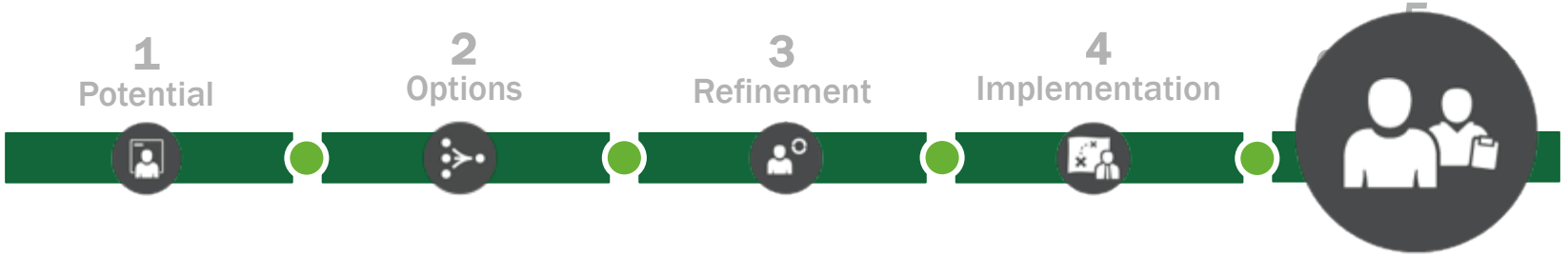
DOE OFFICE OF INDIAN ENERGY

The Five-Step Development Process
Step 5: Project Operations and Maintenance

U.S. DEPARTMENT OF ENERGY | Office of Indian Energy

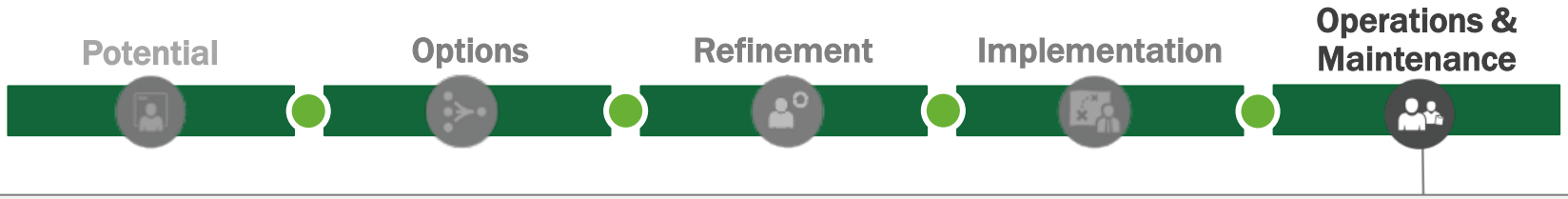
Project Development Process



Presentation Agenda

- Step 5: Project Operations and Maintenance (O&M)
- Post-procurement activities
- Drivers
- Technology examples

Step 5: Operations & Maintenance



Purpose: Conduct or ensure ongoing operations and maintenance (O&M), including repair and replacement (R&R)*

Task:

- O&M Plan and Budget
- System performance
- Monitoring system
- O&M Contracts and agreements
- Warranties
- Production guarantees
- Buyout Options

Photo by Warren Getz, NREL 00180

Outputs:

- Ensure responsible party carries out O&M/R&R*
- Measuring and tracking success
- Correlate with business plan and strategic energy plan
- Contract compliance
- Reporting of generation
- Met or exceeded energy and financial performance

**Especially if owner – role of highest O&M risk*

Drivers for Improved O&M

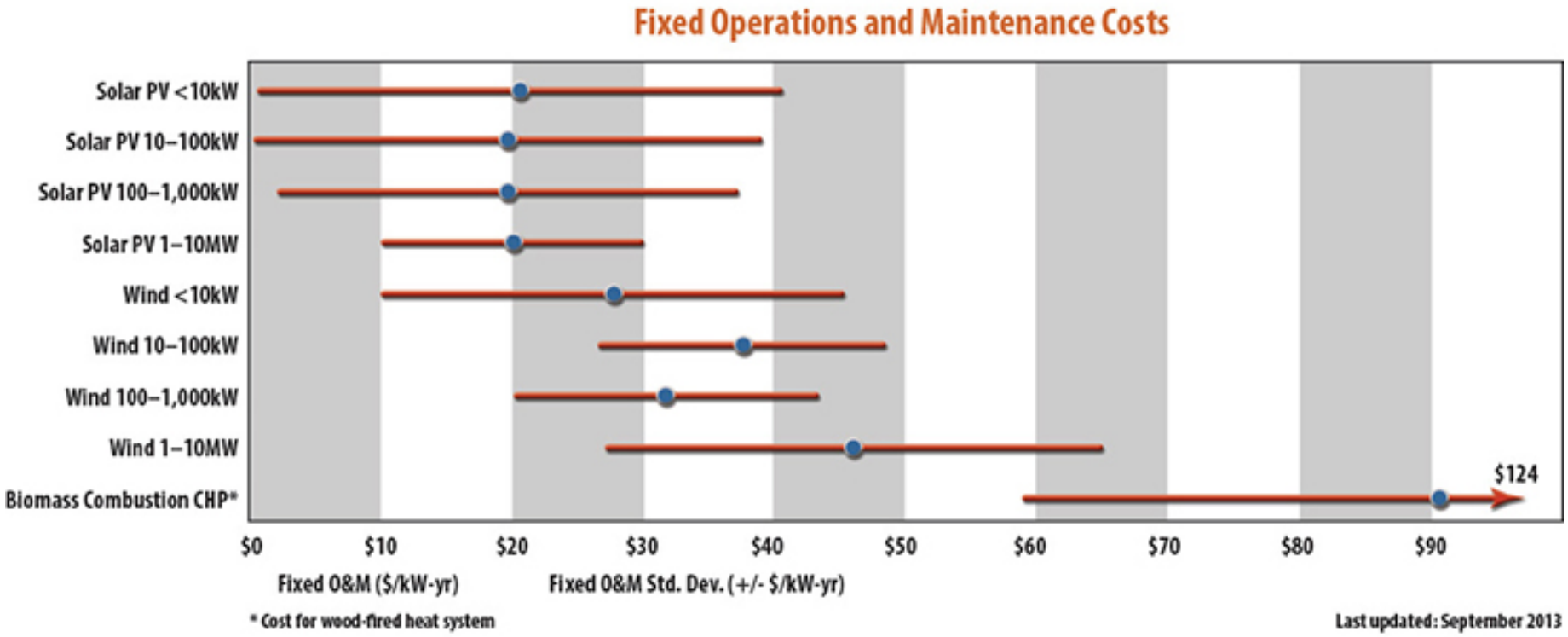
- Increase efficiency and energy delivery (kWh/kW)
- Decrease downtime (hours/year)
- Extend system lifetime (25–40 years)
- Reduce cost of O&M ($/kW/year)
- Ensure safety and reduce risk
- Enhance appearance and image
- Often required in financing and warranty

O&M Activities

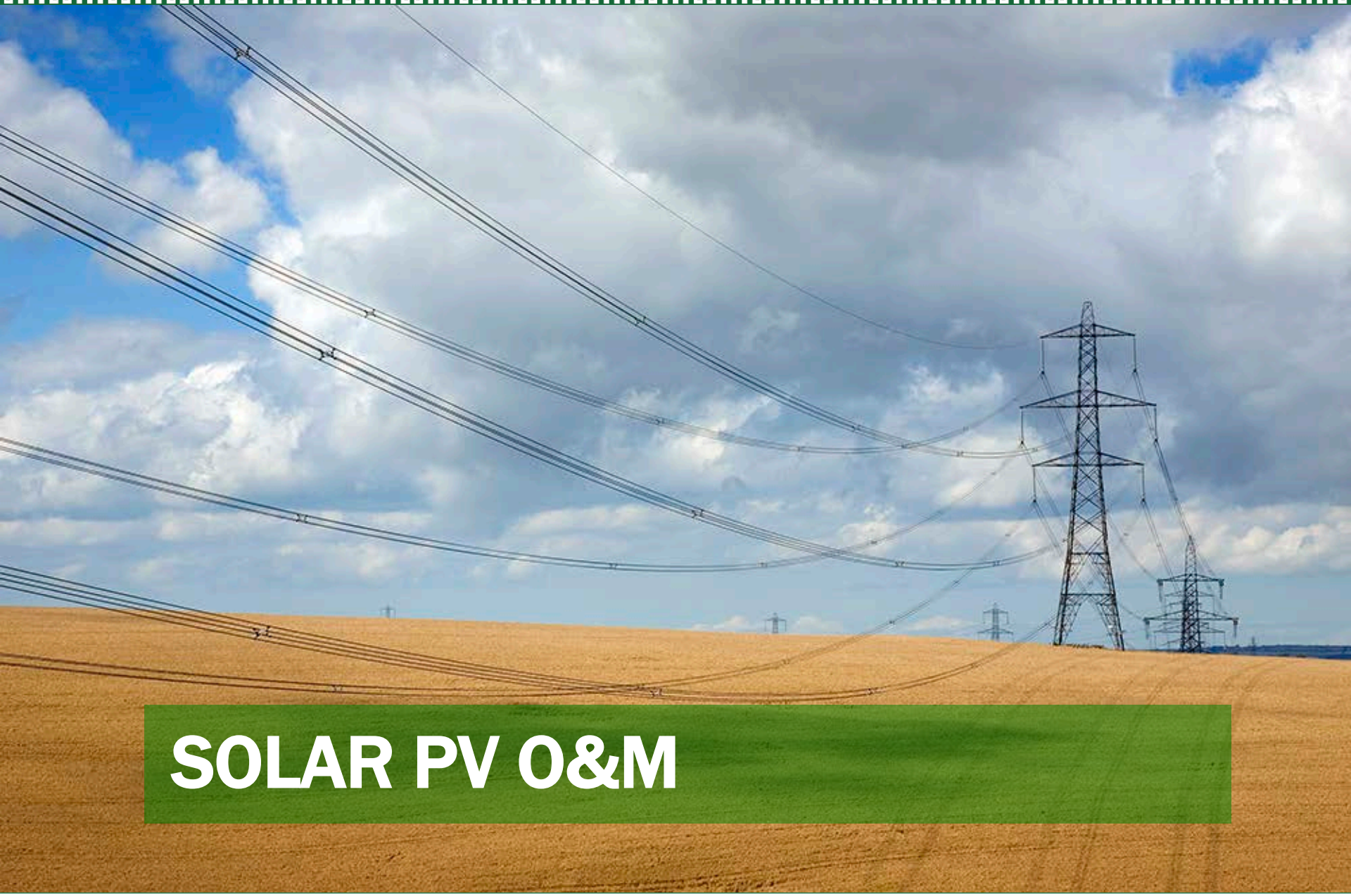
- **Administration**
  - Billing; accounting
  - Hiring subcontractors
  - Enforcement of warranties
  - Management of budget and reserves
- **Monitoring**
  - Metering for revenue
  - Alarms
  - Diagnostics
- **Preventive Maintenance**
  - Scheduled and planned
  - Expenditure is budgeted
- **Corrective Maintenance (repair)**
  - Unplanned or condition-based
  - Possible expenditure is kept in reserve or line-of-credit
  - Must be timely and effective

Inspection of a 67-kW PV system at Mesa Verde National Park.
Photo by Andy Walker, NREL

O&M Costs for Renewable Energy Technologies



http://www.nrel.gov/analysis/tech_cost_om_dg.html



SOLAR PV O&M

PV Commissioning Reports

- Documentation of System
  - As-built drawings
  - O&M Manuals
  - Equipment datasheets
- Verification Certificate
  - Certifies that commissioning was conducted according to standard
  - Needed for financing and warranty
- PV System Inspection Report
  - Compliance with codes and standards
- PV Array Test Report
  - Details of PV array
  - Results of polarity, insulation, grounding, voltage and current tests
- Complete System Performance Test
  - Comparison of actual performance with estimate based on environmental conditions

Applicable Standard

- IEC 62446 grid connected photovoltaic systems
- Minimum requirements for system documentation
- Commissioning tests and inspections

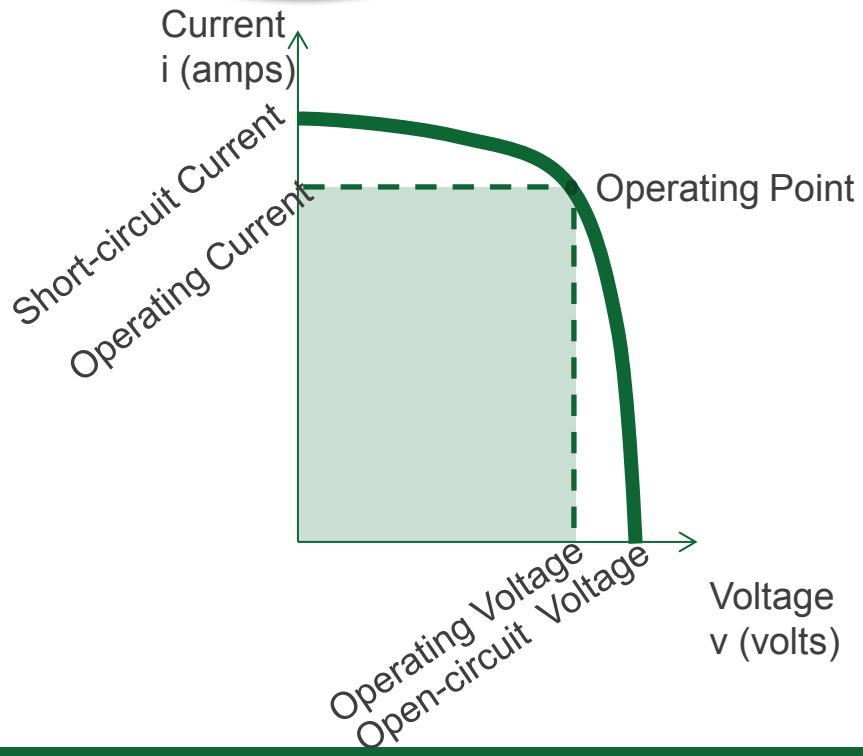
Different Tests of PV Circuits

- Check Fuses in Combiner Boxes and Inverter
  - Ohm-meter - seek zero ohms across removed fuse
- Open Circuit Voltage
  - Voltage meter, at inverter, combiner boxes, module strings
  - Compare to each other and expected value calculated from temperature
- Short Circuit Current
  - Clamp-on current meter at inverter, combiner boxes and module strings
  - Compare to each other and to the expected value calculated from solar radiation
- Continuity of Grounding System
  - Resistance meter - seek zero ohms to ground
- Integrity of Electrical Insulation on Power Circuits
  - Mega-ohm meter (megger), seek infinite ohms to ground
- Operating Voltage
- Operating Current
- I-V Curve Trace
  - Trace entire current /voltage curve by charging a capacitor
- Whole System Performance Test

  Performance ratio = actual/predicted

Applicable Standard:
- IEC 61724 PV system performance monitoring
- Guidelines for measurement:

Part 1: Measurement methods
Part 2: Capacity Test
Part 3: Energy Test



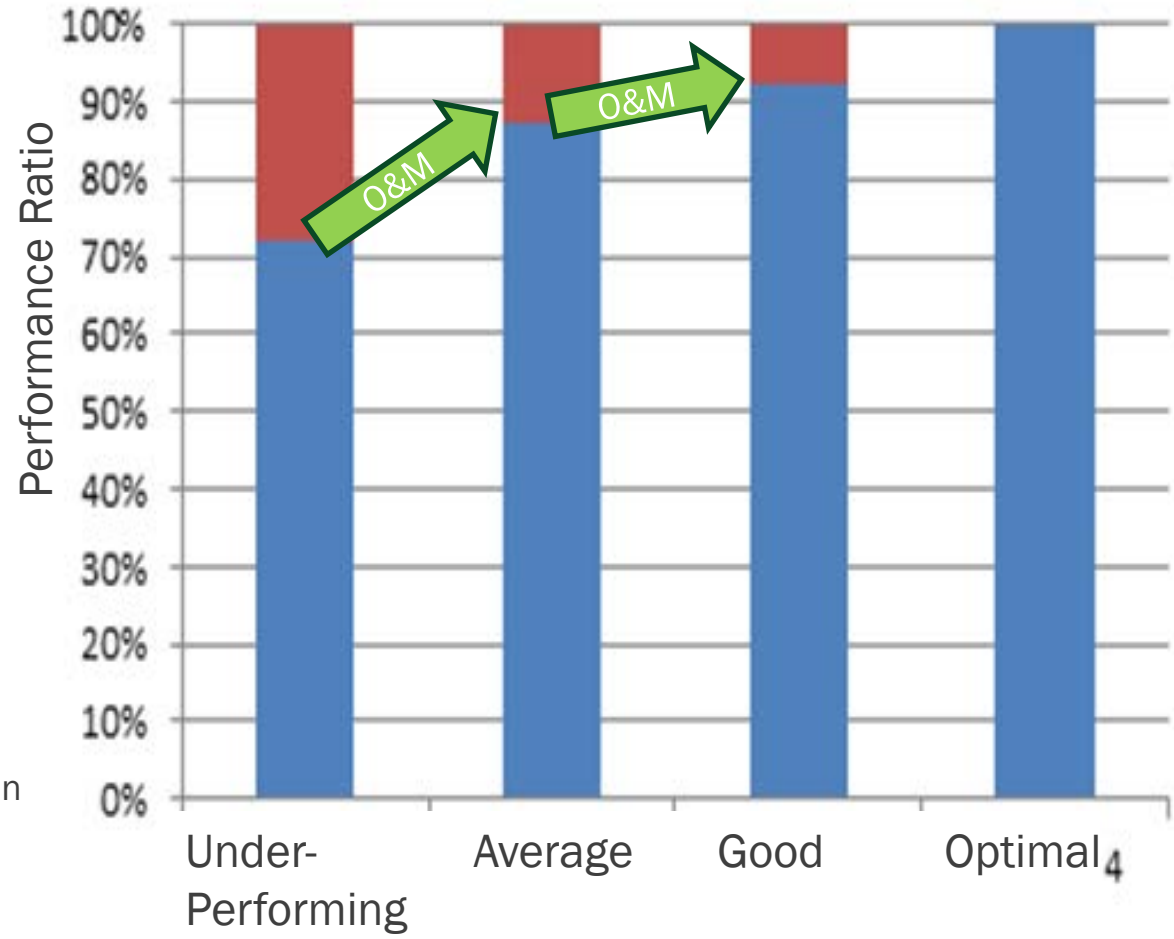
Comprehensive O&M could improve delivery of underperforming 25% of systems from 73% to 93%, and another 25% from 87% to 93% of optimal

Under-Performing (lowest 25%)
- Little or no preventative O&M
- Some corrective O&M

Average (25-50%)
- Some preventative O&M
- Good corrective O&M

Good (50-75%)
- Comprehensive asset management
- Good preventative O&M
- Good corrective O&M

Optimal (100%)
- Full robust quality assurance system in planning and construction phases
- Comprehensive asset management
- Good preventative O&M
- Good corrective O&M



Average Performance Ratio Increases from 88% to 94%

Performance data: OSPARC June 2014 from 2074 systems in 42 states.
Costs data: http://www.nrel.gov/analysis/tech_cost_om_dg.html

Impact on Levelized Cost of Energy (LCOE) ($/kWh)

Goal of PV O&M Program: Demonstrate $0.01/kWh LCOE Reduction

$$LCOE = \frac{\frac{Initial\ Cost}{PWF} + O\&M}{PR\ * Optimal\ Production}$$

$$LCOE\ Impact = \frac{\frac{\$3000/kW}{15\ years} + \frac{\$20}{kWyear}}{0.88 * 1400\ kWh/kWyear} - \frac{\frac{\$3000/kW}{15\ years} + \frac{\$10}{kWyear}}{0.95 * 1400\ kWh/kWyear}$$

$$LCOE\ Impact = \$0.02/kWh$$

PV O&M Best Practices Document

- Definitions
- Select a type of key performance indicator that minimizes cost but ensures optimal system performance under varying conditions
- Performance ratio
- List elements of a documented PV system O&M plan
- Criteria for selecting O&M provider: installer/ in-house/3rd party
- Tracking log and up-to-date document service histories
- Online mobile work order management (Enterprise asset management similar to IBM Maximo, Meteocontrol, Alectris, Draker Labs and TruSouth.)
- Optimize balance between cost of scheduled maintenance, yield and cash flow
- Use reserves or line of credit to make repairs quickly (corrective maintenance)

PV O&M Best Practices Document

Small-system

- Onsite inspections, operational indicators ,and procedures
  - Monitor Shade
  - Name responsibilities of the off-taker
  - Off-taker contacts provided if there is a problem
- Inspection of fleets on a sample rather than every system
- Performance guarantees consider insignificant corrections that can be deferred - consider degradation rates specific to module type

Large system

- Emphasize automated monitoring and analytics
  - Remote reset
  - Push reports to stakeholders
- Report loss of production daily
- Report low production weekly (false positives)
- Monitoring system is transparent , maintainable and auditable
  - Backup is secure
- On-site or remote sensing of environmental conditions

PV O&M Best Practices Document

- Identify Safety Issues
  - Balance response time and urgency with cost of a “truck roll” and lost revenue
  - Address safety problem as soon as possible
- Establish criteria to decide repair or replace of components and inverter
- Establish criteria to order and stock parts
- Establish qualifications for every service provider
  - Cleaning, testing, etc.
  - Follow OSHA and NABCEP
- Document financial solvency of contractors (installer, service provider)
- Verify contractor has health and safety manual
- Check that contractor maintains current and appropriate business insurances (Coverage limits, deductibles, premiums)
- Warranties
  - Performance indicators
  - Requirements to keep in effect
  - Transferability

Service Provider Rates and Qualifications

Service Category	Rate $/hour	Scope of Work	Salary (2080 hrs/year)	Qualifications
Administrator	$17	Record-keeping, service confirmation, correspondence	$34,660	Excellent interpersonal and communication skills (written and verbal). Diligent record keeping. 2 to 5 years of experience. Excellent MS Office and computer skills. Management of contractors and quality.
Cleaner	$11	Cleaning PV Arrays	$22,210	10 OSHA Card; Required level of bonding and insurance; drivers license and reliable transportation; minimum 18 years old.
Designer	$42	Specifications, drawings, modeling and analysis, codes and standards.	$87,920	B.S. in EE (4-year engineering degree); registered PE licensed to practice engineering in the jurisdiction; NABCEP PV Installer Certification; CAD (AutoCAD) and graphics skills; knowledge of IEEE, NEC, NESC, and other codes and standards for PV systems; required level of errors and omissions insurance.
Inspector	$25	Diagnostic analysis; visual inspection, specific testing,	$52,360	Diagnostic analysis; NABCEP PV Installer Certification; 2 to 5 years of experience.
Inverter specialist	$24	Inverter repair, upgrades	$50,000	(estimated) Skills to perform maintenance, diagnostics and repair for inverter: factory trained and certified; 5+ years experience.
Journeyman electrician	$14	Module replacement, Inverter replacement, fuse/breaker replacement, conduit routing, wiring, ground fault repair	$30,000	(estimated) 50 OSHA Card; training in arc-flash, lock-out/tag-out, and other special protective equipment and procedures; NABCEP PV Installer certification; experience in the design of medium voltage electrical systems. 5+ years experience with PV systems; color vision.
Master electrician	$23	Module replacement, inverter replacement, fuse/breaker replacement, conduit routing, wiring, ground fault repair	$48,250	Electrical Contractor's license for the jurisdictions; 50 OSHA Card; NABCEP PV Installer certification; experience in the design of medium voltage electrical systems. 5+ years experience with PV systems; color vision. Certification by the North American Energy Reliability Corporation (NERC) is necessary for positions that affect the power grid.
Mechanic	$21	Maintenance and repair/replace of tracking mount components	$44,160	50 OSHA Card; 2 to 5 years of experience; required level of bonding and insurance.
Network/IT	$33	Internet/network repair, monitoring equipment repair	$69,160	Knowledge of specific monitoring devices (training by system supplier) and how monitoring system is connected through network connections or wireless or cellular modem; knowledge of Modbus, DNP3 and other protocols, HMI operator interfaces; 2 to 5 years of experience. Locus, Enphase, Itron, etc. monitoring device knowledge.
Pest control	$15	Nesting vermin removal, Nesting vermin prevention	$30,340	10 OSHA Card; safety training in handling animals and detritus; required level of bonding and insurance; drivers license and reliable transportation; minimum 18 years old; most states require license for pesticide
PV module/array Specialist	$24	Module repair	$50,000	(estimated) Skills to operate, troubleshoot, maintain, and repair photovoltaic equipment: NABCEP PV Installer certification. 2 to 5 years of experience.
Roofing	$16	Roof leak repair, roof tile repair, re-roof	$34,220	Roofing contractor's license for the jurisdiction; 10 OSHA Card; safety training in fall protection equipment and use (or 50 OSHA Card); required level of bonding and insurance
Structural engineer	$40	Foundations and rack inspection/design	$84,140	B.S. CE (4-year engineering degree); registered PE licensed to practice engineering in the jurisdiction.
Mower/Trimmer	$11	Removal of vegetation	$23,740	50 OSHA Card; drivers license and reliable transportation; required level of insurance; minimum 18 years old; any required training or license for herbicide application.
Utilities locator	$19	Locate underground utilities.	$38,510	2 to5 years of experience.

Solar PV O&M Maintenance Plan Example

Task	As Required	Monthly	Semiannually
Inspect modules for damage			✓
Address array shading issues	✓		
Remove debris around array	✓		✓
Inspect array mounting system			✓
Adjust array tilt	✓		
Check inverter and/or charge controller for correct settings		✓	
Inspect battery enclosure		✓	
Inspect battery terminals and connections		✓	
Equalize batteries	✓	✓	
Water batteries	✓	✓	
Measure specific gravity of each battery cell	✓	✓	
Load-test batteries			✓
Capacity-test batteries			✓
Inspect and clean all electrical equipment			✓
Monitor system for voltage and current	✓	✓	

*Adapted from Dunlop, J.P. (2010). Photovoltaic systems 2nd ed

Solar PV O&M Costs Depend On…

Location
- Remote
- Controlled access
- Restricted hours of operation

System Type
- Roof
- Ground-mount
- Tracking vs. fixed

Components
- Number of modules
- Number of combiners
- Number/type of inverters
- Number of transformers

Warranty Coverage

Environmental Conditions
- Snow
- Pollen
- Bird populations
- Sand/dust
- Humid
- Hot
- High wind
- Hail
- Salt air
- Diesel soot
- Industrial emissions
- Construction site nearby
- High insolation

PVOM O&M Cost Model Tool

Spread Sheet based tool

- Versatile model for residential, commercial rooftop and ground mount systems
- User selectable features: preventative/corrective maintenance methods, labor rates, warranty coverage
- Financial calcs: cost, cash flows, NPV for reserves

Background

- Spread sheet for easy customization
- Single system tool
- Based on bottoms up activity model
- User configurable variables
  - 68 preventive maintenance tasks
  - 54 corrective maintenance tasks
  - 7 administrative tasks
  - 15 job definitions /$ rates

PVOM Cost Model Screen

Inputs

General Inputs		
Analysis Period (Project Life)	20	years (40 max)
Discount Rate	7.00%	% per annum
Inflation Rate	2.00%	% per annum
Truck Rental Cost/ day	$100	
Working Hours/year	2,080	

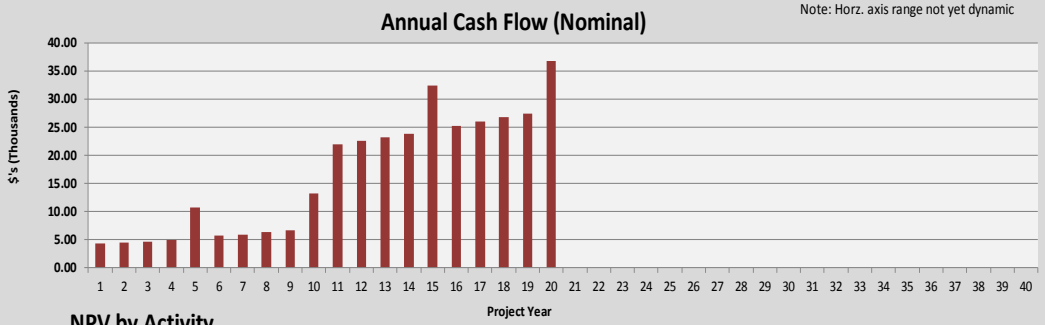
System Inputs		
Name of System	Hypothetical Roof-mount System #1	
Location	Denver, CO	
System Type	Grount-Mount Fixed Tilt (> 100kW)	
System Size (Wp DC)	440,000	
Energy Yield (kWh/kWp/year)	1,596	
Module Power (W STC)	305	
Number of Modules	1443	
Module Type/ Degradation	Mulit-crystal Silicon:0.64%/year	
Module Encapsulant	Ethyl Vinyl Acetate (EVA)	
Modules per String	14	
Number of Strings	103	
Strings per Combiner Box	6	
Number of Combiner Boxes	18	
Combiner boxes per DC disconnect	1	
Number of DC Disconnects	18	
Inverter Type	String Inverter	
Inverter Replacement Cost/ Wp	$0.20	
Number of Inverters	1	
Inverter Capacity (kWp)	400	
Number of Transformers	1	
Inverter Warranty (years)	10	
PV Module Product Warranty (years)	10	
Other equipment (EPC) Warranty (years)	10	
Purchased monitoring contract (years)	5	Enter '0' if not applicable
Ground Coverage Ratio (GCR)	33%	
Site Area (acres)	2.3	
Modules/Row	14	
Total Rows:	103	
Rows per Tracked Block:(ignore untracked)	1	
Total Tracking Blocks:(ignore untracked)	103.0	
Foundations per row: (ignore rooftop)	1	

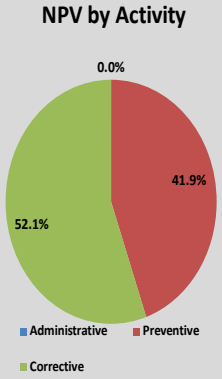
Environmental Conditions	
Indicate "1" if condition applies to project, "0" if not applicable	
Snow	0
Pollen	0
Bird Populations	0

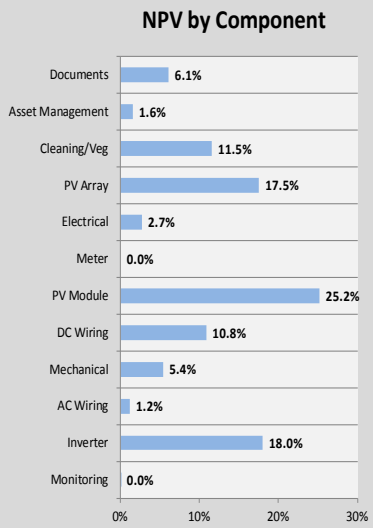
Results

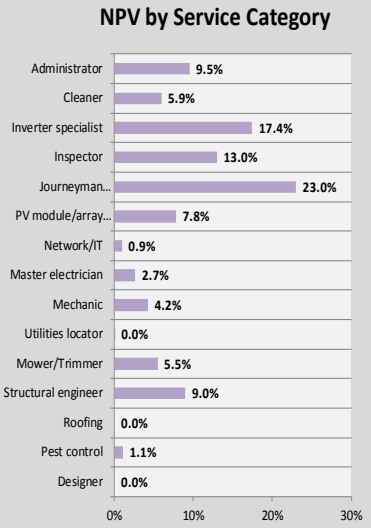
First Year O&M Costs ($/year)	$4,404
First Year Unit O&M Costs ($/kW/year)	$10
Net Present Value O&M Costs (project life)	$137,778
Net Present Value (project life) per Wp	$0.31

Note: Horz. axis range not yet dynamic





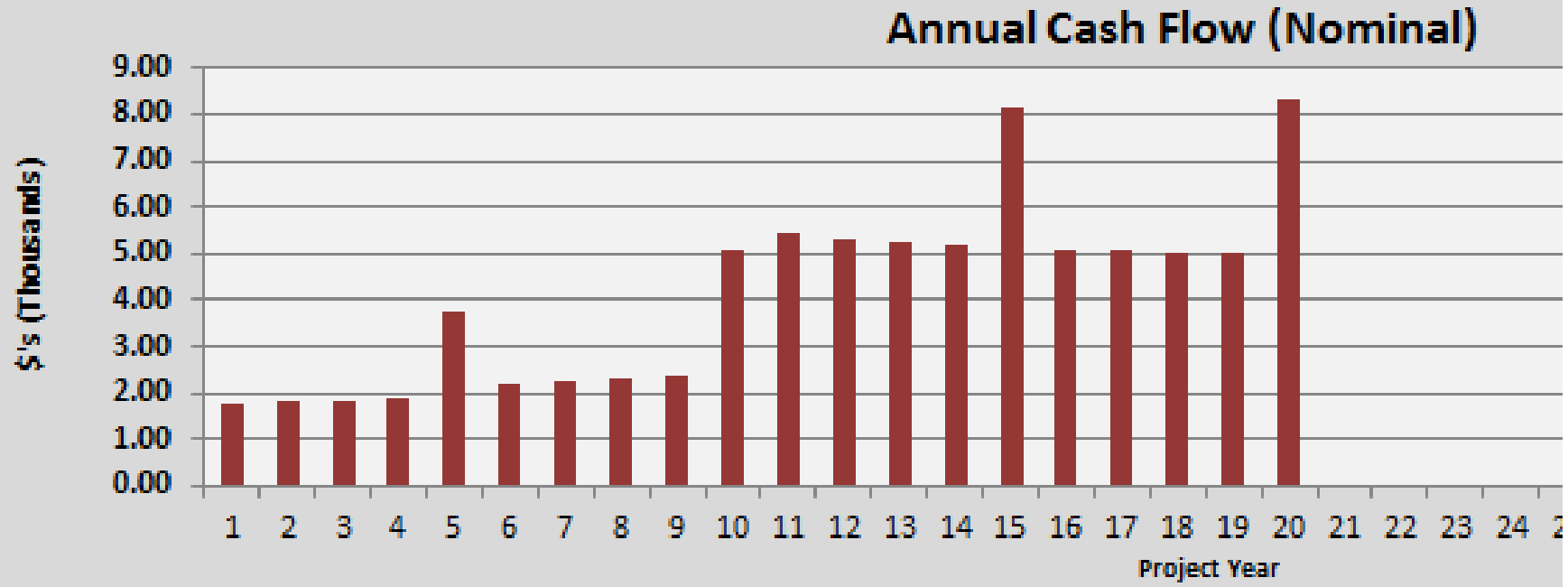




Results: Cash Flow

Results

Annualized O&M Costs ($/year)	$2,977
Annualized Unit O&M Costs ($/kW/year)	$29.77
Net Present Value O&M Costs (project life)	$37,411
Net Present Value (project life) per Wp	$0.37



Warranties

Complete systems are often warranted by the installer for one year. After the first year, the manufacturer's warranty on the PV modules (up to 25 years) and inverter (up to 10 years) as well as on any other components transfer to the owner for enforcement.

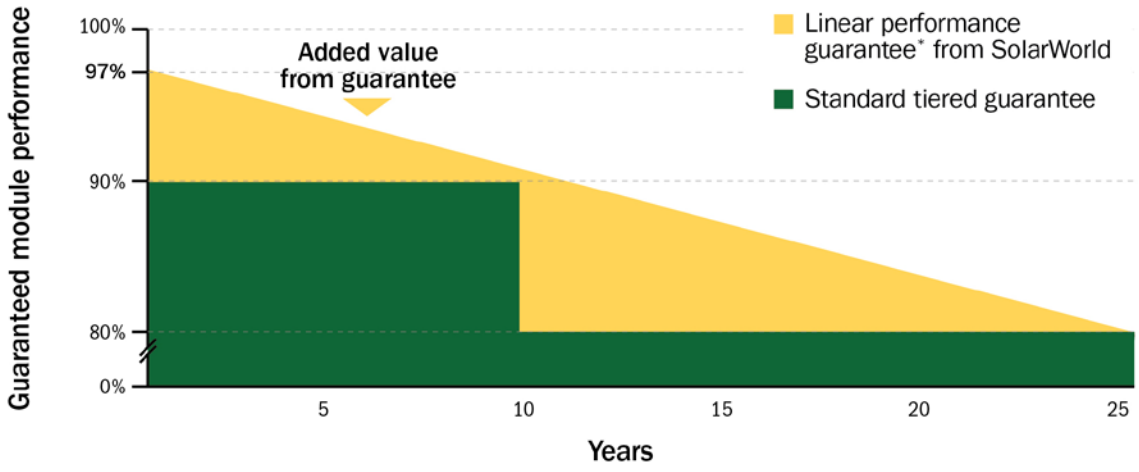
Stepped Warranty

- 90% power warranty for 12 years
- 80% power warranty for 25 years

Linear Warranty

- Starts at 97% in year one
- Maximum annual degradation rate is ~ 0.5% to 0.7%/year

Linear Performance Guarantee
Straightforward Security



Clear added value compared to standard tiered guarantees.

Bird Populations

How birds view your PV array

Bird netting

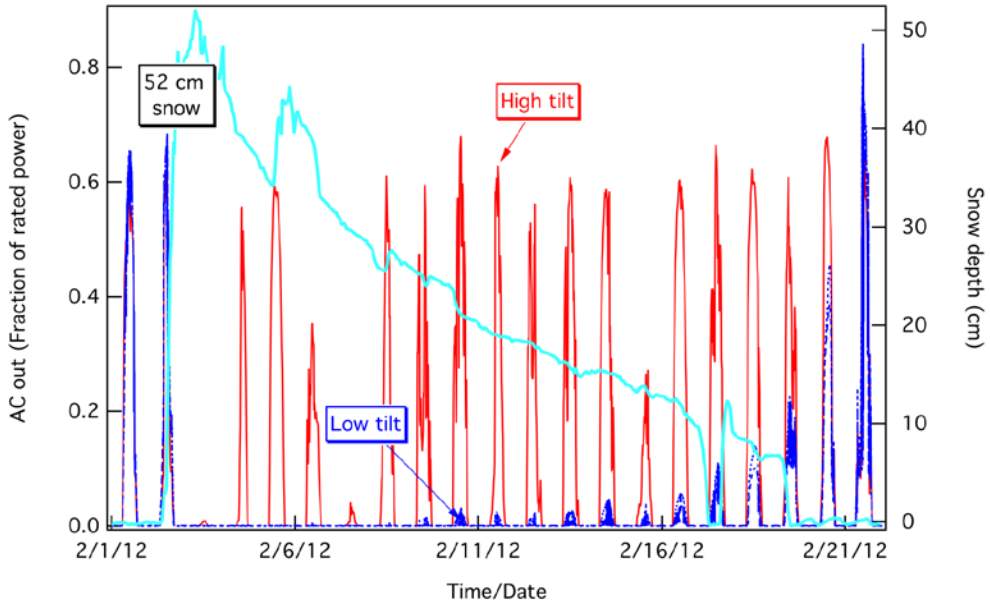
http://www.thesolarco.com/birds-and-solar-panels/

- Array design: reduce open cracks between panels where birds can build nests and use plastic “birdslides” to change flat surfaces to steep-sloped surfaces.
- Bird netting: seal areas under the panels with a wire or plastic mesh that clips directly to the solar panels and goes down to the roof completely around the array.
- Spikes: install bird spikes along the top edge of the array to prevent roosting.
- Imitation birds of prey: use plastic owl or falcon with swivel head to scare off birds.
- Schedule rooftop activities and removal of nests according to nesting season timing.

Snow Accumulation

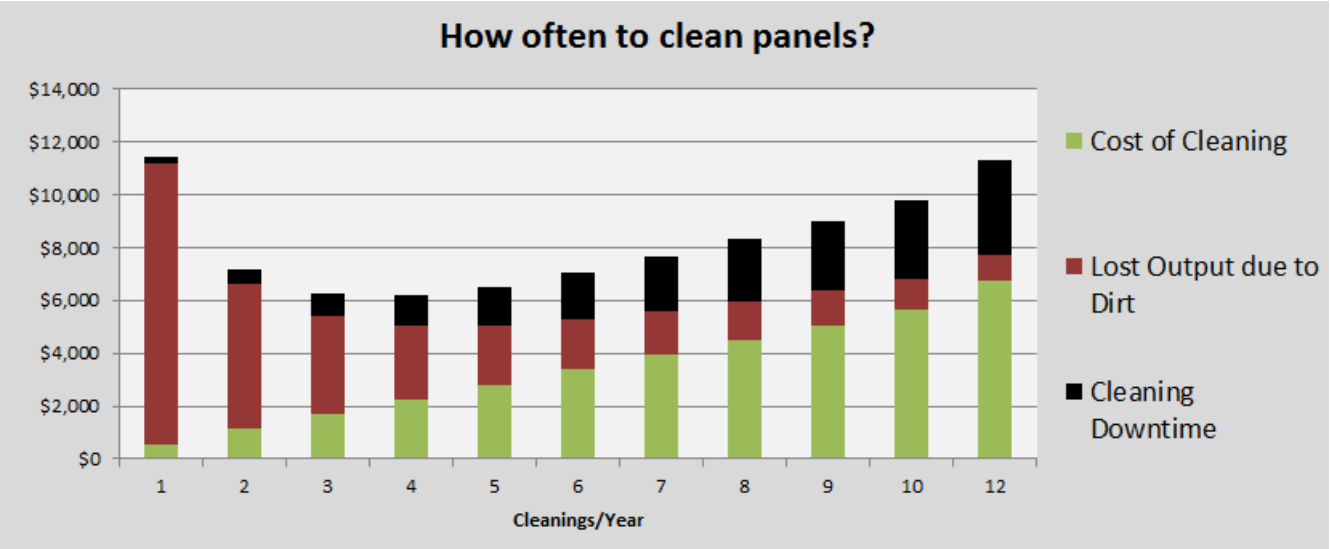
- Design of array can increase or decrease snow accumulation (clearance to allow “scouring” of snow by wind)
- Snow generally sheds off panels at tilt >40°
- Snow removal is by powerful turbo-fan, not shovel or other mechanical means
- Heating to melt snow is generally not cost-effective

Inspection of a PV system at Mesa Verde National Park.
Photo by Andy Walker, NREL



Cleaning Solar PV

- Most rely on rain to keep the array clean; no cleaning regimen
- Cleaning improves output by 6% [SMUD] or 7.4% [http://phys.org/news/2013-07-solar-panels-worth.html]; about 0.05% reduction in output per day due to dirt
- Depends on local sources of dirt (e.g., diesel soot, dust, construction, agriculture, industrial pollution)
- Optimize cost of cleaning versus improvement in performance (see example below)
- Adapt cleaning schedule to rain, pollen season, bird season, etc.
- Clean PV modules with plain water or mild dishwashing detergent. Do not use brushes, any types of solvents, abrasives, or harsh detergents.
- Cleaning robots are available for large systems



Recent Products and Presentations

Keating, T.J., A. Walker, and K. Ardani. 2015. "SAPC PV Operations and Maintenance Best Practices Guide: Considerations for Financial Managers and Industry Practitioners", version 1.0. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy15osti/63235.pdf.

Keating, T.J., A. Walker, "PV O&M Cost Model, version 1.0," an MSExcel Spreadsheet to calculate O&M costs through time by system component and service category- interim deliverable. Available upon request andy.walker@nrel.gov

"O&M Best Practices for Small-Scale PV Systems" 1.5 hour video training; 0.2 CEU; https://www4.eere.energy.gov/femp/training/training/om-best-practices-small-scale-pv-systems

Sandia National Laboratories publication SAND2015-0587, "Precursor Report on Data Needs and Recommended Practices for PV Plant Availability, Operations and Maintenance Reporting" to provide a basis to formalize best practices into codification by the standards processes.

"Standards/Best Practices in PV O&M" Solar O&M 2014, San Diego CA October 1-2, 2014

"Solar Access to Public Capital (SAPC) O&M Best Practice Guide and O&M Cost Model" Better Buildings Alliance Renewable Integration, Dec 2 2014

"Standardizing O&M Practices" PV O&M USA conference, 18-19 November, San Jose CA http://news.pv-insider.com/photovoltaics/standardizing-om-practices-be-discussed-pv-om-usa-november

"PV O&M Gaps Analysis – Final Results" PV Reliability, Operations & Maintenance Workshop, May 7, EPRI Palo Alto CA
"Solar PV O&M Standards and Best Practices – Existing Gaps and Improvement Efforts" SAND2014-19432 November 2014

"Operation and Maintenance (O&M) of Photovoltaic (PV) Systems" NREL Report for Clean Power Finance; April 2014

WIND O&M

O&M Wind Energy Costs

- Generally, the annual O&M costs increase over the life of the turbine, especially in later years of 20- to 25-year useful life
- Industry-recommended practices exist for all aspects of wind turbine maintenance:
  - Towers, rotors/blades/hubs, gearboxes, generators, balance of plant, data collection/reporting, end of warranty

Wind power project at Campo Reservation about 60 miles east of Sand Diego, California. Photo by Robert Gough, NREL 6312056.

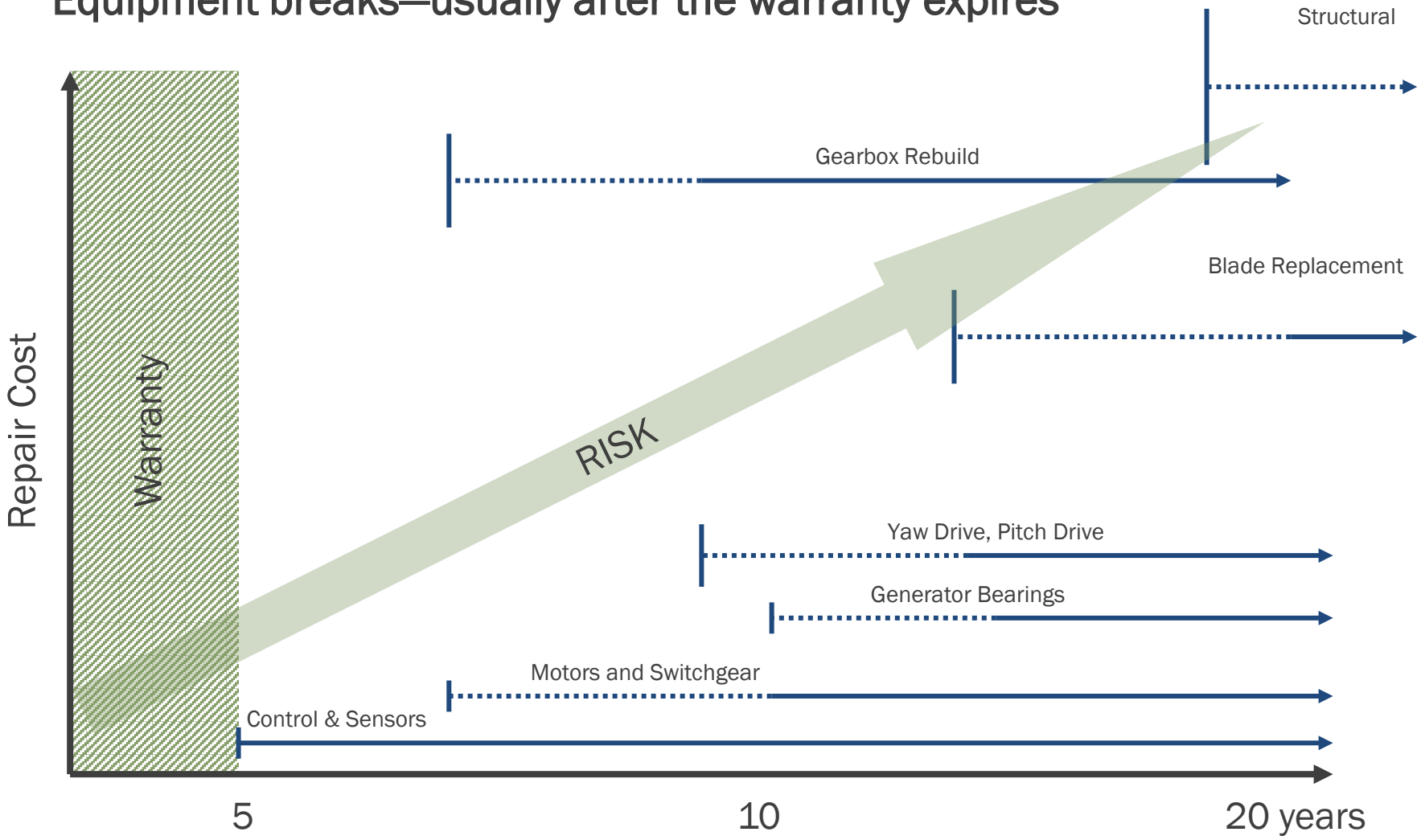
O&M Wind Energy Costs Measured Annually

- O&M costs expressed as:
  - $/kW/yr (capacity-based)
  - $/MWh/yr or $/kWh/yr (energy-based)
  - $/yr (simple)

Kumeyaay Wind Power Project on the Campo Reservation. Photo by Robert Gough

Major Components at Risk

Equipment breaks—usually after the warranty expires



Source: Chris Walford: GEC (now DNV GL)

BIOMASS O&M

Biomass Post-Procurement: Project O&M

- O&M agreements
- Fuel supply
- Warranties
- Biomass plant operations
  (monitoring the system and fuel supply)
- System performance

Biomass O&M

Purpose: Conduct or ensure ongoing O&M, including repair and replacement (R&R)*

O&M Costs:

- Biomass fuel
- Labor
- Equipment maintenance and upkeep
- Insurance
- Extended warranty agreements

If leasing, lessor often manages maintenance

If PPA, vendor typically manages maintenance

*Esp. if owner—role of highest O&M risk

Photos by Randy Hunsberger, NREL

Biomass O&M






Photos by Randy Hunsberger, NREL

Fuel Supply Greatly Affects O&M

- Biomass equipment needs clean fuel
  - Not landscape mulch
  - Not animal bedding
  - Not playground chips
- Biomass fuel suppliers may change
  - Know what your plant needs
  - Inspect new suppliers for quality

Biomass Operators

- Skilled plant operating staff
- Operators monitor a clean fuel supply chain
  - Harvesting biomass
  - Processing into fuel
  - Storage
  - Consistent delivery
  - Plan for a backup fuel source
- Maintain machinery

Biomass Warranties

- Best warranty is guaranteed performance (also most expensive since vendor bears all risk)
- Warranties should cover premature failure of machinery
- Most industrial equipment carries a one-year warranty
- Make sure warranty period begins at startup, not receipt of equipment

Biomass Maintenance

Machinery maintenance:

- Build a maintenance plan with equipment sales team
- Verify O&M plan fulfills all warranty obligations
- Schedule regular maintenance according to your biomass equipment needs
- Contract a maintenance plan for multiple years if possible
- Budget annually for scheduled maintenance

Biomass O&M Case Study on Fuel Supply Failure

- Business plan assumed $38/ton biomass fuel
- Boiler could not tolerate low-grade fuel
- Cost to upgrade fuel exceeded budget at $75 to $100 per ton
- Locate biomass fuel you can afford *first!*
  - Key question: Is it available for life of project?
- ***Then*** choose combustion equipment

Biomass O&M Key Takeaways

- Include O&M budgets and schedules early in the planning process
- Be realistic about fuel costs
- Fuel supply quality should be closely monitored by plant operators with authority to reject loads
- Warranties should cover motors, drivers, controllers, and as many moving parts as possible, regardless of multiple vendors
- Clean fuel and machinery maintenance will determine system performance

Project Risk: - Commercial-Scale

Phases	Risks	Risk Assessment Post Step 5	✓
Development	• Poor or no renewable energy resource assessment	Low; site picked	✓
	• Not identifying all possible costs	Low; detailed model	✓
	• Unrealistic estimation of all costs	Low; detailed model	✓
	• Community push-back and competing land use	None; addressed	✓
Site	• Site access and right of way	None; site secure	✓
	• Not in my backyard (NIMBY)/build absolutely nothing anywhere (BANANA)	None; opposition addressed	✓
	• Transmission constraints/siting new transmission	None; addressed	✓
Permitting	• Tribe-adopted codes and permitting requirements	Low; complete	✓
	• Utility interconnection requirements	Low; complete	✓
	• Interconnection may require new transmission, possible NEPA	None; complete	✓
Finance	• Capital availability	None; finalized	✓
	• Incentive availability risk	None; finalized	✓
	• Credit-worthy purchaser of generated energy	None; finalized	
Construction/ Completion	• EPC difficulties	None; contracted	✓
	• Cost overruns	None; construction complete	✓
	• Schedule	Complete	✓
Operating	• Output shortfall from expected	<u>Being managed by appropriate party</u>	✓
	• Technology O&M, cost of O&M		
	• Maintaining transmission access and possible curtailment		

*NOTE: Underlining signifies that the risk assessment outcome changes during the step at hand.

Adapted from Holland & Hart, RE Project Development & Finance & Infocast, Advanced RE Project Finance & Analysis

Not Quite Done!

- Check back in with planning document—update as necessary
- Identify next potential project from plan

Summary of Actions by Step

Step 1: Gather all relevant data in order to make first pass at potential project, understand tribal role options

Step 2: Estimate value to Tribe, consider ownership approach, begin to identify off-takers, partners, vendors, begin planning permitting and site use

Step 3: Finalize economic assumptions and tribal roles, finalize permitting, interconnection, transmission and off-take agreements, and determine financial partnerships, ownership structure

Step 4: Finalize agreements (including vendor contracting); financial close and construction; project commissioning, begin operation

Celebrate!

Step 5: Maintenance plan implementation (conduct or ensure ongoing O&M)

Wrap-Up: Project Development Process