BUDGETING FOR SOLAR PV PLANT OPERATIONS & MAINTENANCE: PRACTICES AND PRICING

December 2015

Report Abstract

With rising grid interconnections of solar photovoltaic (PV) systems, greater attention is being trained on lifecycle performance, reliability, and project economics. Expected to meet production thresholds over a 20-30 year timeframe, PV plants require a steady diet of operations and maintenance (O&M) oversight to meet contractual terms. However, industry best practices are only just beginning to emerge, and O&M budgets—given the arrangement of the solar project value chain—appear to vary widely. Based on insights from in-depth interviews and survey research, this paper presents an overview of the utility-scale PV O&M budgeting process along with guiding rationales, before detailing perspectives on current plant upkeep activities and price points largely in the U.S. It concludes by pondering potential opportunities for improving upon existing O&M budgeting approaches in ways that can benefit the industry at-large.

Introduction

With expanding deployments of solar PV expected to surpass 26 GW in the U.S. by end 2015—up some 13x since 2010[1]—greater attention is being focused on operations and maintenance (O&M) considerations, particularly for utility-scale plants—the dominant market segment in the U.S.[2] The financing arrangements governing these multi-MW systems, often predicated on meeting production targets across 20 years, place a premium on sustaining plant health and lifecycle performance. Yet O&M practices and protocols remain far from standardized, and as a result, associated budgeting is highly variable, if generally underfunded, according to a number of industry stakeholders.

The continual search for ways to reduce plant capital and operational expenditures is, for one, placing greater pressure on project stakeholders to streamline O&M practices and their accompanying costs. (Global system costs have fallen by 80% from 2008 to 2014[3], and utility-scale installations in the U.S. now average $1.69/W.[4]) Typically considered a "cost center" on the balance sheet, O&M, even if recognized as a value input to a PV plant's enduring welfare, tends to receive modest funding in order to satisfy competitive bid thresholds and/or stringent customer demands.

Record-low power purchase agreement (PPA) prices for utility-scale PV plants in the U.S. are intensifying scrutiny of project budgets, resulting in cuts to O&M among other line items. For perspective, average large-scale PV prices in the U.S. have

Table of Contents

This white paper was prepared by Nadav Enbar and Dean Weng of the Electric Power Research Institute, and Geoff Klise of Sandia National Laboratories.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. Sandia's contribution to this report was sponsored by the U.S. DOE SunShot Initiative.

---

1 *The Future of U.S. Solar: Getting to the Next Order of Magnitude.* GTM Research, Boston MA: 2015.
2 According to MaxGen Energy Services, a specialist PV O&M supplier, the utility-scale segment comprises 7-8 GW. Source: *USA PV O&M Trends and Market* Outlook. PV Insider, London, England: 2015.
3 REthinking Energy: Towards a New Power System, International Renewable Energy Agency (IRENA), 2014.
4 Personal communication, Bloomberg New Energy Finance, September 24, 2015.
5 Utility-Scale Solar 2014: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States, Lawrence Berkeley National Labs, Berkeley, CA: 2015. LBNL-1000917.

dropped by roughly $25/MWh per year from 2006 to 2013 (~$226/MWh to ~$51/MWh), and by another $10/MWh in 2014[5], resulting in PPA prices in the Southwest that today fall below $40/MWh.[6]

The structural manner in which PV plants are developed, owned, and operated is, meanwhile, a primary explanation for the observed variation in PV O&M approaches. The motivations and self-interests of the actors that are financially invested in a plant over the course of its lifespan often assign differing degrees of importance to the O&M function—sometimes at the expense of a PV system's cradle-to-grave financial outlook. Due to divergent cost-benefit perspectives, there tends to be disagreement among involved parties about appropriate O&M funding allocations and the merit of including performance- or availability-based incentives into contractual language.

The relative scarcity of older PV systems installed in the field is a complicating factor further obscuring strategic thinking around O&M strategy and budgeting. The vast majority of PV plants installed worldwide have been commissioned within the last 7-8 years. Consequently, there is little long-term performance data available to analyze system operation and the effectiveness of concomitant O&M activities over multiple decades.[7]

Per Table 1, a constellation of companies inhabits, at least peripherally, the PV O&M space; each entity, however, has differing stakes in the outcome of a plant's health due to their primary and secondary roles in the market. For example, developers and engineering, procurement, and construction firms (EPCs) are usually responsible for providing O&M as part of a service wrap, but may seek to minimally budget for the activity if they intend to flip their projects to a new owner once tax credits have been

Table 1 – Companies and their Roles in the O&M Space

Company Type	Role / Focus
Project Developer/EPC	Build and manage owned and third party assets; typically the default providers of O&M (often outsourced) as part of a service wrap. Often "flip" a project once tax credits are exhausted.
Turnkey Solar Company	Primarily develop and oversee their own portfolios, providing all services from EPC to O&M. Also offer design, build, and O&M services to 3rd party customers. O&M treated as a profit center.
Project Owner, Yieldco	Provide the capital to develop and own assets; usually rely on third parties for O&M provision (though exceptions exist). Owner's business intentions and investment strategies can vary.
Asset Manager	Works as the owner's agent for ensuring contracted O&M services are satisfactorily performed; handle other data collection and reporting tasks to relevant jurisdictions and regulatory agencies.
O&M Service Provider	Contract services to a range of third parties (EPCs, project owners, or asset managers) to conduct PV O&M; do not own assets.
Insurer	Insure whole systems, their constituent parts, and sometimes their performance.
Bank	Finance PV plant development and operation for plant owners, based on a range of factors including anticipated returns.
Tax Equity Provider, Debt Provider	Provide capital to plant development and upkeep, often based on Investment Tax Credit (ITC) considerations; sometimes debt provider is the bank.
Utility	Predominately PPA PV generation; For owned assets, primarily provide build capital, and contract O&M services (a small number of utilities provide in-house plant supervision and upkeep).
Independent Engineer	Objectively identify risk and certify PV system quality for project financiers and developers.

Sources: GTM Research/SoliChamba Consulting, EPRI, Sandia National Laboratories

Note: Some company types can have multiple roles depending on their orientation.

[6] In April, Austin Energy received developer bids priced below $0.04/kWh to meet the utility's 600 MW procurement plan. And in July, NV Energy agreed to pay $0.0387/kWh over 20 years for the generation from a 100-MW plant to be built by First Solar. The latter agreement is a new low for a signed PPA without meaningful state tax credits (though with a 3% cost inflator).

[7] According to MaxGen Energy Services, a specialist PV O&M supplier, the utility-scale segment comprises 7-8 GW. Source: *USA PV O&M Trends and Market* Outlook. PV Insider, London, England: 2015.

fully tapped in 5-7 years, or earlier. Turnkey solar companies seeking to develop and manage their PV portfolios in perpetuity may invest more heavily in O&M, mindful of economy of scale savings that can be derived from effective fleet supervision.

Meanwhile, O&M providers contract their services to meet explicit plant performance criteria at typically low margins, with some overcoming financially onerous EPC and/or plant owner demands by introducing "cost plus" and time and materials pricing to accompany flat fee pricing for other services. And insurers tend to advocate for relatively greater O&M budgeting to help guarantee long-term plant quality and reliability. (They are increasingly developing novel products to insure against plant revenue and production shortfalls, with pricing reflective of O&M risk perceptions.)

These diverging attitudes about PV O&M impact budget allocations earmarked for that function. But a growing awareness of how O&M affects profitability means it now tends to be considered much earlier in the project development process than it has been historically, perhaps signaling the industry's evolving thinking.

Research Methodology and Respondent Profile

To discern current PV O&M practices, their associated budget allocation, and informing rationales, The Electric Power Research Institute (EPRI) and Sandia National Laboratories (SNL) conducted 18 in-depth interviews with a cross section of industry participants and subject matter experts. The interviews, which accompany a comprehensive literature review, were guided by a questionnaire developed to elicit respondent comments and generate discussion. As much as possible, efforts were made to elaborate every question during the course of the interviews with the aim of removing any ambiguity. Once the interviews were completed, results were compiled and analyzed to ensure data integrity and consistency. Where clarifications were required, follow-up communications were completed accordingly.

In addition, an anonymous online survey was administered to support and confirm information gleaned from interview subjects. Altogether, the interviews and surveys were completed by a mix of executives, managers, and field engineers employed by a diversity of companies—including, electric utilities and independent power producers (IPPs), O&M service providers, turnkey solar firms, insurance and banking concerns, and others (see Table 2). All respondents indicated that they were knowledgeable about their organization's PV O&M outlook and budgeting approach.

Table 2 – Make-Up of Interview and Survey Sample

Respondent Type	Respondents
Interview Sample	
Utility / IPP	6
Turnkey Solar Company	2
O&M Provider	5
Insurance / Bank	4
Independent Engineer	1
Total	18
Survey Sample	
O&M Provider	8
Owner	5
EPC	3
Asset manager	4
Total	20

PV O&M Budgeting: Structures and Stipulations

O&M generally represents a small fraction of a plant's lifecycle project development and operational costs. According to data collected through interview and survey, the activity typically accounts for between 1% and 5% of a MW-class plant's total $/kW$_{dc}$ expenditure (see next section for commentary on pricing). The wide range in data points is due to differing plant characteristics (e.g., size, design, equipment/components/moving parts, location), business interests and orientations, instituted O&M approaches with varying levels of rigor, and contractual arrangements (e.g., length, stipulated responsibilities, price structure). There simply is no one-size-fits-all approach to developing an O&M budget. Instead, a broad structure exists for guiding the budgeting process that is informed by multiple factors and attitudes.

That said, there is little consensus surrounding "appropriate" O&M budget levels. For example, O&M service providers tend to embrace higher budget requirements to cover their margins and contractual uncertainties, while developers are inclined to estimate lower O&M costs to increase plant valuations, and still other actors can be motivated to set O&M allocations based on individual project investment horizons and revenue prospects. These contrasting viewpoints, among others, notify budget outcomes and can ultimately undermine a plant's lifecycle performance economics. (An impartial independent engineering firm can help overcome budget biases.)

Stakeholders do, however, tend to agree that O&M budgets have historically been low and remain so, relatively speaking. The percentage of project budgeting allocated to the activity actually appears to be trending upward as capital costs continue to fall; but this is not necessarily resulting in more available dollars. That's because an increasing number of companies are reportedly requiring that utility-scale PV plant EPC and O&M proposals be bid together, leading to sliding O&M prices caused by short-term (5-year) contracts with bidders who are motivated to exploit available warranties.

At bottom, budgeting is a variable cost-benefit exercise, informed by multiple perspectives, that attempts to balance O&M service levels and associated costs with the relative value afforded by enhanced performance and plant health. Though budget levels fluctuate across projects, the structure and key decision vectors, described below, provide the organizing framework for rationalizing associated accounting.

Overarching O&M Approaches

PV O&M approaches are typically broken out into three main categories, each with different cost-benefit tradeoffs and risk profiles:

- **Preventative maintenance (PM)** encompasses routine inspection and servicing of equipment—at frequencies determined by equipment type, environmental conditions, and warranty terms in an O&M services agreement—to prevent breakdowns and unnecessary production losses. This approach is becoming increasingly popular because of its perceived ability to lower the probability of unplanned PV system downtime. However, the upfront costs associated with PM programs are moderate and the underlying structure of PM can engender superfluous labor activity if not optimally designed.
- **Corrective or reactive maintenance** addresses equipment repair needs and breakdowns after their occurrence and, as such, is instituted to mitigate unplanned downtime. The historical industry standard, this "break-fix" method allows for low upfront costs, but also brings with it a higher risk of component failure and accompanying higher costs on the backend (perhaps placing a premium on negotiating extended warranty terms). Though a certain amount of reactive maintenance will likely be necessary over the course of a plant's 20-year lifetime, it can be lessened through more proactive PM and condition-based maintenance (CBM) strategies.[8]
- **Condition-based maintenance (CBM)** uses real-time data to anticipate failures and prioritize maintenance activities and resources. A rising number of third party integrators and turnkey providers are instituting CBM regimes to offer greater O&M efficiency. The increased efficiency, however, comes with a high upfront price tag given communication and monitoring software and hardware requirements. Moreover, the relative novelty of CBM can produce maintenance process challenges caused in part by monitoring equipment malfunction and/or erratic data connection.

[8] Note: some corrective maintenance can be completed remotely (e.g., inverter reset), while other less urgent activities can be combined with scheduled, preventative maintenance activities.

Yieldcos: Emblematic of Industry-wide Inattention to PV O&M?

The emergence of yieldcos—publicly-traded companies that buy and hold operational assets, such as solar PV plants, to then pass on predictable cash flows from those assets to investors through dividends—is, for some, raising long-term plant quality and reliability concerns. The growth-oriented financing vehicle[9] enables development firms to sell the operational assets they have built to established yieldcos and receive lower cost capital that can subsequently be reinvested in new projects.[10]

The novel arrangement, which enjoyed an initial jolt of activity before experiencing a more recent market correction, represents one of a number of innovative financing models that is helping to propel solar deployments and signal the industry's progressive maturity. But some solar stakeholders question whether adequate O&M budgets have been implemented at the various yieldcos to appropriately service their solar assets over the long haul. Their concern emanates from a general industry perception of O&M as a cost center rather than a value generator. Central to their unease is the potential for lagging plant oversight and upkeep to cause increased unplanned downtimes and degraded performance, thus undermining investor confidence.

The implications of unmet plant expectations within the yieldco vehicle could be significant, and are potentially applicable to the broader, non-yieldco PV system install base. Will allocated O&M budgets undermine the promise of long-term, stable yieldco returns and, more generally, those of the broader investor class? The answer may well depend on one's perspective.

Reliability-centered maintenance (RCM) and Reliability Availability and Maintainability (RAM) can also be incorporated into O&M regimens. Both RCM and RAM rely on analysis results from fault and failure information collected from PM, corrective, and CBM approaches applied to singular installations or fleets of plants.[11]

On the whole, the PV segment is trending toward O&M approaches that promote greater oversight and management capability, and conventional approaches seem to be shifting from reactive to preventive maintenance approaches. However, CBM and reliability-centered strategies are anticipated to play a larger role as PV assets proliferate, associated information technology and deployment costs fall, and the overarching cost-benefit equation improves.

Regardless of the O&M approach implemented, the majority of associated contracts clearly delineate the defined activities to be performed along with their frequency. Table 3 provides an example of tasks associated with the three major O&M approaches.

O&M Contract Structure

O&M contracts tend to be structured as either fixed price or pay-per-use arrangements. The former, also referred to as a "full wrap," covers all O&M activities for a fixed annual price. The latter, sometimes called a "cost-plus" plan, provides fixed price coverage to a number of recurring activities, and then charges on a per-task basis for corrective maintenance and other assignments.

Fixed price contracts are common in the industry, especially during the first five years of a plant's life during which time equipment and workmanship warranties are in place. But compared to pay-per-use plans, they are the significantly more expensive long-term service agreement option because of the price escalation that typically occurs once standard warranties expire. As a result, costs associated with repair, replacement, and maintenance issues become the plant owner/investor's financial responsibility. Consequently, full wraps can be considered "gold plated" arrangements that provide comprehensive O&M coverage, but at price points that may be tough to justify given bottom line ob-

9 To date, over 20 yieldcos have been established globally by firms including Abengoa, NextEra Energy, NRG Energy, Pattern Energy, SunEdison, SunPower, First Solar, Transalta, among others. Note: not all of these yieldcos contain PV projects. Source: *Global Yieldco Overview.* SolarPlaza International BV, Rotterdam, The Netherlands: 2015.

10 The power plants that yieldcos buy and operate have, to date, often been developed by their parent companies. Yieldcos collect the contracted electricity fees and pay most of the proceeds out to investors as dividends, with the intention of providing stable returns.

11 *Precursor Report of Data Needs and Recommended Practices for PV Plant Availability, Operations and Maintenance Reporting.* Sandia National Laboratories. Albuquerque, NM: 2015. SAND2015-0587.

Table 3 – Major Elements of PV Operations and Maintenance

Preventative Maintenance (PM)	
Panel Cleaning	Water Drainage
Vegetation Management	Retro-Commissioning†
Wildlife Prevention	Upkeep of Data Acquisition and Monitoring Systems (e.g., electronics, sensors)
Upkeep of Power Generation System (e.g., Inverter Servicing, BOS Inspection, Tracker Maintenance	Site maintenance (e.g., security, road/fence repair, environmental compliance, snow removal, etc.).
Corrective/Reactive Maintenance	
On-Site Monitoring	Non-Critical Reactive Repair**
Critical Reactive Repair* (high priority)	Warranty Enforcement
Condition-Based Maintenance (CBM)	
Active Monitoring—Remote and On-Site Options	Equipment Replacement (Planned and Unplanned)
Warranty Enforcement (Planned and Unplanned)	

Source: EPRI

† Retro-commissioning identifies and solves problems that have developed during the course of the PV system's life.

** Critical reactive repairs address production losses issues.*

*** Non-critical reactive repairs address production degradation issues.*

jectives. (Note: this outlook is predicated on a recognition of the fixed price contract's upfront costs, without considering the potentially long-term financial advantages that may emanate from leveraging the service agreement to address numerous corrective maintenance issues that may surface and, in turn, more economically improve plant lifecycle availability and performance.)

Plant owners/investors are unsurprisingly motivated to negotiate lower full wrap prices which can sometimes lead to contracts that are financially unsustainable for O&M providers. As a partial result, pay-per-use contracts are gaining industry traction. These service agreements allow for activities and their frequencies, as well as general expectations to be clearly defined among contractual parties. Beyond fixed-fee activities, corrective maintenance and other tasks, such as vegetation management or panel washing, can be billed on a time-and-materials (T&M) basis. This approach introduces greater risk-reward tradeoffs to the plant owner/investor: incurred O&M costs could be high if a plant's corrective maintenance needs turn out to be considerable, but they could also be fairly negligible if the opposite should occur. Meanwhile, for O&M providers, cost-plus plans can facilitate a more financially palatable means for meeting a range of contractual benchmarks described below (e.g., performance and/or availability guarantees).

All told, the nature and type of O&M agreement inked will vary based upon a plant owner's motivations and experience, plant size/makeup, location, and other factors. A more conservative plant owner with longer term plant aspirations may, for example, seek to lock in a long-term fixed-price O&M agreement, while an entity interested in flipping a project in 5-7 years (or earlier) from commissioning may opt for a shorter fixed-price O&M contract that can leverage existing warranties. A 10-year pay-

Credit: CPS Energy

per-use plan may, meanwhile, be considered more suitable for an asset holder who purchases a plant in mid-life. Asset managers in Europe appear to mitigating risks by trending towards shorter O&M contract durations and multiple re-signings/negotiations.

Key Contractual Provisos

In recent years, a number of provisions—in the form of guarantees and incentives—have been inserted into O&M contracts. These stipulations, which often indicate performance thresholds under varying conditions, are expected to become more commonplace as the segment evolves. Their function is intended to introduce greater accountability and help assure O&M service quality. Although imperfect given definitional wiggle room and the sometimes complex interrelation of factors used to inform compliance/measurement calculations, these provisions have impacted O&M budgeting considerations and approaches. Following are summaries of some of the more popular contract provisos, along with brief commentary.

- **Service-level agreements (SLA)** – specify compliance timeframes for responding to and resolving a range of plant conditions, based on equipment type and issue severity level.
- **Availability or "uptime" guarantees** – define the percentage of time that a system must be fully able to produce electricity. Availability guarantees are typically set at 97-99% per year. Note, however, that no standard calculation method is used for determining plant availability and both contractual loopholes and ineffectual language can help meet loosely enforced criteria.
  Moreover, availability guarantees are generally not consistent as some are equipment focused, while others are performance focused. This can lead to confusion surrounding the actual objectives of availability guarantees vs. performance guarantee. Sandia National Labs has recently introduced a best practice approach for developing availability guarantees that involves a time-based and reliability-centric method for collecting data on equipment performance.[12]

  Generally speaking given that plant availability is tied to design, workmanship, and equipment reliability, associated guarantees are typically only accepted after thorough plant inspection/recommissioning to manage attendant risks. Insurance providers are exploring product development opportunities that backstop availability guarantees, but nothing is currently available in the marketplace.
- **Performance ratio and yield guarantees** – stipulate plant performance levels (e.g., a minimum amount of energy delivered) according to measured solar irradiation at a site, based on system design and modeled plant behavior—which can be variable, thus introducing risks. Note: these guarantees account for Force Majeure events and warranty defects. However, the recent industry trend to overbuild, in some cases by 30-40%, to exploit comparative dc to ac time-of-day energy production and cost advantages can undercut the purpose of performance and availability guarantees, and potentially lead to substandard O&M practices.
- **Production guarantees** – state annual plant production levels, independent of weather conditions. Insurance coverage can be used to mitigate weather risk, though it can be an expensive policy to underwrite. To help meet system performance goals, some plant owners direct that maintenance be performed at night, and institute design point conditions to improve plant generation profiles.
- **Performance incentives** – reward/penalize for plant performance that misses, meets, or exceeds projected production levels. Considered well suited for aligning asset owner and O&M provider interests, with caveats surrounding the adverse impacts that environmental factors can have on efficiency and production.
- **Energy-based contracts** – links plant production (kWh/yr) with O&M service provider revenues so that associated expenses are calibrated according to low (fall/winter) and high (spring/summer) revenue periods.

Budget Development Process

The overriding process by which O&M budgets are developed and negotiated is not standardized, but seems to follow a general pathway—one that could potentially benefit from institutional reform.

---

12 *A Best Practice for Developing Availability Guarantee Language in Photovoltaic (PV) O&M Agreements.* Sandia National Laboratories, Albuquerque, NM: 2015. SAND2015-10223.

Often, the financing entity will dictate budget parameters based upon return on investment calculations and market drivers. These defined delimitations, however, are frequently developed independent of O&M plant needs and considerations. Consequently, the contracted project EPC/developer can be forced, per communicated budget strictures, to shoehorn the numbers into a "workable" O&M plan. (Note, however, that some larger EPCs and turnkey development entities are beginning to more explicitly recognize the connection between plant design/configuration, construction, and O&M. They are considering these issues earlier in the development process to more vigilantly inform O&M budgets.)

Taken a level further, O&M service providers and/or internal service divisions within EPC/turnkey development companies, will typically negotiate with the project lead to clarify and define the scope of work (e.g., types and levels of service desired, frequency of site visits and activities, etc.) and associated expectations. During these contract negotiations, O&M providers estimate budget according to either an all-encompassing price of service or a cost-plus model. (The industry is allegedly moving toward the latter.[13]) Once negotiations are completed and the SOW is agreed to, the budget is then formulated and relayed to the financing entity that underwrites the project (bank, financial group/investors, utility, etc.) for approval.

Though the O&M budget procedure is fairly finite, it produces a range of estimates that depend on project structure, investor expectations, and occasionally, the organization/design of the project bidding and RFP process. For example, seasoned turnkey solar development companies that self-perform O&M will incorporate specific budget levels based upon their organizational efficiencies, fleet experience, and investment orientation. Newer entrants will often rely on publicly available information or advice from peers to help set their budgets. Banks and lenders, meanwhile, will turn to independent engineering firms to provide them with budget recommendations. And insurers will also rely on third-party reports, or alternatively commission their own, to set policy prices that fluctuate based on the perceived adequacy of the O&M budget.

Separately, the manner in which projects are put to bid can impact O&M budgeting. For instance, one utility in California that outsources O&M services requires developer/EPC bids for all utility-owned projects to include a defined O&M budget. It, moreover, supplies bidders with a mandatory checklist of activities and activity frequencies (e.g., testing, visual inspection, etc.). This practice tends to depress O&M prices due to competitive bid pressures.

PV O&M Perspectives on Practices and Costs

The interview and surveys administered as part of this research effort elicited a number of responses surrounding PV O&M costs and prices for both overarching service packages as well as a range of tasks. Below are associated key metrics and takeaways.

Note: Unearthing accurate PV O&M cost data is fraught with challenges. While every effort has been made by this report's authors to ensure data integrity and consistency, there are a number of contextual factors that color specified costs. For example, costs will vary based on system and fleet size, technology, location, scope (e.g., differing O&M service plans, guarantees). Additional dynamics—such as labor rates/expertise, local energy prices, available incentives, project volume, and profit taking—will also distinguish O&M price points across regional markets.

Separately, particular metrics, such as the oft cited price per megawatt per year ($/MW-yr) statistic, can skew perspectives. For instance, $/MW-yr can be less relevant for relating the costs of specific tasks, like panel washing, because it does not capture technology and form factor discrepancies. As such, the pricing information contained in this document should be considered instructive; it does not convey more explicit O&M pricing that accounts for local, site-specific nuances.

Overview

Today, O&M generally represents a small fraction of a plant's lifecycle project development and operational costs. As previ-

[13] Because O&M is generally considered a part of the project's cost structure, not a profit center, EPCs/developers attempt to reduce O&M budget as much as is possible. Anecdotally, one service provider has been approached by a number of EPC's to take over plant O&M responsibilities under cost parameters that it considered to be infeasible.

ously mentioned, the activity typically accounts for between 1% and 5% of a MW-class plant's total $/kW-yr expenditure, though interview and survey results more widely ranged between roughly $10/kW-yr and over $45/kW-yr. These latter data points encompass a variety of circumstances, including cases in which pricing for services was developed based on pre-existing terms, uncertain contract language, and differing levels of prior O&M experience. In addition, some of these metrics include full service wraps while others do not.

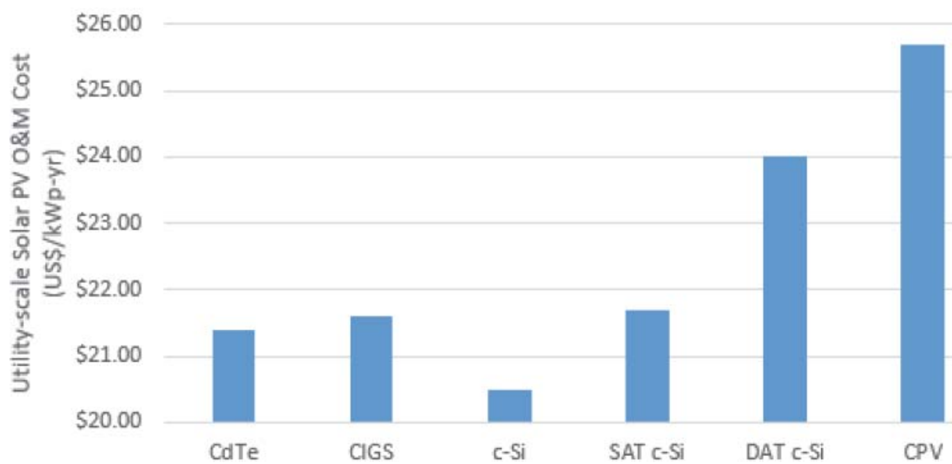
Table 4 (next page) presents a summary of PV O&M budget components and associated cost ranges derived from survey and interview findings. (Note: costs associated with plant monitoring were not adequately collected and thus are not discussed in this paper.) Customer preferences, system size, system location, system characteristics (e.g., tracking vs. non-tracking), warranty levels, expected inverter failure rate, and other variables form unique work scopes that impact costs and thus budgeting. As a result, it is difficult to distinguish overarching O&M budget figures that can be easily normalized or compared. Moreover, the constituent parts of the O&M budget won't necessarily add up to an overall average budget number due to the non-linear nature of different work scope activities.

That said, for larger-system portfolios (i.e., systems under management sized 1 MW and larger), interview and survey responses cited overall baseline O&M budget ranges (e.g., those without cost-plus items) of approximately $10-25/kW-yr. This range corresponds to a set of standard preventative maintenance activities that would typically be performed at most utility-scale sites (e.g., visual/structural system inspection, wires and combiner box inspection, infrared thermography [IR] scanning, IV curve tracing, and inverter maintenance).[14]

Figure 1, meanwhile, conveys EPRI's estimated range in O&M costs for conceptual 10-MW PV systems endowed with different PV technologies and designs. O&M costs for the majority of fixed-tilt systems amount to $20-$22/kW per year. Note that this range is largely based on EPC input.

For smaller systems (< 1 MW), overall O&M budgets become harder to generalize as the number of O&M variables increases (e.g., varying distances to customer sites, site access restrictions, customer preferences, etc.). Collectively, however, smaller and distributed systems tend to underestimate O&M costs. According to an O&M provider servicing both the residential/commercial and utility-scale sectors, smaller systems can often be 2-4x more expensive to maintain compared to large sites even given typically more limited contract scopes.

Furthermore, O&M costs tend to decrease on a $/kW-yr basis as system size increases because fixed costs can be spread across



Source: EPRI

Notes: O&M estimates were developed using a bottoms-up approach that incorporates detailed information gathered in 2015 from EPCs, as well as input from industry data (i.e. equipment cost and labor indices), market analyst information, and feedback from developers. Estimates are for conceptual 10-MW plants.

CdTe = cadmium telluride; CIGS = copper indium gallium selenide; c-Si = crystalline silicon; SAT = single-axis tracking; DAT = dual-axis tracking; CPV = concentrating photovoltaics.

Figure 1 – Average Utility-Scale Solar PV O&M Costs, by Technology ($/kWAC-yr)

[14] Other line items that are either highly site-dependent or more reactive in nature such as panel washing, vegetation control, major maintenance reserves, inverter replacement, contingency events (e.g. lightning strikes, erosion), insurance, and site security often fall under cost-plus categories that would be specifically selected by the customer or triggered by unanticipated events.

Table 4 – PV O&M Budget Components and Costs

Budget Item	Budget Range ($/kW-yr)	Notes
Overall Budget	$10.00-45.00/kW-yr*	Variable based on whether cost plus, extended warranty, and other items are included. Also, some O&M activities are non-linear which can affect overall outlays.
General Site Maintenance	$0.20-$3.00/kW-yr	Variable based on system size, location. (e.g., desert environments are less expensive than snowy locales that require snow removal from critical areas), and frequency of activity.
Wiring/Electrical Inspection	$1.40-$5.00/kW-yr†	Includes inspection of wires, junctions boxes, combiner boxes, AC/DC disconnects, service panel, etc.; string testing. Prices will differ, among other things, based on whether inspection covers 10% or 100% of the plant.
Panel Washing	$0.80-$1.30/kW-yr†	Variable based on technology (different form factors), cleaning regimen, prevailing wages, and other factors. As a result, some stakeholders provide cost metrics on a $/module basis.
Vegetation Management	$0.50-1.80/kW-yr†	Variable based on site characteristics and acreage. Often a "cost-plus" contingency item.
Inverter Maintenance	$3.00-7.50/kW-yr†	Activity typically encompasses cleaning of filters, torqueing, thermal imaging of internal components, minor equipment repair, etc.
Inverter Replacement	$6.00-10.00/kW**	Typically, plant owners only budget for one inverter replacement activity after the initial warranty period. Price ranges encompass different utility-scale inverter sizes and models.
Racking / Tracker Maintenance	Insufficient data	Racking maintenance is negligible, however tracker maintenance is more costly. Specific data points for the latter activity are insufficiently available.
Spares	$2.00-$20.00/kW-yr***	Most critical spares to have on hand include fuses, contacts, wiring, inverter parts (circuit boards, filters, fans, etc.), disconnect switches, and modules.

Notes: Budget numbers exclusively for utility-scale plants; they encompass an entire range of baseline, cost-plus, and warranty terms.

** Constituent components of the O&M budget are non-linear and will not necessarily add up to the overall budget on a $/kW-yr basis.*

*** Inverter replacement metrics are based on a $/kW, and cover a one-time equipment replacement and installation activity over the course of a plant's lifetime.*

**** Budget range for spares primarily encompasses equipment procurement and storage costs.*

† Price points based on a 1x annual frequency (i.e., per event)

a greater number of project components (e.g., modules, inverters, etc.). There are, however, also diminishing returns as plant size grows; O&M costs level out past a certain point. Generally, labor "utilization rates" contribute to O&M cost reductions for larger plants. Meanwhile, multi-MW project sizes, especially in remote locations, can justify full-time oversight by personnel, as savings can be realized from reduced travel time and increased labor efficiency. Maintenance tools and spares can also become site-dedicated rather than needing to be transported from one location to another or procured in duplicate.

Reactive vs. Preventative Maintenance

The budget breakdown for reactive and preventative maintenance (PM) plans depends on several key factors, including climate, plant components and designs, warranties, labor costs, and O&M contract structure. For example, in different climates and site conditions the same PV system may require drastically different panel washing and vegetation management schedules (or be eschewed altogether). As such, these activities are often offered as add-on or cost plus budget items. Meanwhile, component quality and site design will also impact the frequency of site visits.

Regardless, initial PM assumptions may also necessitate modification due, in part, to multiple reactive maintenance issues.

The ability to effectively divide PM and reactive maintenance (RM) visits is important as one additional "truck roll" can impact the O&M budget. Historically, long term O&M budgets have not adequately supported reactive maintenance needs. In general, for 1 MW+ systems, 70-85% of available budget is assigned to preventative maintenance, while 15%-30% is allocated to reactive maintenance.

(Emerging condition-based maintenance strategies and implementations, on the other hand, are not without their challenges. The associated monitoring and communication systems not only increase upfront capital but also require upkeep and troubleshooting which adds to reactive maintenance activities. Problems with communication system uptime has resulted in redundancy and battery back-up due to the importance of measurements they collect.)[15]

Table 5 provides a non-prioritized list of maintenance approaches that interview and survey respondents feel offer the greatest value for the money.

General Site Maintenance

General site maintenance includes tasks such as site upkeep, safety signage, fencing, road/building management, water/waste management, environmental compliance, and other activities. Site location and conditions are primary factors that can affect associated budget amounts. For example, more remote facilities require greater investment in travel/labor time (and likely require that general site maintenance activities be conducted at the same time as other PM or RM tasks). Meanwhile, plants located in snowy environments can require greater site maintenance expense than for those in desert surrounding given the costs of snow removal.

Wiring/Electrical Inspection

Scrutiny of a PV plant's wiring and electrical connections encompasses both visual, thermal scanning, and current-voltage (I-V) curve analysis activities. Prices, meanwhile, will differ based on the scope of inspection performed (i.e., 10% vs. 100% of a plant).

Usually, maintenance personnel will visually check modules for cracks and other damages. In addition, the wiring behind the panels will be inspected, as will the junction boxes, combiner boxes, AC/DC disconnects, service panel, and other items.

Credit: True South Renewables

[15] *A Best Practice for Developing Availability Guarantee Language in Photovoltaic (PV) O&M Agreements.* Sandia National Laboratories, Albuquerque, NM: 2015. SAND2015-10223.

An infrared (IR) gun is also periodically utilized to identify hot spots and other thermal-related issues that may require preemptive attention. Thermal scans are becoming more popular due to their recognized cost-benefit. Though labor and time intensive to administer handheld IR scans, service providers recommend annually examining every module and termination in a system. (IR scans can also be performed through manned and unmanned flight, both of which take less time but require greater financial investment.) The reason? Thermal scans have proven to be effective at identifying potential problem areas before they materialize. That can be a major benefit, as some thermal events—for example, those that affect transformers or combiner boxes—can cause losses equal to 3-4% of annual plant production.

String-level testing and the use of IV curve tracers are an additional practice for measuring PV plant health.[16] Assessing the current-voltage characteristics of a PV cell, module, or string, provides a viable means for more effectively gauging DC system performance and enabling proactive mitigation to boost plant energy production and associated revenues. Absent module-level power electronics, such testing provides a means for discerning with certainty whether each plant string and module is functioning properly. However, the procedures governing the operation of IV curve tracers are tedious; because the devices require individual connections to be made manually, they are only used sparingly, typically inspecting 10-20% of PV plant strings each time they are deployed.[17] As a result, it can take 3-5 years to assess an entire plant (without a statistical sampling). Service providers separately recommend independently testing a spot sample of strings to assure that they favorably compare with the manufacturer's guarantee.

Panel Washing & Vegetation Management

Panel washing and vegetation management activities and costs depend largely on a site's setting and environment. Soiling frequency, climate, distance to water source, equipment requirements (e.g. 50,000 gallon water truck), among other factors will affect associated budgeting. Sites in close proximity to salt water, for example, require erosion monitoring and control. Fast-growing vegetation is a common problem in more humid and warmer climates. To a lesser extent, plant design elements that consider ease of access and vegetation mitigation (e.g. pebbled foundation) also impact panel washing and vegetation management costs.

Because panel washing can oftentimes be a major cost driver for large plants, some providers do not adhere to set panel washing schedules, choosing instead to perform cost-benefit analyses to determine the activity's need on a case-by-case basis. Others have discovered innovative ways to avoid panel washing events. For example, one approach stows systems equipped with tracking at a high tilt (~10°) in order to minimize soiling (i.e., let gravity do the work). In other instances, panel washing is avoided altogether at sites that receive what is determined to be an adequate average level of rainfall.

Table 5 – High Value Maintenance Approaches

Activity	
Data monitoring and analytics (incl. remote/automated event notification, data analytics to manage truck rolls/scheduling)	Annual commissioning
Infrared inspection of modules	Quarterly string testing
Inverter PM	Combiner box inspection
Transformer monitoring and inspection	Tracker calibration
Keeping critical spare parts (particularly fuses) in stock (on site or on truck)	Weather station and MET station inspection, pyranometer calibration (per OEM specifications)
Panel washing (site-specific)	Upfront standardization of plant components during design

16 Ideally, service providers encourage that every string in a plant be tested for Imp (current) and Vmp (voltage). A delta of more than 5% from 1 string to the next is grounds for further evaluation.

17 To relate the magnitude of performance loss, statistical extrapolations are performed on the basis of the 10-20% of the PV plant that is examined via IV curve tracing.

To better characterize pricing for panel washing, one O&M provider provides estimates in dollar-per-panel ($/panel) rather than dollar per capacity ($/kW) price metrics. This approach accounts for differences in technology form factor (e.g., thin film require more panels per watt) and handling. Accordingly, per panel washing costs can vary from ~$0.35 per panel for a simple water spray to over $0.50 per panel for more intense washing (e.g. physical agitation). Meanwhile, vegetation management can, according to one estimate, run between $15,000 and $30,000 per system per year based on site characteristics and acreage.

Inverter Maintenance & Replacement

Historically, plant owners and managers have anticipated that central inverter equipment will need to be replaced sometime during year 10-12 of a system's lifetime. However, over the past several years, many have found that, with steady maintenance, central inverters can remain operable for longer than expected, and thus result in over-budgeting. One large O&M provider claims that, for many of its projects, as little as 25% of the funding budgeted for inverter replacement was used by year 11.

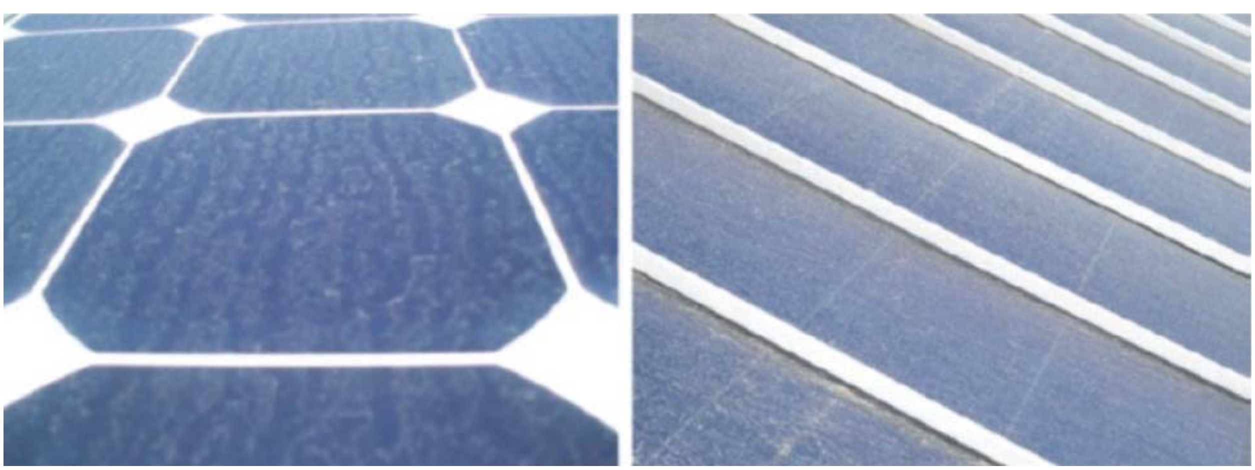
Unsurprisingly, in the budgeted replacement year, system owners often struggle with the decision to either pay the inverter manufacturer for an extended 10-year warranty or to simply replace the inverter (thereby obtaining a new warranty), regardless of its working condition. Rather than set aside a lump sum of cash for inverter replacement, some entities are now opting to instead spread reserves across a fixed-fee maintenance schedule that builds up a cash reserve over time, and, in turn, improves a project's overall cash flow. Another strategy being employed is to group several maintenance reserves together into a major maintenance (i.e. contingency) reserve, thereby offering more spending flexibility.

The cost-benefit behind string and micro inverters is not well established. Many budget string inverter replacement and maintenance similar to central inverters. However, some have found that string inverters do not come with the same level of warranty and support provided for central inverters. String inverters will, on average, require less service *per inverter* during the initial 10 year warranty period but by year 10-12 they will likely need to be replaced. At the same time, while the response time for fixing a string inverter failure may not be as critical, as only a small portion of power is lost, more frequent visits may be required on the whole, incurring higher O&M labor costs in the long run.

A range of experiences with inverter manufacturers colors inverter budgeting outlooks in terms of perceived inverter failure rates and inverter manufacturer solvency. One O&M provider performed a financial analysis of a manufacturer's SEC public filings that revealed a decrease in the company's reserve funds over time. Consideration of larger inverter replacement budget can, as a result, be warranted.

Racking & Tracker Maintenance

Costs associated with the upkeep of racking equipment are negligible, as few long term defects are anticipated[18]. However,



Sources: Florida Solar Energy Center (left), Alabama Power (right)

[18] EPRI is pursuing a research effort to explore racking corrosion from field exposure.

typical of any mechanical system, maintenance requirements and failure rates for trackers are higher relative to other components. The addition of tracking controllers, power supplies, motors, hydraulics, and other components need to be physically inspected as well as maintained (e.g. greasers re-greased) frequently. According to one service provider, including a tracking system in a plant design could double the number of service calls required each year, with more maintenance activities per visit. Moreover, tracking systems can have a failure rate of 5 years and require consistent maintenance (i.e. service or replacement) over a 20-year warranty period.

The cost-benefit of tracker costs relative to the added plant generation they afford is improving, however, as can be seen from their greater uptake in commercial projects—particularly in California and other states in the U.S. Southwest. Based on EPRI research, the average capital cost of polycrystalline silicon-based PV plants outfitted with single-axis is approximately 9-15% higher than it is for similar fixed horizontal systems. But, the modeled energy production for SAT plants is also 20-25% greater than for fixed horizontal installations, which can provide notable economic payback in the right project site environments and price structures.

Spares

Plant owners typically buy a range of equipment spares, either kept on site or at a nearby warehouse, to ensure a high level of plant uptime. However, the number and type of spares maintained—and the associated budgets allocated—vary based on plant size, geographic location, contractual issues, and management philosophy.

Credit: True South Renewables

That said, fuses, contacts, wiring, inverter parts (circuit boards, filters, fans, etc.), disconnect switches, and modules as typically considered to be the most critical spares to have on hand. These items can immediately be utilized to mitigate common nuisance and more serious unplanned plant issues. Meanwhile, some report carrying a large inventory of power supplies for monitoring and tracker motor systems (the latter of which, in some instances, have tended to fail within 5 years), while others recommend keeping several spare distributed inverters and perhaps 1-2 central inverters readily available. And still others recognize MV transformers and switchgear to be critical items, given their severe impact on plant downtime in the event of failure and the long lead time needed (up to 6 months) to order and receive a replacement. But few asset owners, EPCs, and service providers invest in spare transformers because of their high cost.[19] (In contrast, racking and sensitive electronics represent two items that are not worth keeping on site—the former because of its low failure rate, and the latter due to the likelihood that today's electronics will be made obsolete by near-term product advances.)

In general, attitudes surrounding spares appear to be colored by frequency and impact of parts failure, upfront cost, and perceived product availability (supply, shipment time, and potential for manufacturer insolvency/consolidation). As a rule, for example, some asset managers and owners will purchase a surplus of modules (~1% of a plant's installed panels) to hedge against the possibility that the models purchased will be unavailable in the future.

The range in reported budgets allotted to spares—spanning $2,000-$20,000/MW-yr—reflects the diversity of attitudes toward the line item (which primarily encompasses equipment procurement and storage costs). Beyond these attitudinal contexts, budget allocations can be affected by specific O&M arrangements. For example, they can be reduced if spare components are shared across a portfolio of sites under management. Moreover, they can be impacted by the location of the line item in the overall project's context. Spare parts can be included in the initial capital budget or as part of an O&M service plan as a "cost-plus" item, particularly if plant components are no longer under warranty. Separately, annual budgets are not usually increased to purchase and store spare parts as plants age. Maintain-

19 One less common recommendation: spare components for a control room's HVAC system (to avoid an air condition failure that can trip off the SCADA system and take a plant offline).

ing a "roll over budget" to account for some years requiring more maintenance than others is a recommended alternative practice.

Generally, annual budgets for spares are expected to lessen over time along with O&M costs at-large due to learning curve efficiencies and growing business savvy. But some, particularly in the insurance segment, recognize spares management, sourcing, and contingency as an area in need of greater industry attention.

Labor & Staffing

Labor and staffing are important elements of O&M strategy, and represent key budget inputs. Costs can vary based on experience, work scope, unplanned plant maintenance needs, and other factors.

General PV O&M Labor Requirements

PV O&M labor requirements can differ based on technology and environmental factors; in addition, they can fluctuate according to a particular industry segment's viewpoint. But, in general, labor efficiencies are increasing; employees are beginning to more commonly share labor between multiple sites, and companies are utilizing local technicians and electricians close to large sites to avoid costly "truck rolls" across long distances.

Following are perspectives on labor from O&M providers as well as electric utilities:

- **Independent and Vertically Integrated O&M Provider Perspective** – To be economically feasible, one trained technician must be able to supervise at least ~10 MW of PV in a particular region (1 field technician is potentially capable of servicing up to 50 MW.) In some cases, the O&M provider will subcontract installers to do corrective maintenance on an as-needed basis. For larger, central inverter-based systems, standard preventative maintenance activities are usually covered by 2 technicians at 8 hours per MW_{ac} (not including cleaning). Peak irradiance months often require greater staffing levels to ensure the optimal amount of energy is harvested (thus contributing to annual production thresholds). Separately, the ability to have a roll-over budget allows providers to save funds in years with little maintenance (and associated labor) as a contingency for years when more maintenance is required.
- **Electric Utility Perspective** – Utilities contract O&M services and also perform O&M in-house. For the latter option, labor estimates to service utility-scale PV range between 1 full-time employee (FTE) per 18 MW to 1 FTE for 30 MW. Meanwhile, per one respondent, the system size threshold for having someone remain on-site on a full-time basis is around 40 MW. Often, in-house utility O&M personnel are composed of employees with multiple skill sets—such as transformer repair, natural gas and/or fuel cell plant maintenance, etc.—in order to leverage labor efficiencies. One identified utility used to sub-contract for O&M services but later switched to in-house staff due to its cost structure, which provided significant savings. Some utilities that conduct PV O&M in-house have unionized employees, which can upwardly impact labor costs.

O&M Job Functions and Labor Rates

Table 6 provides unburdened labor rates for various PV O&M employment categories. Note that these rates do not differentiate regional salary differences nor do they separate union vs. non-union labor. Resources used by industry stakeholders to develop labor rates, along with site and area-specific adjustments, include RSMeans and the U.S. Bureau of Labor Statistics.

A 2015 report released by the National Renewable Energy Laboratory (NREL), *Best Practices in PV System Operations and Maintenance v. 1.0*, provides more detail on O&M workforce issues.[20] It contains O&M labor service categories, scopes of work/tasks, salaries, and job qualification information. Salaries levels portrayed in the NREL report fall within the value ranges delineated in Table 6. Note: the source of the NREL data is the U.S. Bureau of Labor Statistics, which provides different wage percentiles for specific tasks and other useful labor-related data. The labor rates are, however, not necessarily for PV-specific applications of an identified job function.

[20] *SAPC Best Practices in PV System Operations and Maintenance Version 1.0.* National Renewable Energy Laboratory, Golden, CO: March 2015. NREL/SR-6A20-63235.

Table 6 – Unburdened PV O&M Labor Rates

Job Function	Estimated National Rate	Range of Reported Rates (per hour)
Technician	$22/hr	*$14 - $40*
Apprentice	$25/hr	*$18 - $45*
Journeyman	$36/hr	*$23 - $45*
Master Electrician/Engineer	$51/hr	*$25 - $90*
Plant Manager/Supervisor/Asset Manager	$47/hr	*$31 - $80*

** Values represent a range of labor costs from respondents across the U.S. and include union and non-union labor for PV-specific activities. These values cover all O&M provider ranges, from distributed- to utility-scale. Utility respondents did not provide labor rates.*

Improving O&M Labor Allocation

For large PV systems, O&M labor allocation can be broken out as follows: 40% work completed by an apprentice, 50% by electricians, and the final 10% by electricians with medium voltage (MV) plant experience. Identified areas of improvement surrounding O&M labor allocation and efficiency include:

- Use of unmanned aircraft systems (UAS) for thermal scanning,
- Greater attention to documentation and inventory control,
- More "smart monitoring" features tied to data acquisition system (DAS) and supervisory control and data acquisition (SCADA),
- Fewer and more thorough annual inspections,
- Improved installation standards which are optimized for maintenance,
- Up-front analytics for reducing time spent on-site, and
- Clustering of service calls for multiple sites into one trip, so that preventative and reactive maintenance tasks can be completed simultaneously. (This practice may lead to overqualified personnel performing the work, but time spent in-transit is less and can save money.)

Existing Gaps in the Labor Skillset

In general, more trained technicians are reportedly needed, along with better communication between service reps and technicians. Professional dispatch and inventory management systems are particularly needed, as well as technician and electrician training to diagnose simple repairs. Currently, competition with installation crews is a problem as there are few dedicated repair crews available to do the work. Some believe that licensing is necessary as is a state-level definition of requirements for the profession. Experienced dc- and ac-licensed electricians with computer science and/or networking background are wanted, as it is difficult to find and train these people.

Warranty

How equipment warranties are handled can significantly impact O&M budgeting. Some O&M service providers manage warranty claims for plant owners while others do not. Anecdotally, warranty claims against inverter manufacturers have been easier to manage than against module manufacturers. To get ahead of equipment issues, a robust commissioning process can identify potential problems and ensure that warranty claims are honored. A suggested best practice is to have a third-party assess a plant's health before different component warranties expire. Overall, there is a question about the quality of O&M activities that occur during the warranty period, which is the environment in which most of todays installed PV plants are currently operating. When those warranties expire, what condition will the plant be in, and how much will it cost to address neglected areas of service?

Labor costs can be high due to overtime payment if the owner requires warranty equipment repair or replacement occur at night. If this is not a cost plus item, then the O&M budget can be quickly depleted. Some O&M contracts do not even budget labor for a warranty claim.

Credit: SolarPro

Extended Warranty

There is a common concern about whether manufacturers will remain in business to honor warranty claims. Based on its past experience with other equipment manufacturers, one electric utility routinely purchases extended inverter warranties as a hedge.

New products are starting to be offered by equipment manufacturers that include both general service and warranty work. These products result in manufacturer guarantees of higher equipment uptimes. For example, an inverter availability guarantee, which is more likely a warranty type than a standard insurance product, protects against events that can reduce equipment availability (i.e., during times when the inverter is not functioning). Insurers refer to this type of arrangement as "warranty insurance." The owners that buy this additional product will get their site serviced first ahead of others that don't have the insurance add-on.

Honoring Warranty Claims

Common questions facing industry stakeholders are how preventative maintenance impacts warranty claims, and who is allowed to work on the equipment. For example, some inverter manufacturers restrict servicing of their inverters to in-house technicians and others require certified training be completed before non-affiliated technicians can conduct warranty service. This situation is more typical with larger central inverters that are not generally replaced in their entirety. Servicing of string and microinverters that are designed to be fully replaced after failure depends on the particulars of the manufacturer's agreement.

Insurance officials have found it to be difficult for claimants to file a successful warranty claim given burden of proof obligations. Even more difficult to win are claims against manufacturers based in other countries. Because of these challenges, insurers may be paying out more in claims than is necessary. Product quality and improved industry standards should help mitigate this issue. Some warrantied products, however, are excluded from insurance during the active warranty period—though when considering insurance products on the *performance* of the equipment, the financial viability of the component manufacturer and warranty terms do play an important role. Insurance providers may get involved if a warranty claim is denied due to third-party damage to the equipment or poor maintenance. In these cases, they may pay the plant owner, then try and recover from the party that caused the damage.

One insurance product for manufacturers addresses the issue of defective products leading to downstream contractual defaults. It essentially provides the manufacturer with a way to payout potential lost PPA revenue to the owner (who is now in default on the PPA contract) while defects are being addressed as part of a warranty claim.

Generally, manufacturers are reluctant to deny claims outright as their reputation depends on being able to service equipment. To what degree they ignore preventative maintenance lapses that may lead to a claim remains unclear.

Insurance and O&M

Insurance touches many aspects of O&M, including the costs to insure companies physically working on plant sites, as well as equipment losses from force majeure or other unintended events. Newer insurance products also provide coverage for lower than expected kWh performance, tax credit recapture, and cyber-attacks.

General Insurance Coverage

Insurers that provide coverage for large PV systems examine everything from system design and redundancy, the number of different equipment manufacturers represented in site portfolios, as well as installation and commissioning items. In addition, during the EPC-to-O&M-provider handover that typically occurs post plant commissioning or, in some cases, at plant recommissioning, insurers evaluate the different O&M practices that have occurred to date against those that are planned and look for discrepancies that may presage problems. Separately, O&M service agreements as well as spare parts plans are also assessed to evaluate project impacts. Finally, PV performance model inputs, as well as assumptions and qualifications of modeling personnel are evaluated if any type of solar underperformance insurance is being negotiated.

O&M providers pay an estimated 5-7% of their revenue toward general insurance costs, depending on company size, annual revenue, and the number of claims submitted. Meanwhile, electric utility companies overseeing O&M of their owned sites, include insurance costs as part of their overhead, which is not reflected as a line item in the PV O&M budget.

One suggested rule of thumb is to budget $0.10 for every $100 of insurable value for the components in a PV system. That rate is impacted by how well the company offering the insurance product backs up the warranty. Another unearthed data point: for an all-risk product, costs range between $3,000-$5,000/MW-yr.

Specific Cost Details

Specific insurance costs remain largely unknown surrounding O&M activities for General Liability, Property Risk, Environmental Risk, Business Interruption, and Contractor Bonding and Risk Management. Generally, "standard market rates" are paid to cover these services. Meanwhile, outside of General Liability, the other categories are often covered by the asset manager (for systems that utilize asset management services). Following are a few insurance subcategories with additional detail.

- **General Liability.** Some O&M service providers carry a large umbrella policy which can be costly, while others set a general liability rate based on total salary pool, at approximately $30 per $1,000 field employee on payroll. One service provider reports general liability costs to be around $2.50/kW$_p$.
- **Business Interruption.** This insurance area is difficult to quantify as insurance companies reimburse more than just equipment replacement costs. Other issues that can impact restitution levels include the value of the interconnection agreement, potential solar renewable energy credit (SREC) and feed-in tariff (FIT) revenue, and/or unknown future utility demand charges. One electric utility reports a Business Interruption price of around $0.04 for every $100 of insurable value due to the presence of its multiple generating facilities. But for those entities with smaller generation portfolios (i.e., a small fleet of PV systems), the cost is much higher; rates are approximately $0.20 for every $100 of insurable value.
- **Underperformance.** Costs associated with insurance products that cover plant underperformance account for approximately 25-30% of the all-risk premium. Attitudes vary regarding the risk that weather pose to plant performance, however, these types of insurance products can also protect against improper installation and inaccurate modeling estimates, perhaps adding to their perceived value. Another available insurance product provides coverage for revenue shortfalls that lead to liquidated damages.

Popular/Emerging Insurance Products

There are a number of insurance products that are gaining traction in the solar PV O&M space. Among the more notable are:

- *PV Plant Performance Coverage.* These products protect against shortfalls in energy production guarantees. So far, they are not widespread, however those providing financing for large PV systems are starting to require them as a condition of closing. Performance insurance requires that more due diligence be conducted primarily through PV performance modeling. Pricing reflects assumed risks by the insurer.
- *Cyber Security and SCADA Insurance.* These products are specifically becoming more popular among the utility-owned PV segment.
- *Coverage of Additional Contract Claims.* These emerging products are targeted at PV equipment manufacturers and cover additional contract claims when a product defect is being addressed under the manufacturer's warranty. From an O&M

perspective, this coverage provides owners with a backstop for performance guarantees, where module replacement may take longer than anticipated, thereby leading to defaults in power purchase agreements.

- *Forced Outage Insurance.* These products are available to utilities and provide coverage for situations when PV plant downtimes may require expensive electricity be purchased on the open market. Though the current uptake of this option is low, it may potentially become more popular as PV generation becomes a larger share of the utility portfolio.

Insurance Needs Looking Forward

The universe of insurance products geared to PV O&M has notably expanded, particularly over the past five years, and is likely to continue to do so over the near term. As listed below, a number of ideas are currently circulating regarding new insurance offerings that can better inform and improve O&M approaches.

Re-Imagining the O&M Budget Process: A Future Outlook

Strategic reforms to mainstream PV O&M budgeting approaches—through the incorporation of both small and more far reaching ideas—can help optimize O&M activities and, in turn, maximize financial returns. The solar industry appears to have made concerted strides in the servicing of PV plants over the last several years. But additional learning and tactical modification can likely further improve plant reliability at a cost that enhances the resource's lifecycle competitiveness with other energy sources, and a level of foresight that allows for future flexibility.

Industry stakeholders either interviewed or surveyed for this research effort voiced a number of "food for thought" recommendations for advancing PV O&M budgeting precepts. Some of these suggestions are discussed below.

General Budgeting Process-related Reforms

According to interview and survey respondents, documentation and information sharing associated with the O&M budgeting process is improving, thereby enabling the assignment of funding levels that more accurately reflect the costs of adequately maintaining plant health. However, there is room for further improvement.

- **Instill greater budget transparency.** To some, O&M budgeting is improving due to greater recognition of site-related specifics and better definition of work scope elements. However, allowing independent O&M contractors and banks/insurers to review EPC budgeting to better understand how O&M and plant installation/commissioning are broken out would further improve coordination among stakeholders. Oftentimes, EPCs roll O&M into the overall installation cost which can obscure the amount of actual budget apportioned to the activity. Rather than wrapping O&M into installation cost, it should be mapped to an SOW to allow for more realistic budget allocation. (To more clearly stipulate service and cost expectations, most O&M providers are now using the cost plus model) Likewise, O&M budget should be separated from commissioning so that service providers aren't forced to perform commissioning on behalf of EPCs (essentially for free).

- **Align incentives along the value chain.** The multiple actors involved in a plant's development and upkeep have different incentives which can result in long-term owners being saddled with low O&M budget that can compromise plant output and project success.

  Profit sharing represents a more involved structural budgeting reform for instituting O&M approaches that incentivize greater coordination among project stakeholders. Under this concept, if the cost of capital continues to decrease, the potential for higher margins offers an opportunity to reserve funds for incentivizing quality O&M or providing additional services. Because most contracts have liquidated damages clauses, there could arguably also be clauses for upside sharing and bonuses when targets are exceeded, for instance, akin to Incentive Distribution Rights employed in some Master Limited Partnerships. Today, the low cost capital only appears to be decreasing margins for O&M activities.

- **Evaluate and refine budgeting during initial years.** Frequently, O&M requirements and associated funding needs are underestimated. Performing an analysis of site conditions over the first couple years of a project's life and modifying

Table 7 – Suggestions for New Insurance Offerings/Approaches

Summary Ideas	
Insurance that accounts for potential fire concerns associated with the coupling of solar plus energy storage, insurance products need to be modified for potential fire concerns.	Curtailment insurance to protect against instances when a PV system temporarily suspends power delivery and, in turn, impacts other contracts depending on the length of the curtailment.
Improved insurance products tied to weather and performance modeling risk. Some stakeholders claim that these produced are currently too expensive. Derivatives based on weather and irradiance impacts to PV performance may be another option.	Manufacturer bankruptcy insurance for backstopping situations in which another product may have to be purchased and installed if an equipment failure occurs after a manufacturer goes bankrupt and a spare part or unit is unavailable as a replacement.
Availability insurance tied to an availability guarantee in an O&M contract.	Insurance to backstop O&M activities if a large vertically integrated company goes out of business.
The use of off balance sheet surety bonds to cover losses.	Guidelines for managing insurance claims
Insurance that adjusts for newer PV systems outfitted with arc fault detectors vs. older systems without them.	More attention toward Business Interruption insurance due to rising potential for revenue losses that exceed replacement costs.
Efficacy coverage, which considers the performance of components designed for use in one system, and maps them to other systems. The weakest link (component) in the system would be covered if the desired output by deploying the technology in the new setting is not realized. For example, use of the same battery for PV energy storage that is already used in EV applications could be covered if it fails in the new application, ultimately if the scalability risk can be determined.	

budget accordingly can mitigate shortcomings of initially instituted O&M strategies. Moreover, allowing for better estimates of maintenance costs once many of the initial warranties have expired would help improve proforma cost estimates early in the project lifetime.

- **Require O&M review in independent engineering (IE) reports commissioned by lenders.** In general, IE reports are customized to different client needs and many do not contain a thorough review of a project's O&M strategy. While certain topics, such as energy production estimates, are commonly addressed, O&M is often overlooked; even when included, it represents a small sub-portion of the entire report.
- **Incorporate new approaches for determining service requirements to maintain component warranties.** From a reliability perspective, the ability to aggregate plant performance across the U.S. to enable the identification of the top five O&M events would help improve the budgeting process and determine a reasonable availability guarantee that balances efficiency and cost with electric generation.
- **Consider decommissioning activities.** Many owners do not budget for the decommissioning process. Due to lagging knowledge surrounding the costs of this activity, prices paid for the service may be higher than if there were greater competition. Decommissioning may include hazardous waste recycling depending on the markets available for module and inverter recycling.

Standardizing Budgeting and Tasks

Standardization of various aspects of the budgeting process can potentially increase efficiencies and level set expectations. For example, standardizing on PV project components can lead to cost competitiveness and lower prices paid for spares. (However, it is uncertain that parts standardization will lead to greater plant reliability if a plant's complexity is consequently increased.) Moreover, standardizing procedures can lead to improved efficiencies for O&M technicians in the field. That said, standardization may work best if it is allowed to organically take root, rather than be forced on the industry.

Competition & O&M Budgeting

Many O&M service providers expect both costs and pricing to initially increase for O&M services as demand rises in the near term. However, this anticipated uptick in costs and pric-

ing is also predicted to be short lived, as competition from other O&M providers grows, and summarily drives down price points. The greater presence of O&M providers nearby customer sites is also expected to depress prices.

Open ended questions currently exist surrounding the direction of the O&M competitive landscape. It's unclear, for example, if and to what degree EPCs might enter the O&M services field or whether PV installers will begin to more commonly include O&M services in their product offerings. There is already a shortage of skilled labor available to perform O&M services, and decreasing budgets (as defined in proformas) is likely to make it more difficult to contract the right person for the work.

More fundamentally, outstanding questions remain regarding the value of O&M provider services over a project's lifetime. Should O&M experience command a price premium? In some cases, O&M providers are getting involved in projects early on, providing consulting and review services prior to plant construction. Pre-qualification of providers is occurring in some markets, distinguishing those that follow safety standards and have a track record of safe operations, as well as the ability to develop and follow industry best practices.

O&M Services for Utility-owned PV Systems

Looking ahead, electric utilities are likely to increase their PV plant portfolios from their current (largely insignificant) levels. As a result of greater PV asset ownership, utilities are also likely to more broadly evaluate the financial (and other) tradeoffs of managing their PV O&M needs either in-house or externally through 3rd party providers. (Today, the vast majority of utilities source their PV generation through power purchase agreements; as such, they are not responsible for plant O&M.) The emergence of specialty sub-contractors, internal labor efficiencies, and potential new revenue stream opportunities (e.g., offering PV O&M as a service), are among the factors that will require future consideration by both regulated and unregulated power companies.

Suggested Reading

PV O&M Index 2015: Emphasis on Boosting Returns. Bloomberg New Energy Finance, New York, NY: September 2015.

SAPC Best Practices in PV System Operations and Maintenance Version 1.0. National Renewable Energy Laboratory, Golden, CO: March 2015. NREL/SR-6A20-63235.

A Best Practice for Developing Availability Guarantee Language in Photovoltaic O&M Agreements. Sandia National Laboratories, Albuquerque, NM: 2015. SAND2015-10223.

Precursor Report of Data Needs and Recommended Practices for PV Plant Availability, Operations and Maintenance Reporting. Sandia National Laboratories, Albuquerque, NM: 2015. SAND2015-0587.

Utilizing Unmanned Aircraft Systems as a Solar Photovoltaics Operations and Maintenance Tool. EPRI, Palo Alto, CA: 2015. 3002006216.

Solar Energy Technology Guide. EPRI, Palo Alto, CA: 2015. 3002006365.

Megawatt-Scale PV O&M and Asset Management 2015-2020: Services, Markets and Competitors. GTM Research, Boston, MA: September 2015.

PV Reliability Operations and Maintenance (PVROM) Database Initiative: 2014 Progress Report, Sandia National Laboratories, Albuquerque, NM: 2014. SAND2014-20612.

PV System Operations and Maintenance Fundamentals. Solar America Board for Codes and Standards, Cocoa, FL: August 2013

Continuing Developments in PV Risk Management: Strategies, Solutions, and Implications. National Renewable Energy Laboratory, Golden, CO: February 2013. NREL/TP-6A20-57143.

PV Reliability Operations Maintenance (PVROM) Database Initiative: 2013 Project Report. EPRI, Palo Alto, CA: 2013. 3002001399.

Southern California Edison's Solar Rooftop Program: Utility-Scale PV System Installation Best Practices. EPRI, Palo Alto, CA: 2011. 1026662.

Solar Photovoltaic System Operations and Maintenance: Utility Case Studies. EPRI, Palo Alto, CA: 2011. 1021988.

Addressing Solar Photovoltaic Operations and Maintenance Challenges: A Survey of Current Knowledge and Practices, EPRI, Palo Alto, CA: 2010. 1008434.

Insuring Solar Photovoltaics: Challenges and Possible Solutions. National Renewable Energy Laboratory, Golden, CO: February 2010. NREL/TP-6A2-46932

Five Years of Operating Experience at a Large, Utility-scale Photovoltaic Generating Plant. L. M. Moore et al., Prog. Photovolt: Res. Appl. 2008, 16:249–259.

FOR FURTHER INFORMATION

Nadav Enbar, *Principal Project Manager, Power Delivery & Utilization, EPRI,* nenbar@epri.com

Dean Weng, *Engineer Scientist, Distributed Renewables, EPRI,* dweng@epri.com

Geoff Klise, *Principal Member of the Technical Staff, Sandia National Laboratories,* gklise@sandia.gov

EPRI ID: 3002006218, Sandia ID: SAND2015-10851 R

December 2015

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com