500 | 806 | 879 | 930 | 977 | 1,024 | 1,075 | 1,122 | 1,169 | 1,216 | 1,262 | 1,304 | 1,350 | 1,399 | 1,455 | 1,520 | 1,599 | 1,726 | 1,909 | 2,204 | 3,000 |
| 2020 DOE Expanded | 300 | 464 | 550 | 619 | 687 | 744 | 801 | 857 | 904 | 948 | 984 | 1,023 | 1,064 | 1,108 | 1,151 | 1,203 | 1,272 | 1,365 | 1,520 | 1,738 | 3,000 |

| Inverter Cost (2009$/kW) | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 |
| 2010 No DOE | 51 | 178 | 224 | 256 | 284 | 306 | 312 | 316 | 320 | 323 | 327 | 332 | 339 | 359 | 389 | 425 | 442 | 456 | 470 | 470 | 470 |
| 2015 No DOE | 50 | 143 | 170 | 191 | 206 | 219 | 232 | 245 | 258 | 272 | 287 | 302 | 314 | 322 | 331 | 348 | 374 | 410 | 428 | 446 | 470 |
| 2020 No DOE | 50 | 131 | 153 | 167 | 179 | 190 | 201 | 211 | 221 | 234 | 247 | 262 | 275 | 290 | 305 | 321 | 337 | 367 | 391 | 407 | 470 |
| 2010 DOE Planned | 51 | 161 | 211 | 240 | 268 | 294 | 305 | 310 | 314 | 317 | 320 | 323 | 328 | 334 | 349 | 363 | 375 | 386 | 404 | 440 | 470 |
| 2015 DOE Planned | 50 | 137 | 162 | 177 | 191 | 202 | 211 | 221 | 230 | 240 | 249 | 259 | 270 | 284 | 301 | 313 | 324 | 337 | 350 | 366 | 470 |
| 2020 DOE Planned | 50 | 121 | 141 | 151 | 161 | 171 | 181 | 190 | 200 | 209 | 217 | 225 | 234 | 244 | 255 | 271 | 291 | 309 | 321 | 333 | 470 |
| 2010 DOE Expanded | 50 | 147 | 200 | 233 | 266 | 293 | 301 | 305 | 309 | 312 | 315 | 319 | 324 | 330 | 340 | 350 | 361 | 374 | 400 | 441 | 470 |
| 2015 DOE Expanded | 50 | 126 | 146 | 158 | 168 | 177 | 184 | 192 | 199 | 205 | 212 | 219 | 227 | 236 | 246 | 255 | 265 | 275 | 286 | 314 | 470 |
| 2020 DOE Expanded | 50 | 110 | 126 | 136 | 144 | 151 | 158 | 165 | 171 | 178 | 185 | 191 | 200 | 204 | 208 | 213 | 219 | 227 | 242 | 276 | 470 |

| Total System Cost (2009$/kW) | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 |
| 2010 No DOE | 1,888 | 2,782 | 3,103 | 3,369 | 3,629 | 3,892 | 4,118 | 4,310 | 4,471 | 4,616 | 4,746 | 4,829 | 4,896 | 4,952 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 |
| 2015 No DOE | 1,713 | 2,328 | 2,583 | 2,747 | 2,873 | 2,974 | 3,063 | 3,157 | 3,260 | 3,373 | 3,502 | 3,661 | 3,822 | 4,019 | 4,253 | 4,531 | 4,793 | 4,961 | 5,000 | 5,000 | 5,000 |
| 2020 No DOE | 1,359 | 1,940 | 2,118 | 2,277 | 2,424 | 2,568 | 2,700 | 2,815 | 2,918 | 3,010 | 3,094 | 3,179 | 3,278 | 3,388 | 3,529 | 3,717 | 3,972 | 4,344 | 4,793 | 5,000 | 5,000 |
| 2010 DOE Planned | 1,698 | 2,561 | 2,875 | 3,111 | 3,347 | 3,541 | 3,731 | 3,902 | 4,084 | 4,267 | 4,447 | 4,633 | 4,709 | 4,762 | 4,808 | 4,853 | 4,905 | 4,981 | 5,000 | 5,000 | 5,000 |
| 2015 DOE Planned | 1,424 | 1,929 | 2,099 | 2,234 | 2,355 | 2,452 | 2,534 | 2,609 | 2,697 | 2,790 | 2,918 | 3,100 | 3,331 | 3,541 | 3,757 | 3,996 | 4,259 | 4,588 | 4,814 | 5,000 | 5,000 |
| 2020 DOE Planned | 1,241 | 1,579 | 1,682 | 1,786 | 1,896 | 1,999 | 2,084 | 2,163 | 2,254 | 2,339 | 2,418 | 2,505 | 2,600 | 2,708 | 2,825 | 2,965 | 3,149 | 3,384 | 3,708 | 4,388 | 5,000 |
| 2010 DOE Expanded | 1,686 | 2,483 | 2,749 | 2,972 | 3,169 | 3,347 | 3,514 | 3,715 | 3,967 | 4,216 | 4,415 | 4,563 | 4,633 | 4,686 | 4,732 | 4,788 | 4,852 | 4,940 | 5,000 | 5,000 | 5,000 |
| 2015 DOE Expanded | 1,284 | 1,703 | 1,853 | 1,972 | 2,113 | 2,252 | 2,341 | 2,409 | 2,472 | 2,546 | 2,632 | 2,729 | 2,849 | 3,007 | 3,178 | 3,365 | 3,563 | 3,809 | 4,091 | 4,539 | 5,000 |
| 2020 DOE Expanded | 1,200 | 1,411 | 1,505 | 1,590 | 1,687 | 1,783 | 1,869 | 1,951 | 2,025 | 2,095 | 2,164 | 2,242 | 2,332 | 2,417 | 2,515 | 2,613 | 2,733 | 2,888 | 3,101 | 3,447 | 5,000 |

| **O&M Cost (2009$/kW-yr)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| 2010 No DOE | 4.4 | 19.2 | 21.8 | 23.6 | 24.8 | 25.7 | 26.4 | 27.0 | 27.5 | 28.0 | 28.3 | 28.7 | 29.1 | 29.5 | 29.9 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| 2015 No DOE | 6.6 | 13.3 | 15.5 | 17.1 | 18.3 | 19.3 | 20.2 | 21.1 | 21.9 | 22.7 | 23.4 | 24.2 | 24.9 | 25.8 | 26.7 | 27.8 | 28.8 | 29.8 | 30.0 | 30.0 | 30.0 |
| 2020 No DOE | 4.1 | 8.4 | 10.2 | 11.4 | 12.3 | 13.1 | 13.9 | 14.8 | 15.7 | 16.8 | 18.0 | 19.4 | 20.8 | 21.8 | 22.8 | 23.9 | 25.2 | 27.1 | 29.0 | 30.0 | 30.0 |
| 2010 DOE Planned | 4.2 | 16.2 | 19.3 | 21.5 | 23.2 | 24.3 | 25.1 | 25.8 | 26.4 | 26.9 | 27.3 | 27.7 | 28.1 | 28.5 | 28.9 | 29.3 | 29.8 | 30.1 | 30.0 | 30.0 | 30.0 |
| 2015 DOE Planned | 4.1 | 11.5 | 13.4 | 14.4 | 15.1 | 15.6 | 16.1 | 16.5 | 17.0 | 17.6 | 18.3 | 19.5 | 22.2 | 23.7 | 24.7 | 25.8 | 27.0 | 28.3 | 29.7 | 30.0 | 30.0 |
| 2020 DOE Planned | 3.0 | 6.2 | 7.0 | 7.6 | 8.2 | 8.7 | 9.4 | 10.1 | 10.7 | 11.4 | 12.5 | 14.4 | 15.7 | 17.0 | 19.1 | 21.3 | 22.2 | 23.3 | 25.5 | 28.5 | 30.0 |
| 2010 DOE Expanded | 4.1 | 16.5 | 19.2 | 21.0 | 22.4 | 23.7 | 24.6 | 25.3 | 25.8 | 26.3 | 26.8 | 27.2 | 27.6 | 27.9 | 28.3 | 28.7 | 29.2 | 29.8 | 30.0 | 30.0 | 30.0 |
| 2015 DOE Expanded | 3.0 | 8.6 | 11.0 | 12.2 | 12.8 | 13.3 | 13.7 | 14.0 | 14.4 | 14.7 | 15.1 | 15.7 | 17.2 | 19.8 | 22.6 | 23.9 | 24.9 | 26.2 | 28.6 | 30.0 | 30.0 |
| 2020 DOE Expanded | 3.0 | 5.2 | 5.9 | 6.4 | 6.9 | 7.3 | 7.8 | 8.4 | 9.1 | 10.1 | 10.8 | 11.7 | 13.1 | 14.5 | 16.1 | 19.0 | 21.1 | 22.2 | 23.3 | 26.5 | 30.0 |

| **Inverter Lifetime (yrs)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 2010 No DOE | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.5 | 11.1 | 11.8 | 12.5 | 13.2 | 14.1 | 15.3 | 17.5 | 23.9 |
| 2015 No DOE | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.2 | 11.6 | 12.5 | 13.2 | 13.8 | 14.3 | 15.0 | 15.9 | 17.2 | 18.9 | 20.6 | 23.1 | 30.0 |
| 2020 No DOE | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.5 | 12.8 | 13.9 | 14.5 | 15.1 | 15.6 | 16.1 | 16.9 | 17.8 | 18.8 | 20.0 | 21.5 | 24.0 | 30.0 |
| 2010 DOE Planned | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.3 | 10.9 | 11.5 | 12.0 | 12.5 | 13.0 | 13.6 | 14.4 | 15.3 | 16.7 | 18.8 | 24.0 |
| 2015 DOE Planned | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 11.3 | 12.3 | 13.2 | 13.8 | 14.5 | 15.1 | 15.9 | 16.7 | 17.6 | 18.8 | 20.6 | 23.1 | 30.0 |
| 2020 DOE Planned | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.7 | 12.7 | 14.1 | 14.8 | 15.4 | 16.1 | 17.0 | 17.9 | 18.7 | 19.6 | 20.7 | 22.7 | 25.5 | 30.0 |
| 2010 DOE Expanded | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.8 | 11.6 | 12.2 | 12.8 | 13.5 | 14.0 | 14.6 | 15.3 | 16.1 | 17.1 | 18.8 | 24.0 |
| 2015 DOE Expanded | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.2 | 12.1 | 13.1 | 13.9 | 14.7 | 15.7 | 17.3 | 18.5 | 19.5 | 20.3 | 21.2 | 22.6 | 24.8 | 30.0 |
| 2020 DOE Expanded | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 11.0 | 13.5 | 14.5 | 15.2 | 15.9 | 17.5 | 19.4 | 20.9 | 22.5 | 23.8 | 24.7 | 25.8 | 27.3 | 30.0 |

| LBD | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Module Cost | 0.00 | 0.03 | 0.04 | 0.05 | 0.06 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.22 | 0.26 |
| Inverter Cost | 0.01 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.14 | 0.15 | 0.16 | 0.16 | 0.16 | 0.17 | 0.18 | 0.20 |
| Total System Cost | 0.00 | 0.05 | 0.06 | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.19 | 0.20 | 0.21 | 0.22 | 0.26 |
| O&M Cost | 0.00 | 0.04 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.16 | 0.17 | 0.17 | 0.18 | 0.19 | 0.19 | 0.20 | 0.27 |
| Inverter Lifetime | 0.01 | 0.03 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.19 |

### *F.4 Photovoltaic—Commercial*

## 2009 Risk Analysis for Photovoltaic (PV) Technologies

**Technology:** **Crystalline Silicon / Thin Film / CPV in a Commercial Market Application**

**Plant Size:** **150 kW**

| **Module Cost (2009$/kW)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 |
| 2010 No DOE | 1,216 | 1,813 | 1,981 | 2,114 | 2,224 | 2,318 | 2,405 | 2,479 | 2,542 | 2,600 | 2,658 | 2,719 | 2,786 | 2,868 | 2,965 | 3,090 | 3,316 | 3,500 | 3,500 | 3,500 | 3,500 |
| 2015 No DOE | 696 | 1,166 | 1,290 | 1,395 | 1,487 | 1,585 | 1,681 | 1,761 | 1,832 | 1,899 | 1,964 | 2,036 | 2,105 | 2,177 | 2,254 | 2,352 | 2,480 | 2,687 | 2,992 | 3,500 | 3,500 |
| 2020 No DOE | 237 | 552 | 728 | 898 | 1,048 | 1,162 | 1,248 | 1,321 | 1,387 | 1,446 | 1,504 | 1,565 | 1,629 | 1,695 | 1,762 | 1,835 | 1,919 | 2,015 | 2,172 | 2,517 | 3,500 |
| 2010 DOE Planned | 1,216 | 1,733 | 1,861 | 1,946 | 2,021 | 2,084 | 2,153 | 2,218 | 2,286 | 2,355 | 2,424 | 2,494 | 2,559 | 2,620 | 2,678 | 2,744 | 2,826 | 2,925 | 3,139 | 3,500 | 3,500 |
| 2015 DOE Planned | 585 | 1,005 | 1,106 | 1,185 | 1,267 | 1,337 | 1,409 | 1,479 | 1,554 | 1,636 | 1,710 | 1,789 | 1,863 | 1,940 | 2,014 | 2,096 | 2,192 | 2,331 | 2,562 | 2,857 | 3,500 |
| 2020 DOE Planned | 157 | 490 | 627 | 741 | 852 | 951 | 1,022 | 1,079 | 1,131 | 1,182 | 1,231 | 1,287 | 1,349 | 1,412 | 1,486 | 1,569 | 1,657 | 1,755 | 1,884 | 2,085 | 3,500 |
| 2010 DOE Expanded | 1,216 | 1,649 | 1,749 | 1,826 | 1,901 | 1,968 | 2,035 | 2,099 | 2,162 | 2,222 | 2,281 | 2,338 | 2,394 | 2,457 | 2,513 | 2,583 | 2,664 | 2,770 | 2,940 | 3,291 | 3,500 |
| 2015 DOE Expanded | 190 | 879 | 960 | 1,016 | 1,064 | 1,111 | 1,158 | 1,208 | 1,258 | 1,315 | 1,379 | 1,462 | 1,552 | 1,636 | 1,726 | 1,822 | 1,914 | 2,022 | 2,148 | 2,390 | 3,500 |
| 2020 DOE Expanded | 100 | 427 | 532 | 629 | 718 | 795 | 848 | 896 | 940 | 986 | 1,030 | 1,080 | 1,136 | 1,200 | 1,267 | 1,337 | 1,412 | 1,498 | 1,601 | 1,788 | 3,500 |

| **Inverter Cost (2009$/kW)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 | 470 |
| 2010 No DOE | 200 | 298 | 323 | 327 | 331 | 333 | 336 | 338 | 341 | 344 | 348 | 354 | 419 | 439 | 450 | 462 | 470 | 470 | 470 | 470 | 470 |
| 2015 No DOE | 135 | 182 | 202 | 213 | 224 | 236 | 249 | 263 | 280 | 301 | 325 | 335 | 345 | 403 | 423 | 435 | 451 | 470 | 470 | 470 | 470 |
| 2020 No DOE | 128 | 159 | 172 | 182 | 191 | 201 | 208 | 217 | 227 | 240 | 257 | 288 | 329 | 365 | 391 | 402 | 418 | 470 | 470 | 470 | 470 |
| 2010 DOE Planned | 200 | 284 | 317 | 322 | 325 | 328 | 330 | 332 | 335 | 337 | 341 | 345 | 350 | 363 | 375 | 387 | 421 | 470 | 470 | 470 | 470 |
| 2015 DOE Planned | 133 | 174 | 192 | 204 | 213 | 225 | 235 | 248 | 263 | 281 | 306 | 324 | 332 | 339 | 348 | 357 | 372 | 470 | 470 | 470 | 470 |
| 2020 DOE Planned | 118 | 149 | 161 | 170 | 179 | 190 | 201 | 210 | 220 | 231 | 247 | 272 | 302 | 316 | 325 | 334 | 347 | 470 | 470 | 470 | 470 |
| 2010 DOE Expanded | 200 | 278 | 312 | 317 | 320 | 323 | 325 | 327 | 329 | 332 | 335 | 337 | 341 | 346 | 353 | 366 | 417 | 470 | 470 | 470 | 470 |
| 2015 DOE Expanded | 124 | 163 | 179 | 191 | 201 | 209 | 218 | 227 | 238 | 248 | 257 | 265 | 273 | 280 | 289 | 304 | 346 | 470 | 470 | 470 | 470 |
| 2020 DOE Expanded | 110 | 138 | 150 | 160 | 169 | 179 | 190 | 200 | 204 | 208 | 212 | 217 | 223 | 232 | 250 | 279 | 333 | 470 | 470 | 470 | 470 |

| **Total System Cost (2009$/kW)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 |
| 2010 No DOE | 2,320 | 3,090 | 3,399 | 3,703 | 4,045 | 4,291 | 4,450 | 4,569 | 4,679 | 4,777 | 4,887 | 5,015 | 5,192 | 5,313 | 5,377 | 5,429 | 5,500 | 5,500 | 5,500 | 5,500 | 5,500 |
| 2015 No DOE | 1,570 | 2,298 | 2,556 | 2,777 | 2,964 | 3,062 | 3,145 | 3,231 | 3,332 | 3,469 | 3,611 | 3,739 | 3,858 | 3,969 | 4,090 | 4,229 | 4,447 | 4,801 | 5,340 | 5,500 | 5,500 |
| 2020 No DOE | 640 | 1,357 | 1,711 | 1,994 | 2,162 | 2,300 | 2,451 | 2,679 | 2,847 | 2,969 | 3,057 | 3,123 | 3,193 | 3,269 | 3,351 | 3,453 | 3,590 | 3,791 | 4,441 | 5,356 | 5,500 |
| 2010 DOE Planned | 2,159 | 2,945 | 3,168 | 3,332 | 3,463 | 3,602 | 3,782 | 4,082 | 4,348 | 4,512 | 4,656 | 4,801 | 4,970 | 5,106 | 5,176 | 5,233 | 5,280 | 5,331 | 5,388 | 5,482 | 5,500 |
| 2015 DOE Planned | 860 | 1,966 | 2,217 | 2,370 | 2,510 | 2,611 | 2,694 | 2,768 | 2,838 | 2,902 | 2,967 | 3,046 | 3,173 | 3,418 | 3,594 | 3,732 | 3,884 | 4,106 | 4,769 | 5,253 | 5,500 |
| 2020 DOE Planned | 511 | 1,185 | 1,570 | 1,704 | 1,783 | 1,853 | 1,931 | 2,023 | 2,117 | 2,211 | 2,311 | 2,416 | 2,542 | 2,665 | 2,773 | 2,871 | 2,970 | 3,084 | 3,255 | 3,764 | 5,500 |
| 2010 DOE Expanded | 2,088 | 2,787 | 2,979 | 3,126 | 3,278 | 3,437 | 3,651 | 3,963 | 4,161 | 4,314 | 4,456 | 4,626 | 4,795 | 4,871 | 4,932 | 4,988 | 5,047 | 5,122 | 5,200 | 5,336 | 5,500 |
| 2015 DOE Expanded | 822 | 1,794 | 1,975 | 2,119 | 2,246 | 2,391 | 2,503 | 2,578 | 2,636 | 2,710 | 2,783 | 2,861 | 2,947 | 3,074 | 3,227 | 3,362 | 3,489 | 3,639 | 3,856 | 4,319 | 5,500 |
| 2020 DOE Expanded | 501 | 993 | 1,270 | 1,519 | 1,591 | 1,646 | 1,713 | 1,795 | 1,911 | 2,020 | 2,124 | 2,226 | 2,324 | 2,416 | 2,512 | 2,604 | 2,697 | 2,792 | 2,913 | 3,167 | 5,500 |

| **O&M Cost (2009$/kW-yr)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 |
| 2010 No DOE | 4.0 | 22.6 | 26.2 | 28.0 | 29.1 | 29.8 | 30.4 | 30.9 | 31.4 | 31.8 | 32.1 | 32.6 | 33.0 | 33.4 | 33.8 | 34.3 | 34.9 | 35.0 | 35.2 | 35.0 | 35.0 |
| 2015 No DOE | 4.0 | 14.2 | 16.3 | 17.8 | 19.2 | 20.1 | 20.9 | 21.7 | 22.5 | 23.1 | 23.8 | 24.6 | 25.4 | 26.4 | 27.6 | 28.9 | 30.5 | 31.8 | 33.2 | 35.0 | 35.0 |
| 2020 No DOE | 4.0 | 8.7 | 10.2 | 11.5 | 12.4 | 13.1 | 13.8 | 14.4 | 15.0 | 15.7 | 16.4 | 17.3 | 18.3 | 19.5 | 21.0 | 22.6 | 24.3 | 26.8 | 29.9 | 33.0 | 35.0 |
| 2010 DOE Planned | 4.0 | 20.5 | 23.7 | 26.0 | 27.5 | 28.5 | 29.2 | 29.7 | 30.2 | 30.6 | 31.0 | 31.5 | 31.9 | 32.3 | 32.8 | 33.3 | 33.8 | 34.4 | 35.0 | 35.0 | 35.0 |
| 2015 DOE Planned | 4.0 | 11.1 | 13.1 | 14.6 | 15.6 | 16.2 | 16.6 | 17.0 | 17.3 | 17.7 | 17.9 | 18.2 | 18.5 | 18.9 | 19.3 | 19.8 | 20.6 | 27.6 | 31.0 | 33.4 | 35.0 |
| 2020 DOE Planned | 4.0 | 6.8 | 7.4 | 7.8 | 8.2 | 8.5 | 8.8 | 9.1 | 9.5 | 9.8 | 10.2 | 10.6 | 11.1 | 11.7 | 12.4 | 13.7 | 16.0 | 17.4 | 18.5 | 21.0 | 35.0 |
| 2010 DOE Expanded | 4.0 | 19.3 | 22.4 | 24.4 | 25.6 | 26.6 | 27.5 | 28.2 | 28.8 | 29.3 | 29.8 | 30.3 | 30.6 | 31.0 | 31.5 | 31.9 | 32.5 | 33.2 | 34.0 | 35.0 | 35.0 |
| 2015 DOE Expanded | 4.0 | 9.1 | 10.6 | 11.7 | 12.7 | 13.3 | 13.7 | 14.1 | 14.4 | 14.8 | 15.1 | 15.4 | 15.6 | 15.9 | 16.1 | 16.3 | 16.6 | 17.0 | 17.8 | 24.7 | 35.0 |
| 2020 DOE Expanded | 4.0 | 5.5 | 6.4 | 6.8 | 7.1 | 7.3 | 7.6 | 7.8 | 8.1 | 8.3 | 8.6 | 9.0 | 9.3 | 9.7 | 10.2 | 10.7 | 11.6 | 13.1 | 14.9 | 16.4 | 35.0 |

| **Inverter Lifetime (yrs)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 2010 No DOE | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.7 | 11.4 | 12.0 | 12.9 | 14.0 | 18.0 |
| 2015 No DOE | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 11.2 | 12.5 | 13.4 | 14.1 | 14.9 | 15.9 | 17.4 | 23.6 |
| 2020 No DOE | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 13.4 | 14.6 | 15.5 | 16.2 | 16.8 | 17.8 | 19.0 | 23.2 |
| 2010 DOE Planned | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.1 | 10.9 | 11.6 | 12.3 | 13.0 | 14.1 | 18.1 |
| 2015 DOE Planned | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.7 | 13.2 | 14.4 | 15.2 | 16.0 | 16.9 | 18.1 | 24.0 |
| 2020 DOE Planned | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 13.1 | 15.5 | 16.7 | 17.5 | 18.2 | 18.9 | 19.7 | 23.2 |
| 2010 DOE Expanded | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.8 | 12.3 | 13.3 | 14.1 | 14.9 | 16.0 | 18.7 |
| 2015 DOE Expanded | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 12.4 | 15.5 | 17.8 | 19.0 | 19.9 | 20.7 | 21.8 | 30.0 |
| 2020 DOE Expanded | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 15.0 | 18.9 | 22.3 | 23.7 | 24.7 | 25.6 | 26.6 | 30.0 |
| | | | | 10.0 | | | | | | | | | | | | | | | | | |
| | | | | 10.0 | | | | | | | | | | | | | | | | | |

| **LBD** | 0% | 5% | 10% | 10.0 | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Module Cost | 0.01 | 0.04 | 0.05 | 10.0 | 0.08 | 0.09 | 0.10 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.23 | 0.32 |
| Inverter Cost | 0.01 | 0.05 | 0.07 | 10.0 | 0.10 | 0.11 | 0.13 | 0.13 | 0.14 | 0.14 | 0.15 | 0.15 | 0.16 | 0.16 | 0.16 | 0.16 | 0.17 | 0.17 | 0.18 | 0.18 | 0.20 |
| Total System Cost | 0.01 | 0.04 | 0.05 | 10.0 | 0.07 | 0.09 | 0.10 | 0.12 | 0.13 | 0.15 | 0.16 | 0.17 | 0.18 | 0.18 | 0.19 | 0.20 | 0.20 | 0.20 | 0.21 | 0.22 | 0.27 |
| O&M Cost | 0.01 | 0.05 | 0.07 | 10.0 | 0.10 | 0.11 | 0.13 | 0.14 | 0.15 | 0.15 | 0.16 | 0.16 | 0.17 | 0.17 | 0.18 | 0.18 | 0.18 | 0.19 | 0.19 | 0.20 | 0.22 |
| Inverter Lifetime | 0.01 | 0.04 | 0.05 | 10.0 | 0.07 | 0.07 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.13 | 0.13 | 0.14 | 0.15 | 0.16 | 0.19 |

## *F.5 Photovoltaic—Residential*

**2009 Risk Analysis for Photovoltaic (PV) Technologies**

**Technology:** **Crystalline Silicon / Thin Film in a Residential Market Application**
**Plant Size:** **4 kW**

| **Module Cost (2009$/kW)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 |
| 2010 No DOE | 1,122 | 1,861 | 2,006 | 2,112 | 2,218 | 2,316 | 2,407 | 2,492 | 2,571 | 2,665 | 2,766 | 2,873 | 2,984 | 3,091 | 3,229 | 3,439 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 |
| 2015 No DOE | 951 | 1,536 | 1,677 | 1,761 | 1,816 | 1,865 | 1,908 | 1,950 | 1,989 | 2,031 | 2,075 | 2,116 | 2,161 | 2,214 | 2,276 | 2,353 | 2,479 | 2,957 | 3,761 | 4,000 | 4,000 |
| 2020 No DOE | 361 | 646 | 879 | 1,191 | 1,343 | 1,437 | 1,512 | 1,572 | 1,626 | 1,677 | 1,730 | 1,784 | 1,837 | 1,898 | 1,963 | 2,030 | 2,106 | 2,203 | 2,420 | 3,852 | 4,000 |
| 2010 DOE Planned | 1,131 | 1,519 | 1,732 | 1,874 | 1,963 | 2,039 | 2,106 | 2,172 | 2,237 | 2,302 | 2,370 | 2,439 | 2,520 | 2,624 | 2,756 | 2,872 | 2,987 | 3,116 | 3,309 | 4,000 | 4,000 |
| 2015 DOE Planned | 810 | 1,184 | 1,265 | 1,324 | 1,374 | 1,418 | 1,461 | 1,499 | 1,534 | 1,571 | 1,608 | 1,646 | 1,687 | 1,736 | 1,792 | 1,860 | 1,983 | 2,162 | 2,481 | 3,033 | 4,000 |
| 2020 DOE Planned | 360 | 602 | 782 | 918 | 1,011 | 1,086 | 1,148 | 1,203 | 1,249 | 1,291 | 1,332 | 1,373 | 1,412 | 1,450 | 1,486 | 1,524 | 1,565 | 1,620 | 1,697 | 1,981 | 4,000 |
| 2010 DOE Expanded | 948 | 1,295 | 1,520 | 1,734 | 1,846 | 1,939 | 2,018 | 2,088 | 2,160 | 2,228 | 2,301 | 2,372 | 2,445 | 2,520 | 2,605 | 2,704 | 2,812 | 2,944 | 3,107 | 3,926 | 4,000 |
| 2015 DOE Expanded | 637 | 961 | 1,029 | 1,078 | 1,121 | 1,162 | 1,204 | 1,241 | 1,277 | 1,313 | 1,353 | 1,398 | 1,445 | 1,499 | 1,564 | 1,644 | 1,738 | 1,866 | 2,027 | 2,337 | 4,000 |
| 2020 DOE Expanded | 361 | 556 | 683 | 778 | 846 | 893 | 932 | 969 | 1,000 | 1,030 | 1,062 | 1,099 | 1,134 | 1,170 | 1,210 | 1,253 | 1,301 | 1,358 | 1,437 | 1,651 | 4,000 |

| **Inverter Cost (2009$/kW)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| 2010 No DOE | 200 | 323 | 338 | 347 | 355 | 361 | 366 | 371 | 376 | 381 | 386 | 393 | 400 | 412 | 466 | 491 | 507 | 525 | 553 | 600 | 600 |
| 2015 No DOE | 142 | 194 | 212 | 226 | 238 | 248 | 259 | 271 | 284 | 298 | 317 | 337 | 354 | 373 | 390 | 421 | 439 | 450 | 459 | 474 | 600 |
| 2020 No DOE | 140 | 168 | 181 | 191 | 199 | 207 | 214 | 223 | 231 | 241 | 252 | 265 | 285 | 320 | 358 | 381 | 392 | 401 | 410 | 425 | 600 |
| 2010 DOE Planned | 200 | 313 | 331 | 340 | 347 | 354 | 359 | 364 | 369 | 373 | 378 | 383 | 390 | 398 | 409 | 427 | 444 | 456 | 472 | 499 | 600 |
| 2015 DOE Planned | 140 | 186 | 205 | 218 | 230 | 240 | 250 | 261 | 272 | 286 | 301 | 319 | 340 | 362 | 376 | 386 | 395 | 404 | 414 | 432 | 600 |
| 2020 DOE Planned | 140 | 163 | 175 | 184 | 192 | 200 | 207 | 215 | 224 | 233 | 243 | 254 | 269 | 300 | 322 | 335 | 346 | 356 | 366 | 386 | 600 |
| 2010 DOE Expanded | 201 | 312 | 327 | 336 | 343 | 350 | 355 | 360 | 364 | 368 | 373 | 378 | 383 | 388 | 394 | 400 | 408 | 421 | 441 | 484 | 600 |
| 2015 DOE Expanded | 140 | 178 | 195 | 208 | 219 | 228 | 236 | 245 | 254 | 263 | 272 | 280 | 287 | 294 | 300 | 306 | 314 | 324 | 348 | 403 | 600 |
| 2020 DOE Expanded | 140 | 158 | 168 | 177 | 184 | 193 | 201 | 208 | 216 | 225 | 234 | 245 | 255 | 266 | 275 | 285 | 295 | 308 | 325 | 374 | 600 |

| **Total System Cost (2009$/kW)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 |
| 2010 No DOE | 3,006 | 4,138 | 4,635 | 5,221 | 5,804 | 6,106 | 6,285 | 6,408 | 6,494 | 6,578 | 6,658 | 6,731 | 6,801 | 6,873 | 6,961 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 |
| 2015 No DOE | 2,303 | 3,414 | 3,789 | 4,008 | 4,184 | 4,353 | 4,516 | 4,665 | 4,838 | 5,011 | 5,190 | 5,360 | 5,549 | 5,764 | 6,088 | 6,474 | 6,744 | 7,000 | 7,000 | 7,000 | 7,000 |
| 2020 No DOE | 1,914 | 2,804 | 2,968 | 3,102 | 3,239 | 3,403 | 3,564 | 3,759 | 3,921 | 4,074 | 4,218 | 4,356 | 4,491 | 4,621 | 4,811 | 5,042 | 5,471 | 6,409 | 6,918 | 7,000 | 7,000 |
| 2010 DOE Planned | 2,971 | 4,048 | 4,407 | 4,630 | 4,828 | 5,008 | 5,189 | 5,382 | 5,625 | 5,965 | 6,237 | 6,374 | 6,479 | 6,567 | 6,647 | 6,720 | 6,796 | 6,883 | 7,000 | 7,000 | 7,000 |
| 2015 DOE Planned | 2,212 | 2,952 | 3,141 | 3,291 | 3,414 | 3,515 | 3,607 | 3,702 | 3,798 | 3,898 | 3,998 | 4,122 | 4,245 | 4,381 | 4,556 | 4,770 | 5,093 | 5,760 | 6,511 | 6,826 | 7,000 |
| 2020 DOE Planned | 1,773 | 2,375 | 2,483 | 2,558 | 2,619 | 2,686 | 2,755 | 2,828 | 2,897 | 2,976 | 3,052 | 3,142 | 3,254 | 3,362 | 3,480 | 3,602 | 3,744 | 3,919 | 4,228 | 4,994 | 7,000 |
| 2010 DOE Expanded | 2,776 | 3,777 | 4,067 | 4,294 | 4,470 | 4,650 | 4,862 | 5,123 | 5,486 | 5,824 | 6,108 | 6,245 | 6,340 | 6,421 | 6,495 | 6,561 | 6,641 | 6,739 | 6,862 | 7,000 | 7,000 |
| 2015 DOE Expanded | 1,786 | 2,517 | 2,723 | 2,867 | 2,989 | 3,106 | 3,211 | 3,313 | 3,428 | 3,537 | 3,644 | 3,756 | 3,881 | 4,007 | 4,135 | 4,290 | 4,454 | 4,669 | 5,053 | 6,236 | 7,000 |
| 2020 DOE Expanded | 1,705 | 2,123 | 2,225 | 2,298 | 2,359 | 2,410 | 2,458 | 2,513 | 2,567 | 2,634 | 2,713 | 2,798 | 2,880 | 2,974 | 3,069 | 3,172 | 3,310 | 3,469 | 3,688 | 4,160 | 7,000 |

| **O&M Cost (2009$/kW-yr)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 |
| 2010 No DOE | 4.0 | 15.5 | 23.2 | 29.3 | 34.3 | 38.9 | 42.9 | 46.9 | 47.9 | 48.4 | 48.9 | 49.3 | 49.6 | 50.0 | 50.3 | 50.6 | 51.0 | 51.4 | 52.0 | 52.0 | 52.0 |
| 2015 No DOE | 4.0 | 11.2 | 16.4 | 20.7 | 24.8 | 29.2 | 33.0 | 34.6 | 36.0 | 37.1 | 38.1 | 39.0 | 39.8 | 40.6 | 41.5 | 42.4 | 43.4 | 44.7 | 46.3 | 49.5 | 52.0 |
| 2020 No DOE | 4.0 | 10.4 | 13.3 | 14.9 | 16.1 | 17.2 | 18.1 | 18.9 | 19.7 | 20.5 | 21.3 | 22.2 | 23.1 | 24.2 | 25.6 | 27.4 | 31.0 | 35.6 | 40.7 | 46.6 | 52.0 |
| 2010 DOE Planned | 4.1 | 14.7 | 21.4 | 26.7 | 31.1 | 35.2 | 36.5 | 37.5 | 38.2 | 38.9 | 39.4 | 39.9 | 40.4 | 40.9 | 41.4 | 42.1 | 42.9 | 43.9 | 46.6 | 51.2 | 52.0 |
| 2015 DOE Planned | 4.0 | 10.4 | 13.3 | 14.7 | 16.0 | 17.0 | 18.0 | 18.8 | 19.6 | 20.3 | 21.1 | 22.0 | 23.0 | 24.0 | 25.4 | 27.0 | 30.3 | 34.7 | 39.8 | 46.5 | 52.0 |
| 2020 DOE Planned | 4.0 | 7.9 | 9.6 | 10.8 | 11.8 | 12.7 | 13.5 | 14.3 | 15.0 | 15.7 | 16.5 | 17.3 | 18.2 | 19.2 | 20.4 | 22.1 | 24.9 | 29.1 | 34.0 | 40.6 | 52.0 |
| 2010 DOE Expanded | 4.1 | 14.1 | 20.5 | 25.6 | 28.6 | 30.1 | 31.4 | 32.3 | 33.3 | 34.1 | 34.9 | 35.7 | 36.5 | 37.4 | 38.5 | 39.6 | 41.0 | 42.9 | 47.0 | 52.0 | 52.0 |
| 2015 DOE Expanded | 4.0 | 7.9 | 9.6 | 10.9 | 11.9 | 12.8 | 13.7 | 14.5 | 15.2 | 15.9 | 16.7 | 17.7 | 18.6 | 19.8 | 21.2 | 23.1 | 26.9 | 31.0 | 36.9 | 44.0 | 52.0 |
| 2020 DOE Expanded | 4.0 | 5.8 | 6.8 | 7.6 | 8.4 | 9.1 | 9.7 | 10.3 | 11.0 | 11.7 | 12.4 | 13.2 | 14.2 | 15.2 | 16.4 | 18.1 | 21.1 | 24.8 | 29.9 | 38.7 | 52.0 |

| **Inverter Lifetime (yrs)** | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| 2010 No DOE | 5.0 | 5.0 | 5.4 | 5.9 | 6.3 | 6.7 | 7.0 | 7.3 | 7.7 | 8.0 | 8.4 | 8.7 | 9.1 | 9.6 | 10.0 | 10.6 | 11.2 | 12.0 | 13.3 | 15.0 | 19.0 |
| 2015 No DOE | 5.0 | 6.5 | 7.4 | 8.0 | 8.5 | 8.9 | 9.3 | 9.6 | 9.9 | 10.2 | 10.5 | 10.8 | 11.2 | 11.5 | 12.0 | 12.6 | 13.5 | 15.2 | 17.2 | 19.9 | 26.4 |
| 2020 No DOE | 5.0 | 6.9 | 8.4 | 9.2 | 9.8 | 10.3 | 10.8 | 11.2 | 11.6 | 12.0 | 12.3 | 12.7 | 13.1 | 13.5 | 14.0 | 14.6 | 15.2 | 16.1 | 17.7 | 20.3 | 26.6 |
| 2010 DOE Planned | 5.0 | 6.2 | 7.1 | 7.7 | 8.2 | 8.6 | 9.0 | 9.3 | 9.6 | 9.9 | 10.2 | 10.5 | 10.8 | 11.1 | 11.5 | 11.9 | 12.3 | 12.9 | 13.8 | 15.1 | 18.3 |
| 2015 DOE Planned | 5.0 | 8.4 | 10.0 | 11.2 | 12.1 | 12.7 | 13.2 | 13.6 | 14.0 | 14.3 | 14.6 | 14.9 | 15.2 | 15.5 | 15.8 | 16.2 | 16.6 | 17.0 | 17.7 | 19.1 | 23.9 |
| 2020 DOE Planned | 5.0 | 9.5 | 11.2 | 12.5 | 13.6 | 14.3 | 14.8 | 15.3 | 15.7 | 16.0 | 16.3 | 16.7 | 16.9 | 17.2 | 17.5 | 17.9 | 18.2 | 18.7 | 19.2 | 20.0 | 23.9 |
| 2010 DOE Expanded | 5.0 | 6.6 | 8.1 | 9.4 | 10.5 | 11.5 | 12.3 | 12.9 | 13.4 | 13.8 | 14.2 | 14.6 | 14.9 | 15.2 | 15.6 | 16.0 | 16.4 | 16.9 | 17.6 | 19.3 | 25.2 |
| 2015 DOE Expanded | 5.0 | 8.3 | 10.1 | 11.6 | 13.2 | 14.3 | 14.9 | 15.4 | 15.8 | 16.2 | 16.6 | 16.9 | 17.2 | 17.6 | 18.0 | 18.4 | 18.9 | 19.5 | 20.8 | 23.7 | 30.0 |
| 2020 DOE Expanded | 5.0 | 11.2 | 13.8 | 15.7 | 17.1 | 17.8 | 18.3 | 18.8 | 19.2 | 19.5 | 19.8 | 20.1 | 20.5 | 20.8 | 21.1 | 21.6 | 22.1 | 22.7 | 24.2 | 26.6 | 30.0 |

| LBD | 0% | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Module Cost | 0.01 | 0.05 | 0.07 | 0.09 | 0.10 | 0.11 | 0.12 | 0.12 | 0.13 | 0.14 | 0.15 | 0.15 | 0.16 | 0.17 | 0.18 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.27 |
| Inverter Cost | 0.01 | 0.05 | 0.07 | 0.09 | 0.10 | 0.11 | 0.13 | 0.13 | 0.14 | 0.15 | 0.15 | 0.15 | 0.16 | 0.16 | 0.16 | 0.16 | 0.17 | 0.17 | 0.18 | 0.18 | 0.20 |
| Total System Cost | 0.01 | 0.05 | 0.07 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.18 | 0.19 | 0.20 | 0.20 | 0.21 | 0.21 | 0.22 | 0.24 |
| O&M Cost | 0.01 | 0.04 | 0.05 | 0.06 | 0.07 | 0.07 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.13 | 0.13 | 0.14 | 0.15 | 0.16 | 0.19 |
| Inverter Lifetime | 0.01 | 0.04 | 0.05 | 0.06 | 0.07 | 0.07 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.13 | 0.14 | 0.15 | 0.16 | 0.19 |

# Appendix G: Aggregated Percent Likelihoods for Photovoltaic (PV) Disruptive Advancements

| Technology Advancement | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Module** | | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
| Kerfless wafering @ ~1g/W >20% of wafering industry's annual production | No DOE | 1% | 13% | 29% | 51% | 67% | 73% |
| | Planned | 1% | 19% | 40% | 63% | 70% | 73% |
| | Expanded | 1% | 27% | 51% | 69% | 71% | 73% |
| UMG silicon (no Siemens or FBR processing) provides >20% of industry's annual cell manufacturing | No DOE | 0% | 12% | 30% | 42% | 48% | 55% |
| | Planned | 1% | 16% | 39% | 47% | 52% | 57% |
| | Expanded | 2% | 23% | 45% | 50% | 55% | 57% |
| ≤100um wafer thickness achieved in >20% of annual wiresaw wafering production | No DOE | 1% | 8% | 18% | 30% | 40% | 48% |
| | Planned | 1% | 14% | 28% | 39% | 46% | 49% |
| | Expanded | 2% | 20% | 38% | 45% | 47% | 50% |
| | | | | | | | |
| | | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
| ≥15% thin film module efficiency in unconcentrated, terrestrial commercial modules | No DOE | 1% | 14% | 32% | 54% | 61% | 68% |
| | Planned | 1% | 18% | 39% | 59% | 64% | 72% |
| | Expanded | 1% | 24% | 44% | 62% | 71% | 74% |
| Flexible modules comprise >20% of annual market | No DOE | 0% | 3% | 8% | 18% | 24% | 25% |
| | Planned | 0% | 6% | 13% | 22% | 26% | 31% |
| | Expanded | 0% | 8% | 19% | 26% | 32% | 37% |
| Organic PV modules comprise >20% of annual market | No DOE | 0% | 0% | 4% | 10% | 11% | 12% |
| | Planned | 0% | 2% | 6% | 11% | 12% | 17% |
| | Expanded | 0% | 4% | 8% | 12% | 17% | 22% |
| CIGS modules comprise >20% of annual market | No DOE | 0% | 12% | 20% | 28% | 32% | 35% |
| | Planned | 0% | 15% | 23% | 30% | 32% | 35% |
| | Expanded | 0% | 17% | 26% | 31% | 34% | 36% |
| | | | | | | | |
| | | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
| Use of III-V devices in non-tracking modules to achieve commercial modules with >25% efficiency at competitive cost | No DOE | 0% | 3% | 6% | 21% | 27% | 30% |
| | Planned | 0% | 7% | 12% | 28% | 35% | 37% |
| | Expanded | 0% | 13% | 22% | 35% | 40% | 44% |
| Multi-exiton photogeneration or intermediate band structure devices sold in a commercial terrestrial PV product | No DOE | 3% | 8% | 14% | 22% | 39% | 53% |
| | Planned | 7% | 11% | 20% | 31% | 48% | 58% |
| | Expanded | 10% | 15% | 27% | 40% | 54% | 62% |
| Commercial CPV modules >30% efficiency | No DOE | 19% | 35% | 56% | 67% | 79% | 86% |
| | Planned | 24% | 46% | 69% | 82% | 91% | 97% |
| | Expanded | 27% | 66% | 79% | 84% | 93% | 99% |

| Technology Advancement | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Inverter/System** | | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
| Economical 30 year warrantee available on > 20% annual inverter market | No DOE | 4% | 14% | 38% | 80% | 81% | 82% |
| | Planned | 8% | 27% | 65% | 81% | 82% | 82% |
| | Expanded | 16% | 50% | 70% | 81% | 82% | 82% |
| AC PV modules (microinverters) achieve > 20% annual market share of residential rooftop installations | No DOE | 0% | 19% | 36% | 60% | 68% | 78% |
| | Planned | 0% | 29% | 48% | 64% | 72% | 82% |
| | Expanded | 0% | 39% | 56% | 68% | 76% | 86% |
| 20% of new inverters installations employ time-of-use pricing operation | No DOE | 4% | 37% | 80% | 88% | 90% | 90% |
| | Planned | 12% | 54% | 82% | 88% | 90% | 90% |
| | Expanded | 20% | 72% | 84% | 88% | 90% | 90% |
| 20% of grid tied systems incorporating energy storage functionality (i.e. battery or PHEV) | No DOE | 0% | 13% | 44% | 74% | 81% | 86% |
| | Planned | 0% | 30% | 69% | 79% | 86% | 86% |
| | Expanded | 0% | 62% | 72% | 84% | 86% | 86% |
| | | | | | | | |
| **Technology Advancement** | | | | | | | |
| **Installation and Market Penetration** | | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
| Physical installation of BIPV shingle by non-PV-trained roofer achieves >20% of annual residential installations | No DOE | 11% | 28% | 58% | 73% | 81% | 86% |
| | Planned | 14% | 38% | 65% | 78% | 81% | 86% |
| | Expanded | 18% | 49% | 74% | 78% | 82% | 87% |
| Commercial Roofing PV membrane comprise >20% of annual commercial rooftop installations | No DOE | 13% | 22% | 36% | 50% | 67% | 68% |
| | Planned | 16% | 28% | 46% | 59% | 69% | 71% |
| | Expanded | 19% | 37% | 58% | 65% | 72% | 76% |
| Highly automated ground installations (~1 MW/year/installer) | No DOE | 14% | 25% | 49% | 76% | 92% | 96% |
| | Planned | 22% | 37% | 64% | 92% | 96% | 96% |
| | Expanded | 30% | 54% | 73% | 96% | 96% | 96% |
| CPV (>100x concentration) achieves 20% of annual ground mount installations | No DOE | 0% | 8% | 21% | 30% | 39% | 43% |
| | Planned | 0% | 18% | 31% | 39% | 49% | 54% |
| | Expanded | 0% | 44% | 54% | 58% | 65% | 68% |

| **REPORT DOCUMENTATION PAGE** | *Form Approved* *OMB No. 0704-0188* |
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| 1. **REPORT DATE** *(DD-MM-YYYY)* | 2. **REPORT TYPE** | 3. **DATES COVERED** *(From - To)* |
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| October 2010 | Subcontract Report | |

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| | 5b. **GRANT NUMBER** |
| | 5c. **PROGRAM ELEMENT NUMBER** |
| 6. **AUTHOR(S)**<br>J. McVeigh, M. Lausten, E. Eugeni, and A. Soni | 5d. **PROJECT NUMBER**<br>NREL/SR-6A20-48043 |
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14. **ABSTRACT** *(Maximum 200 Words)*
The U.S. Department of Energy (DOE) Solar Energy Technologies Program (SETP) conducted a 2009 Technical Risk and Uncertainty Analysis to better assess its cost goals for concentrating solar power (CSP) and photovoltaic (PV) systems, and to potentially rebalance its R&D portfolio. This report details the methodology, schedule, and results of this technical risk and uncertainty analysis.

15. **SUBJECT TERMS**
Solar Energy Technologies Program; SETP; clean energy; risk analysis; concentrating solar power; CSP; solar trough; photovoltaics; PV; solar risk analysis; system cost; energy analysis; Department of Energy; DOE

| 16. **SECURITY CLASSIFICATION OF:** | | | 17. **LIMITATION OF ABSTRACT** | 18. **NUMBER OF PAGES** | 19a. **NAME OF RESPONSIBLE PERSON** |
|---|---|---|---|---|---|
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