PV Reliability and Durability
Perspectives from SETO
Lenny Tinker
PV R&D Program Manager
Solar Energy Technologies Office
Solar Energy Technologies Office

**WHAT WE DO**

The Solar Energy Technologies Office funds research and development in three technology areas: photovoltaics, concentrating solar power, and systems integration with the goal of improving the **affordability**, **reliability**, and **performance** of solar technologies on the grid.

**HOW WE DO IT**

- Cutting-edge **technology development** that drives U.S. leadership and supports a growing and skilled workforce.
- Research and development to **address integration of solar** to the nation’s electricity grid.
- **Relevant and objective technical information** on solar technologies to stakeholders and decision-makers.
# Solar Energy Technologies Office Budget

<table>
<thead>
<tr>
<th>SETO SUBPROGRAM</th>
<th>2016 ($K)</th>
<th>2017 ($K)</th>
<th>2018 ($K)</th>
<th>2019 ($K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrating Solar Power</td>
<td>$48,400</td>
<td>$55,000</td>
<td>$55,000</td>
<td>$55,000</td>
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<tr>
<td>Photovoltaic R&amp;D</td>
<td>$53,152</td>
<td>$64,000</td>
<td>$70,000</td>
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<td>Systems Integration</td>
<td>$52,447</td>
<td>$57,000</td>
<td>$71,200</td>
<td>$54,500</td>
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<tr>
<td>Balance of Systems (Soft Costs)</td>
<td>$34,913</td>
<td>$15,000</td>
<td>$11,000</td>
<td>$35,000</td>
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<tr>
<td>Innovations in Manufacturing (Technology to Market)</td>
<td>$43,488</td>
<td>$16,600</td>
<td>$34,400</td>
<td>$30,000</td>
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<tr>
<td>NREL Facility Support</td>
<td>$9,200</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$241,600</strong></td>
<td><strong>$207,600</strong></td>
<td><strong>$241,600</strong></td>
<td><strong>$246,500</strong></td>
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SETO’s Budget... vs. Pet Halloween Costumes

2016 EERE budget in millions
Total: $2.1 billion

Wait, Americans Spend How Much on Halloween?
The National Retail Federation estimates that people will cough up $350 million just on Halloween costumes—for their pets.
SETO invests in innovative research efforts that securely integrate more solar energy into the grid, enhance the use and storage of solar energy, and lower solar electricity costs.

*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010-17.*
50% More Solar by 2030 at $0.03 per kWh

* The solar-storage synergy: As solar costs come down and deployment increases, the market potential for storage grows. At the same time, as storage costs decline and deployment increases, the value of solar to the grid increases. Energy can be dispatched as needed.
A Pathway To 3 Cents per kWh for Utility PV

100 MWp One-Axis Tracking Systems With 1,860 kWh/kWp/kWh, First-Year Performance. Includes 5 Year MACRS. Horizontal Lines Indicate Low, Median, and High U.S. Solar Resources.
A Pathway To 3 Cents per kWh for Utility PV

Improve upon today’s best-in-class reliability in low-cost modules.
Example 1: Glass polymer modules can transition to more durable glass-glass module construction.
Example 2: New accelerated testing methods to provide rapid feedback to guide improvements in module durability.

2017 Real LCOE (U.S. Cents/kWh)

- Seattle, WA (7.3¢)
- Kansas City, MO
- Daggett, CA
- Daggett, CA w/ITC

2017 Benchmark
- Lower Module Price: $0.35 to $0.25/W
- Lower Balance of System Hardware and Soft Costs: $0.75 to $0.50/W
- Improve Lifetime 30 to 50 years; Lower Degradation Rate: 0.75% to 0.2%
- Lower O&M: $14 to $4/kW-year

SunShot 2030 Utility Goal

100 MWp One-Axis Tracking Systems With 1,860 kWh/MWhp First-Year Performance. Includes 5 Year MACRS. Horizontal Lines Indicate Low, Median, and High U.S. Solar Resources.
There are Many Technology Pathways

- Cost and performance tradeoffs open up numerous possible pathways.
- All pathways require sustained, multifaceted innovation.

<table>
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<tr>
<th>Module Price ($/Wdc)</th>
<th>Total-Area Module Efficiency</th>
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<tbody>
<tr>
<td></td>
<td>10%</td>
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<td></td>
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<td>35%</td>
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<td>40%</td>
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All curves represent 3¢/kWh LCOE in average U.S. climate

Scenarios assume: 7% WACC, 2.5% inflation, $4/kW-yr O&M, 21% capacity factor

2030 Example Scenario, 50 yr life
30 yr life
1%/yr degradation, 20 yr life

www.energy.gov/eere/solar/sunshot-2030
SETO PV Research Funding Allocation (December 2019)

- **National Lab**: $115M (61%)
- **University**: $56M (30%)
- **Industry**: $15M (8%)
- **Non-Profit**: $2.5M (1%)

**SECTOR**
- **Reliability / Bankability**: 40%
- **Cell**: 40%
- **Advanced Characterization**: 9%
- **Academic Consortia**: 4.5%
- **Module**: 4%
- **System Design**: 1.5%
- **Supply Chain**: 1%
- **Other**: <0.1%
PV Reliability Funding by Topic (December 2019)

~$80M total for projects spanning 3-5 years

Fielded Performance Data Gathering and Analytical Tools (31%)

Accelerated Testing and Standards (49%)

New Durable Modules (20%)
PV Reliability Funding by Topic (December 2019)

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First, to be clear: PV modules are durable

Silicon Modules

Median: 0.5 %/year
Average: 0.7 %/year
# reported rates = 1751

First, to be clear: PV modules are durable

Is the degradation linear?
Is the degradation linear?
Is the degradation linear?
Is the degradation linear? – Characterize Distributions

DOE PV Fleet Performance Data Initiative

RdTools used to calculate annual degradation rates and confidence intervals from time-series performance data

PV Plant Power Data

State-of-the-Art System & Degradation Rate Analysis

Anonymized and Added to Aggregate Long-Term PV System Performance Benchmark

Performance Report to PV Data Owner

Open-access Data Sets


energy.gov/solar-office
DOE PV Fleet Performance Data Initiative

What data is needed?

- **Time-series PV system power output** for large-scale installations (>250 kW) for ≥ 5 years collected at 1-15 min intervals, with
- **On-site irradiance and meteorological data**
- **“Metadata”** (type of PV modules, location, mounting, azimuth and tilt)

- Detailed Data Partner document will be provided.
- Available public data sets will be incorporated if data meets the requirements. Pointers to those are appreciated.

**Confidentiality** of data protected via standardized NREL-approved NDA agreements and negotiated anonymization procedure, in progress.

Accelerated Degradation Testing

Image: *Infrastructure: Last Week Tonight with John Oliver*
We Have Minimal Data on 20+ Year Durability

Deployment is expected to double in the next 3-5 years

73% of installed capacity deployed in the past 5 years

Source: BNEF
energy.gov/solar-office
Accelerated Degradation Testing

- Accelerated aging 100°C, 5 minutes
- Shelf-life aging 25°C, 30 days
- Henshous aging 30 days

400F for ~30 min

Microwave on high for 4 minutes

Food Network recipe for microwaved bread

Image: John Wohlgemuth, SunShot Grand Challenge Summit and Peer Review 2014, Anaheim, CA
Unsurprisingly... Different modules behave differently

Extended thermal cycling from -40C to 85C

PVEL 2019 PV Module Reliability Scorecard, https://www.pvel.com

energy.gov/solar-office
And sequential tests don’t fully simulate real-word exposure

NREL Combined Accelerated Stress Testing (C-AST)

Peter Hacke DuraMat Monthly Webinar 5/13/19
NREL/PR-5K00-73984
But well-designed tests do give insight into lifetime

Example: Increasing thermal cycle temperature to accelerate solder bond failure

- 200 thermal cycles doesn’t fully simulate field stress but don’t want to extend test
- Finite element modeling analyses on the rate of solder fatigue reveals that the number of thermal cycles can be reduced by increasing the maximum cycle temperature
- Leads to Committee Draft on IEC 62892 ED. 1 "Extended Thermal Cycling of PV Modules - Test Procedure" in review by IEC TC82/WG2

https://www.pvqat.org/project-status/task-group-2.html
energy.gov/solar-office
PV Quality Assurance Task Force (PVQAT)

The International PV Quality Assurance Task Force (PVQAT, "PV cat") leads global efforts to craft quality and reliability standards including:

- **MODULE DURABILITY**: A rating system to ensure durable design of PV modules for the climate and application of interest. [Progress Update]
- **MANUFACTURING CONSISTENCY**: A guideline for factory inspections and quality assurance (QA) during module manufacturing. [Progress Update]
- **SYSTEM VERIFICATION**: A comprehensive system for certification of PV systems, verifying appropriate design, installation, and operation. [Progress Update]

www.pvqat.org
Reliable 50-year Modules?
DuraMat: Durable Module Materials Consortium

- Brings national laboratory and university infrastructure together with photovoltaic (PV) supply chain and manufacturing industry to accelerate development of durable packaging materials and technology transfer.
- Industry Advisory Board guides strategic and technical direction of consortium.

### Capability Network

<table>
<thead>
<tr>
<th>DuraMAT Projects</th>
<th>Data Management &amp; Analysis</th>
<th>Predictive Simulation</th>
<th>Materials Forensics</th>
<th>Module Phototyping &amp; Test</th>
<th>Outdoor Testing</th>
<th>Techno-economic Analysis</th>
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<tr>
<td>DataHub</td>
<td>Multi-scale Module Simulation</td>
<td>Material Properties and Aging</td>
<td>Accelerated Testing</td>
<td>Non-Destructive Testing</td>
<td>Quantify LCOE</td>
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<tr>
<td>PVD/DAQ Upgrade</td>
<td>Flexible Modules</td>
<td>Barrier and Encapsulants</td>
<td>ECA and Contacts</td>
<td>Wind Loading and Structural Materials</td>
<td>Financial Modeling</td>
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<tr>
<td>Data Visualization</td>
<td>Materials Selection</td>
<td>Cell Cracking</td>
<td>Module Design and Fabrication</td>
<td>Circular Economy</td>
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<td>Front Coating</td>
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Combining accelerated stress testing at NREL to identify PV degradation modes.

[energy.gov/solar-office](https://www.duramat.org/)
A Quick Recap

- System lifetime is a large lever on LCOE but must be reliable and financeable
- Most of global fleet is young and technologies are continually changing
- PV deployment is accelerating and the industry needs to be able to predict, understand, and mitigate degradation
- We need performance data, acceleration protocols, and advanced modules to extend the bankable 25 year service life
Ways to Stay in Touch

SETO newsletters highlight the key activities, events, funding opportunities, and publications that the solar program has funded.

SIGN UP NOW:
energy.gov/solar-newsletter

SETO quarterly stakeholder webinars discuss SETO’s priorities, as well as provide information on current and upcoming activities.

Visit energy.gov/seto-webinars

Or just email me: lenny.tinker@ee.doe.gov!
QUESTIONS?