U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

PV Reliability and Durability

Perspectives from SETO

Lenny Tinker

PV R&D Program Manager

Solar Energy Technologies Office

energy.gov/solar-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.

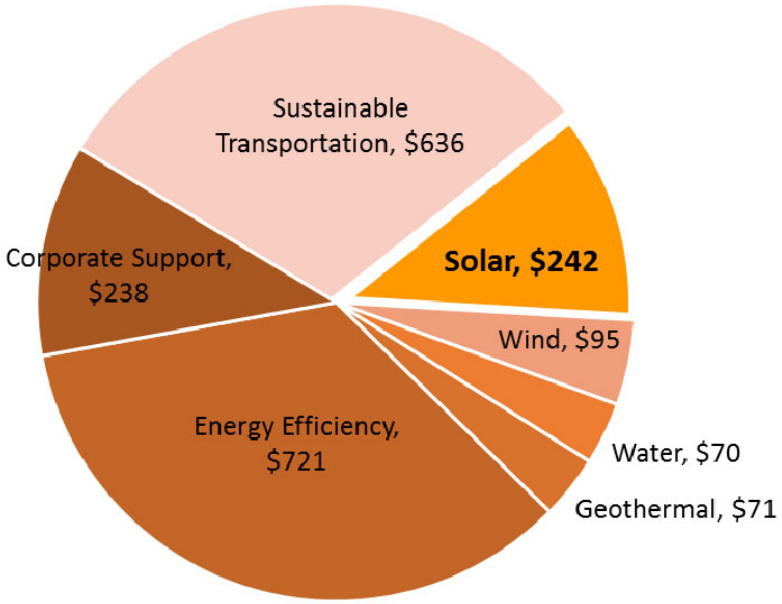
Research and development to **address integration of solar** to the nation's electricity grid.

Relevant and objective technical information on solar technologies to stakeholders and decision-makers.

Solar Energy Technologies Office Budget

SETO SUBPROGRAM	2016 ($K)	2017 ($K)	2018 ($K)	2019 ($K)
Concentrating Solar Power	$48,400	$55,000	$55,000	$55,000
Photovoltaic R&D	$53,152	$64,000	$70,000	$72,000
Systems Integration	$52,447	$57,000	$71,200	$54,500
Balance of Systems (Soft Costs)	$34,913	$15,000	$11,000	$35,000
Innovations in Manufacturing (Technology to Market)	$43,488	$16,600	$34,400	$30,000
NREL Facility Support	$9,200			
TOTAL	**$241,600**	**$207,600**	**$241,600**	**$246,500**

SETO's Budget… vs. Pet Halloween Costumes



2016 EERE budget in millions

Total: $2.1 billion

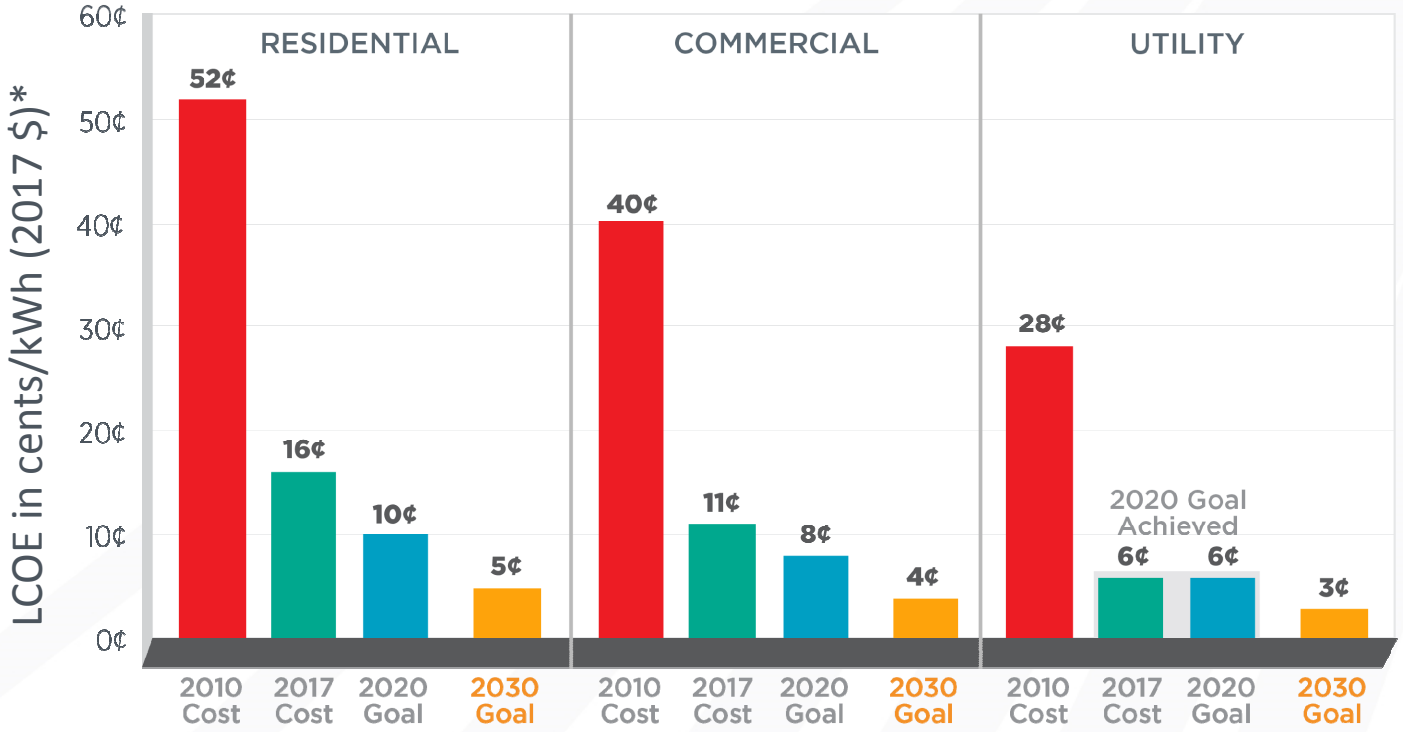
Wait, Americans Spend How Much on Halloween?

The National Retail Federation estimates that people will cough up $350 million just on Halloween costumes—for their pets.

Pets Adviser/Flickr

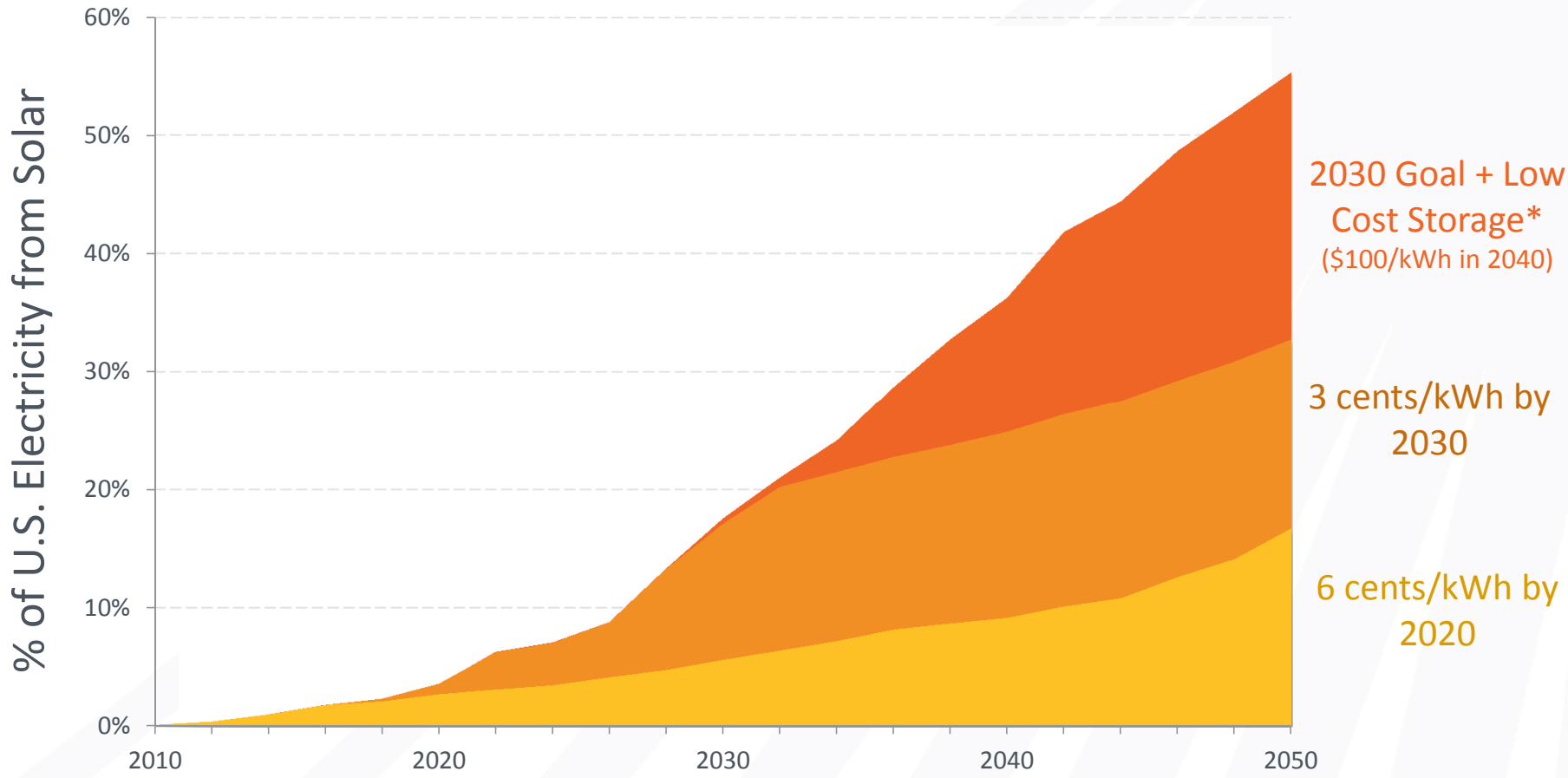
Progress and Goals: 2030 Photovoltaics Goals

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.



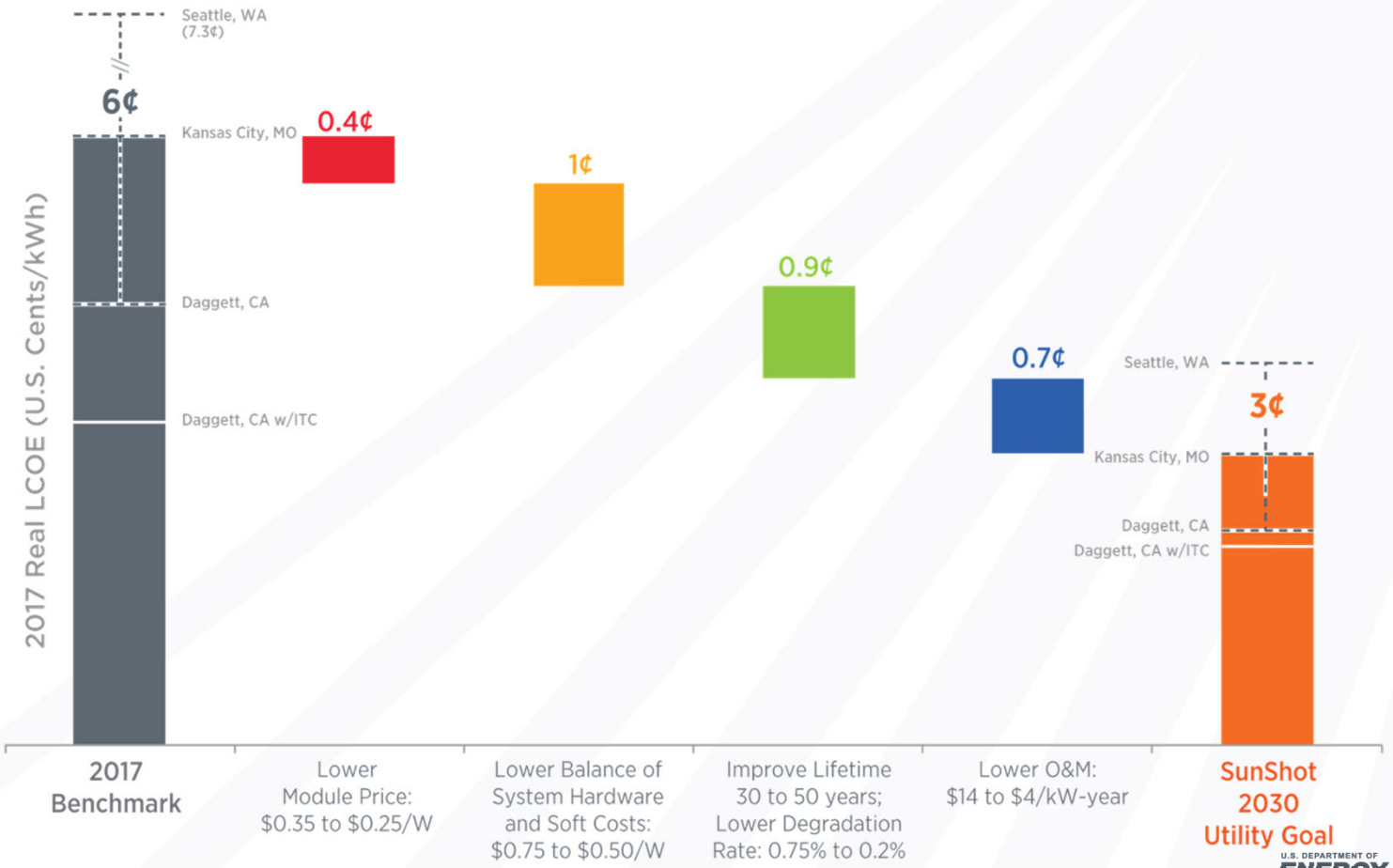
*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010-17.

50% More Solar by 2030 at $0.03 per kWh



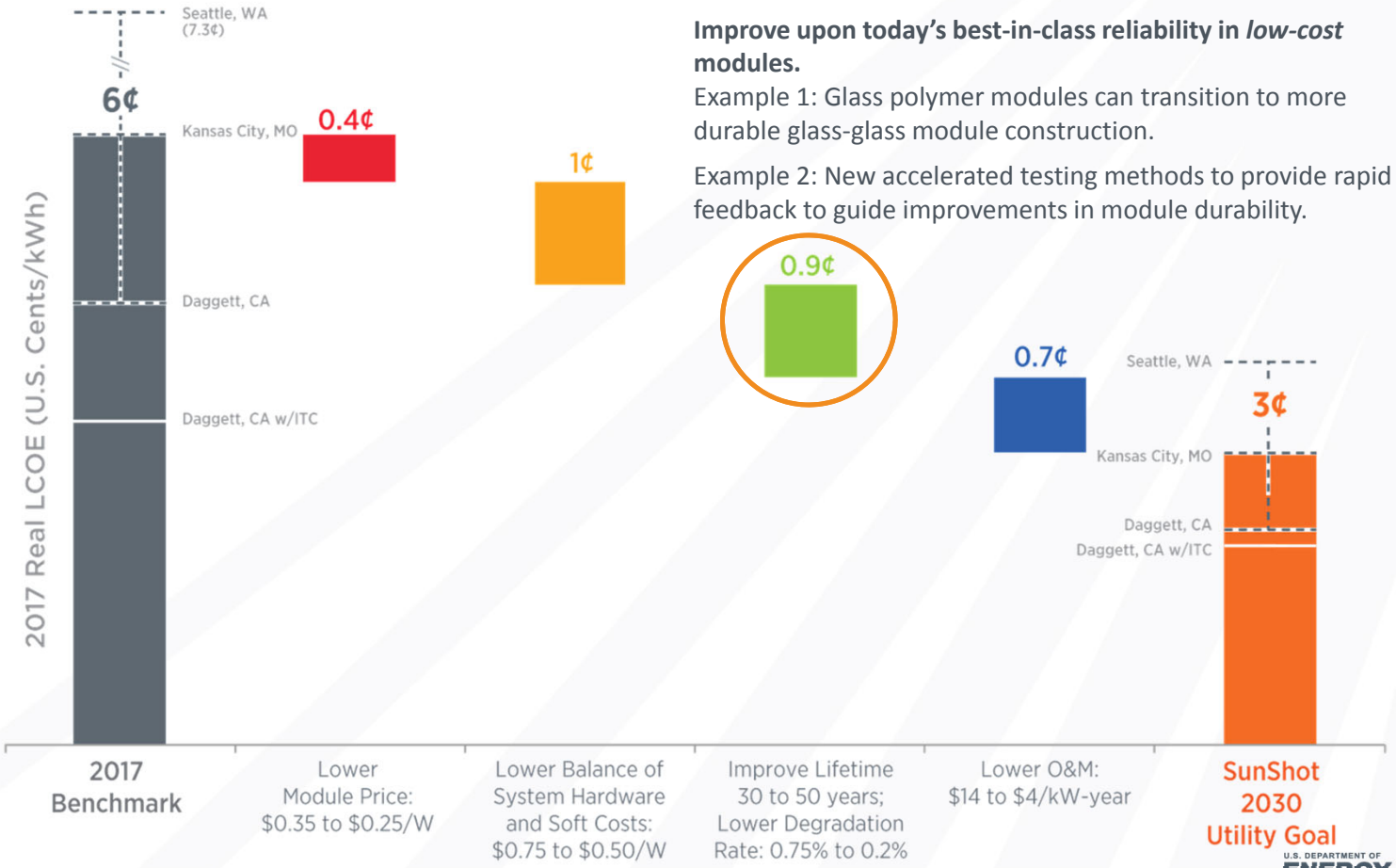
* The solar-storage synergy: As solar costs come down and deployment increases, the market potential for storage grows. At the same time, as storage costs decline and deployment increases, the value of solar to the grid increases. Energy can be dispatched as needed.

A Pathway To 3 Cents per kWh for Utility PV



100 $MW_{(DC)}$ One-Axis Tracking Systems With 1,860 $kWh_{(AC)}/kW_{(DC)}$ 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.

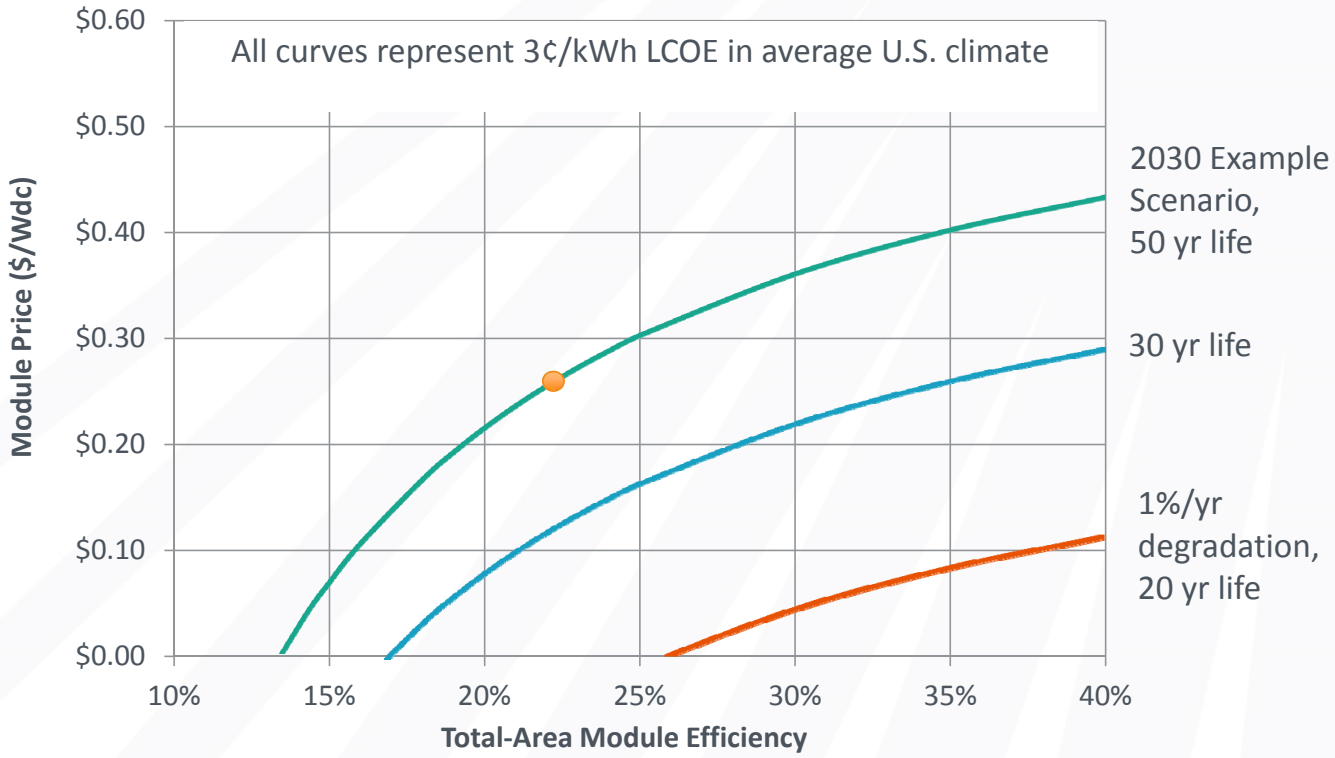
Example 1: Glass polymer modules can transition to more durable glass-glass module construction.

Example 2: New accelerated testing methods to provide rapid feedback to guide improvements in module durability.

100 $MW_{(DC)}$ One-Axis Tracking Systems With 1,860 $kWh_{(AC)}/kW_{(DC)}$ First-Year Performance.
Includes 5 Year MACRS. Horizontal Lines Indicate Low, Median, and High U.S. Solar Resources.

There are Many Technology Pathways

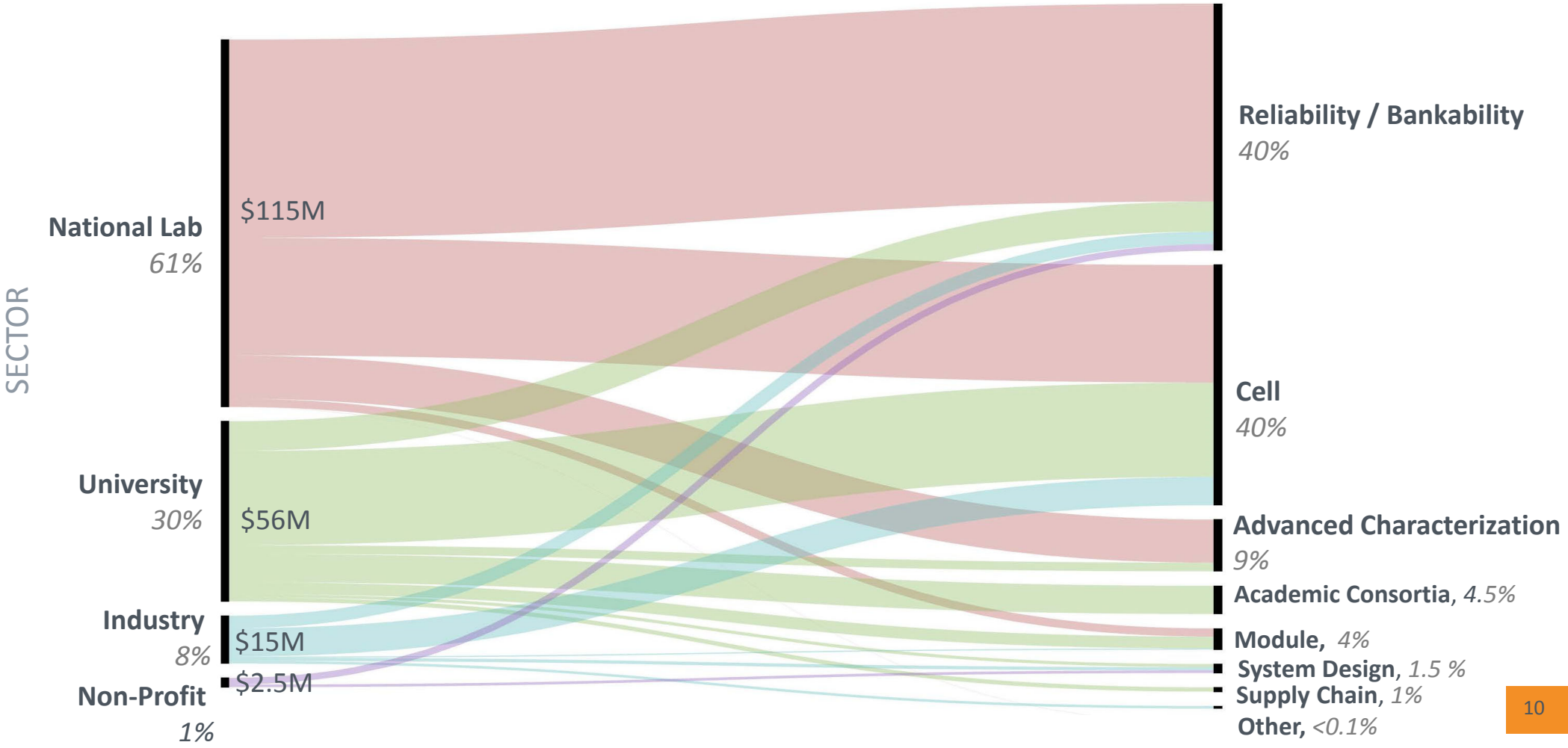
- Cost and performance tradeoffs open up numerous possible pathways.
- All pathways require sustained, multifaceted innovation.



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

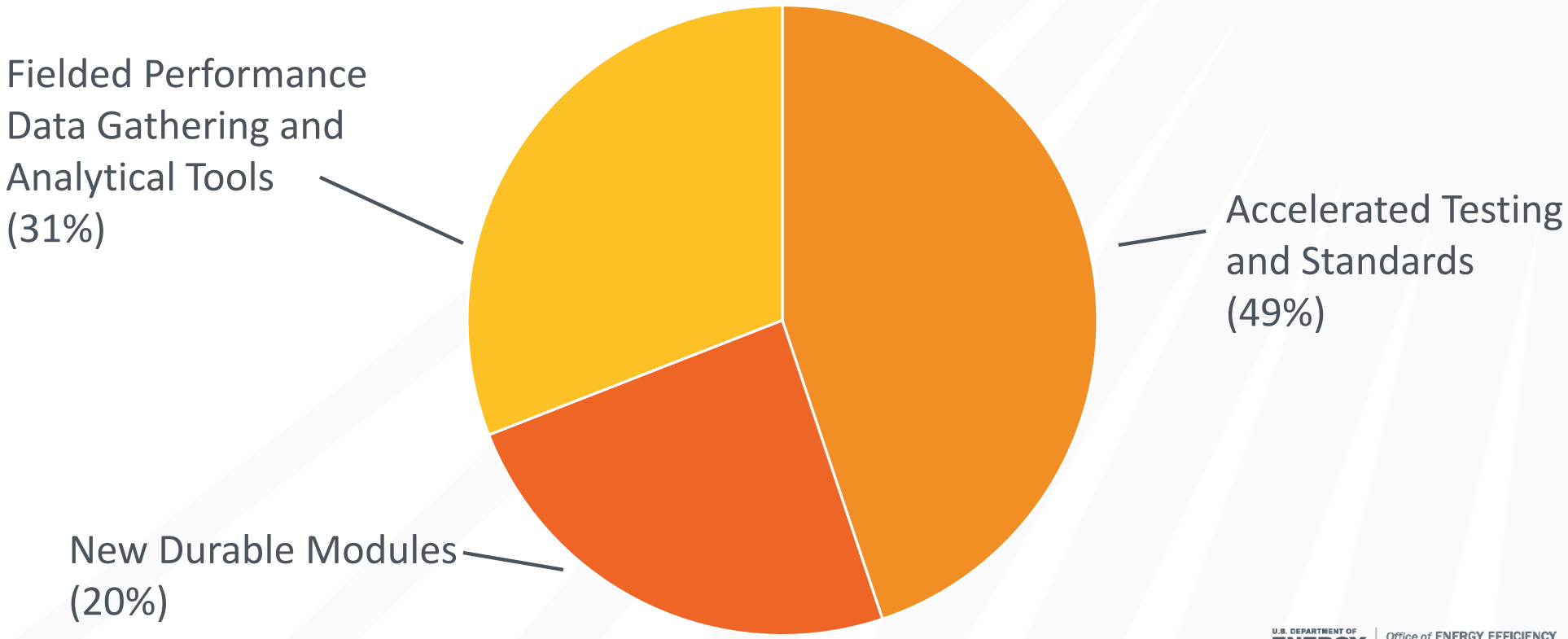
www.energy.gov/eere/solar/sunshot-2030

SETO PV Research Funding Allocation (December 2019)



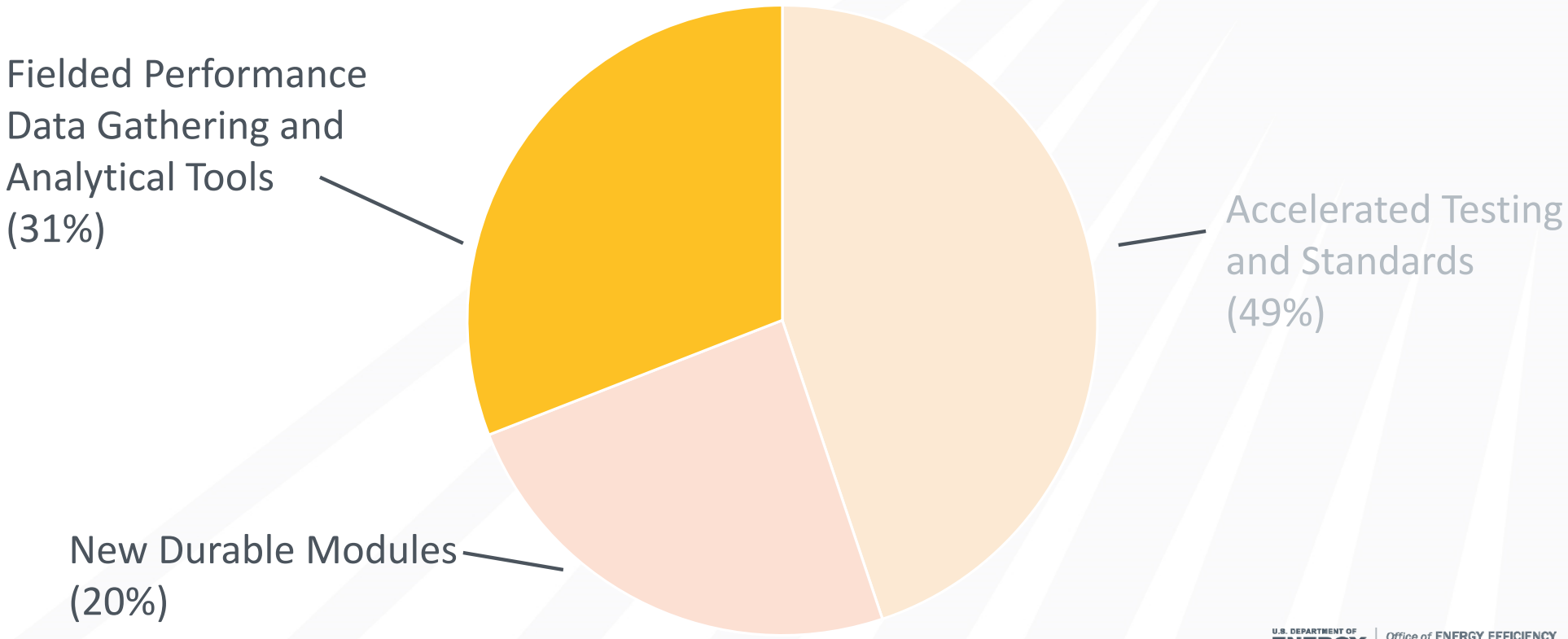
PV Reliability Funding by Topic (December 2019)

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



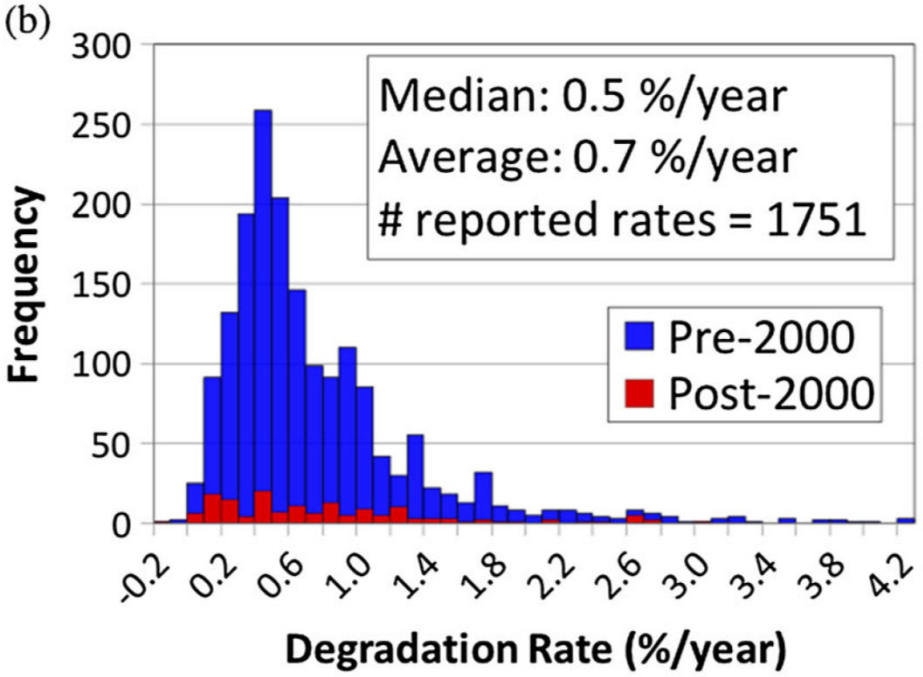
PV Reliability Funding by Topic (December 2019)

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



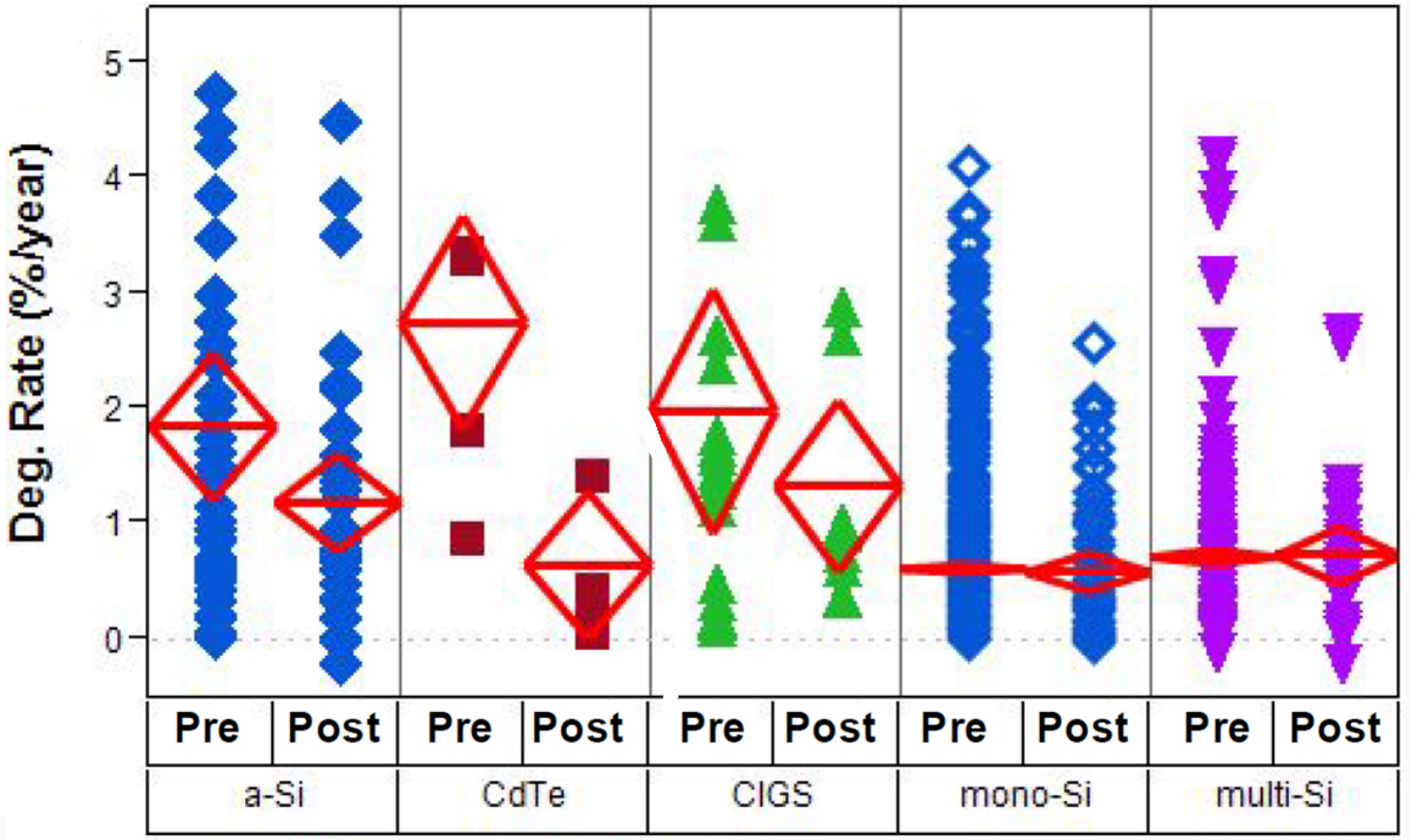
First, to be clear: PV modules are durable

Silicon Modules



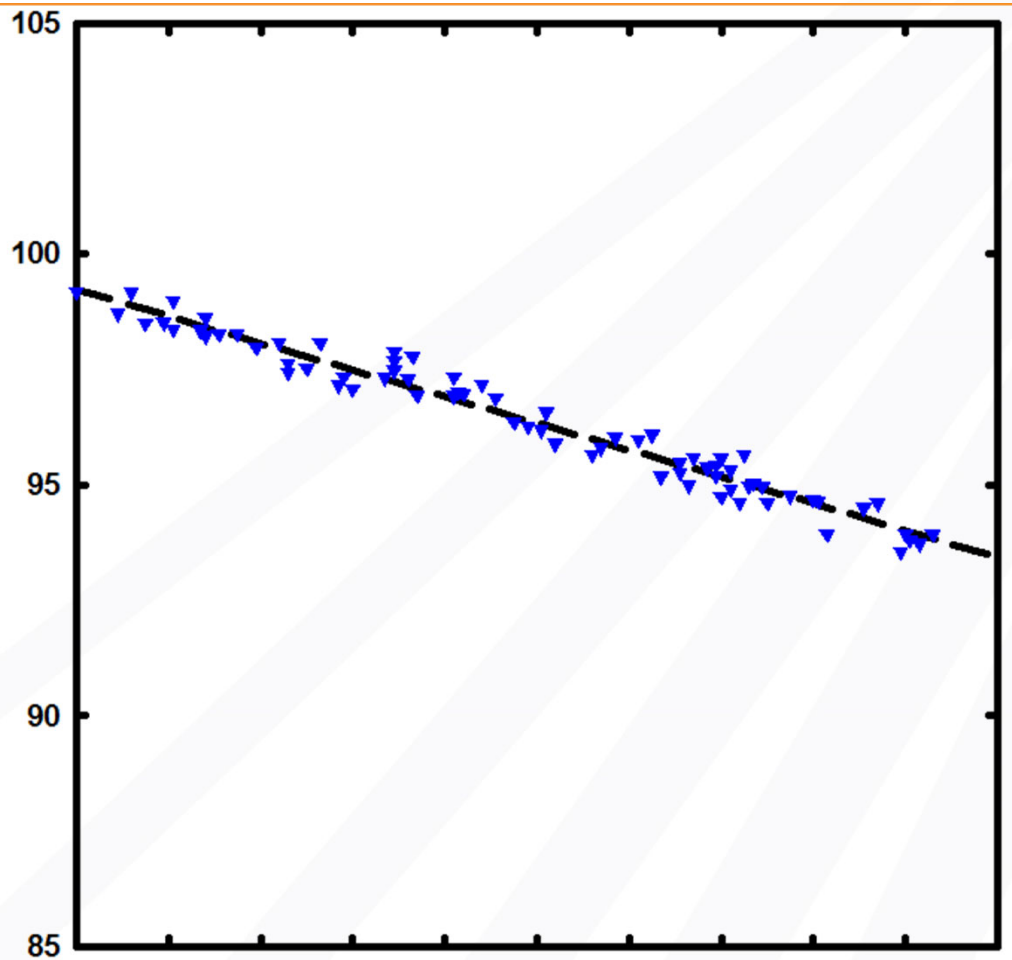
Jordan, D.C.; Kurtz, S.R. "Photovoltaic Degradation Rates—an Analytical Review", Prog. Photovolt: Res. Appl. 2013; 21:12–29

First, to be clear: PV modules are durable

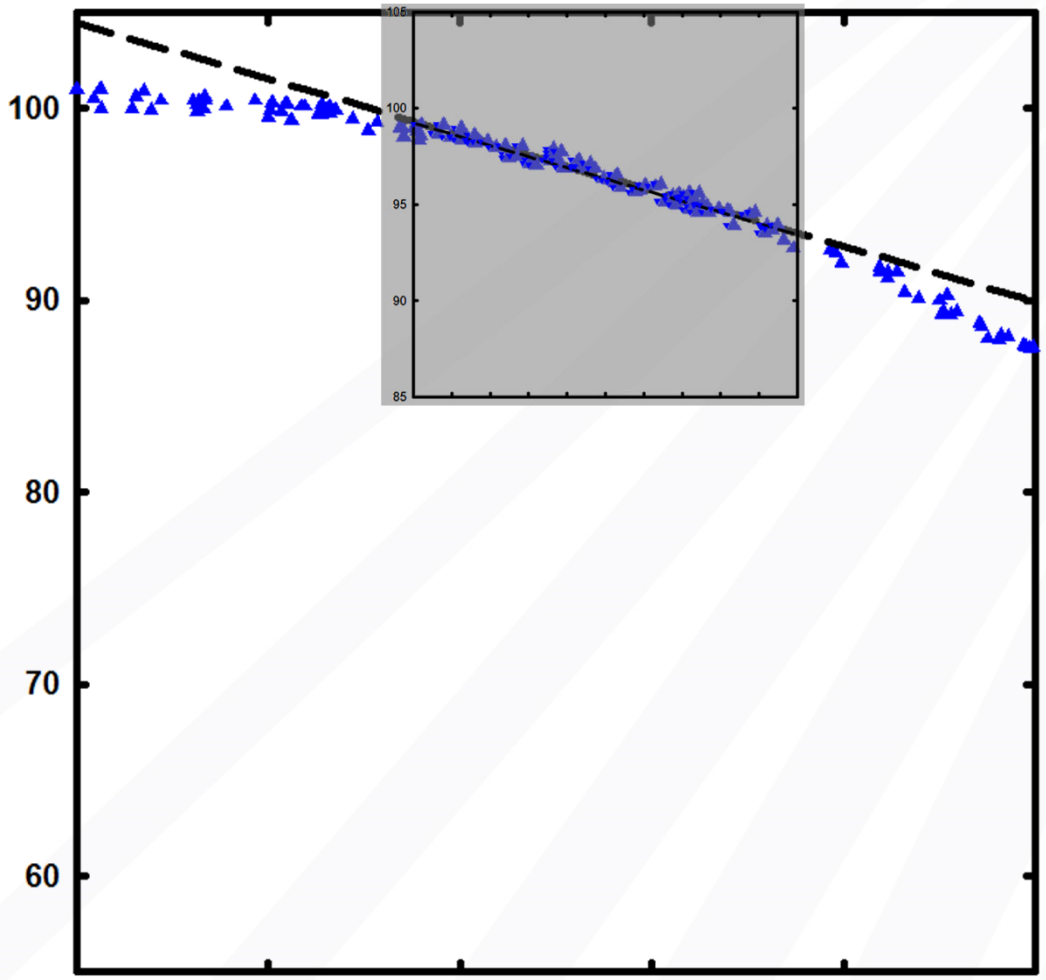


Jordan, D.C.; Kurtz, S.R. "Photovoltaic Degradation Rates—an Analytical Review", Prog. Photovolt: Res. Appl. 2013; 21:12–29

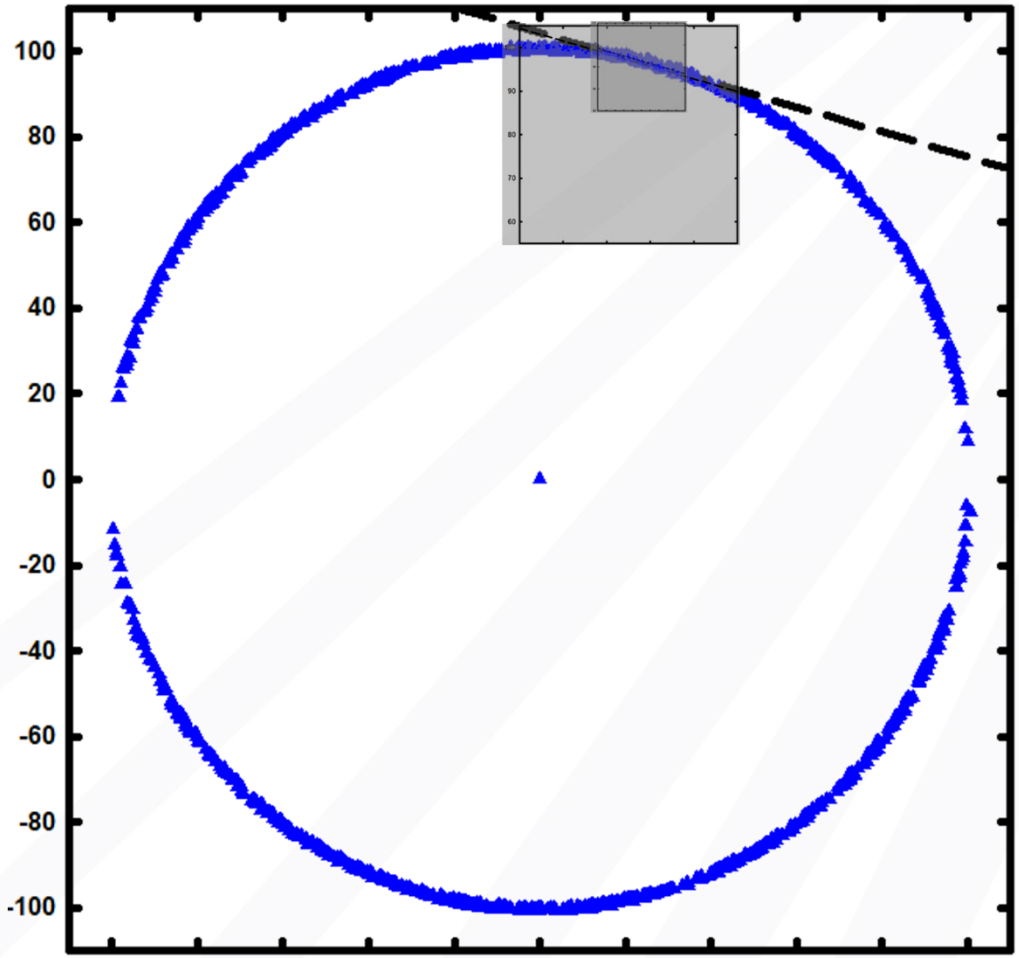
Is the degradation linear?



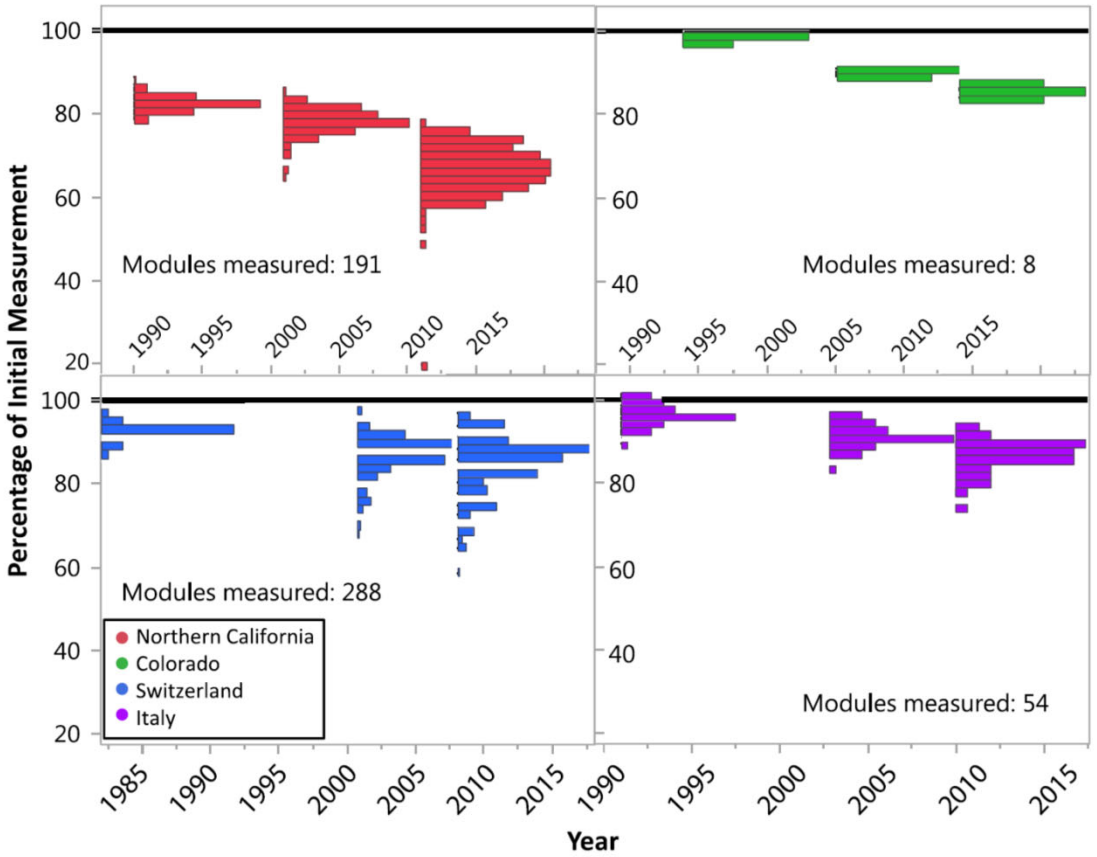
Is the degradation linear?



Is the degradation linear?

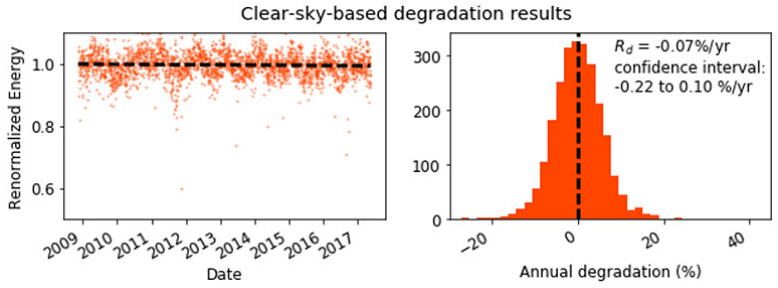


Is the degradation linear? – Characterize Distributions



Jordan, D. C.; Kurtz, S. R.; VanSant, K. and Newmiller, J., "Compendium of photovoltaic degradation rates", Prog. Photovolt: Res. Appl. 2016; 24:978–989

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

CONFIDENTIAL

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

Anonymized

Performance Report to PV Data Owner

CONFIDENTIAL

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

PUBLISHED YEARLY

Open-access Data Sets

PUBLISHED

www.nrel.gov/pv/fleet-performance-data-initiative.html

DOE PV Fleet Performance Data Initiative

PV Plant Power Data

CONFIDENTIAL

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.

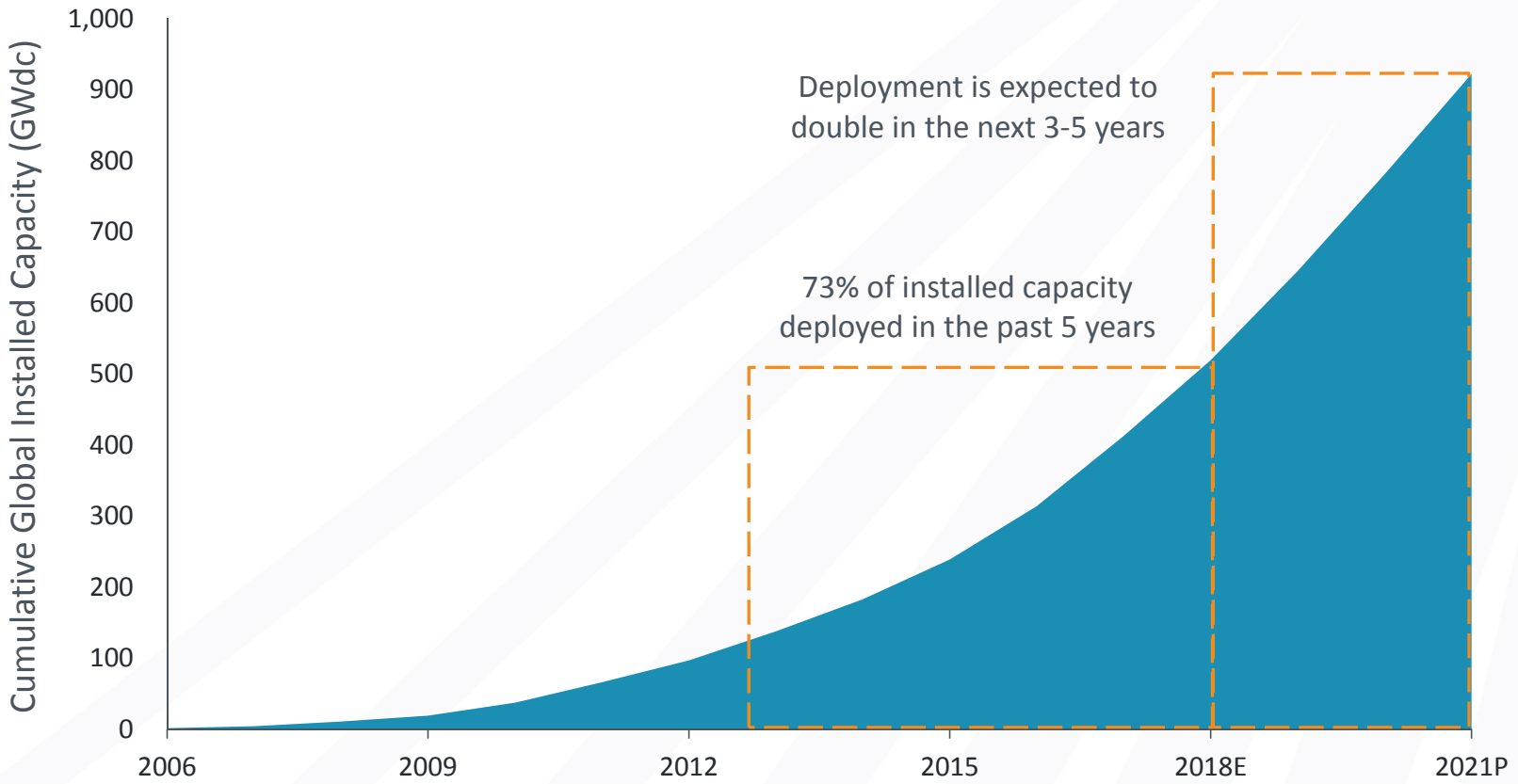
Confidentiality of data protected via standardized NREL-approved NDA agreements and negotiated anonymization procedure, in progress.

www.nrel.gov/pv/fleet-performance-data-initiative.html

Accelerated Degradation Testing

Image: *Infrastructure: Last Week Tonight with John Oliver*

We Have Minimal Data on 20+ Year Durability



Source: BNEF

energy.gov/solar-office

Accelerated Degradation Testing

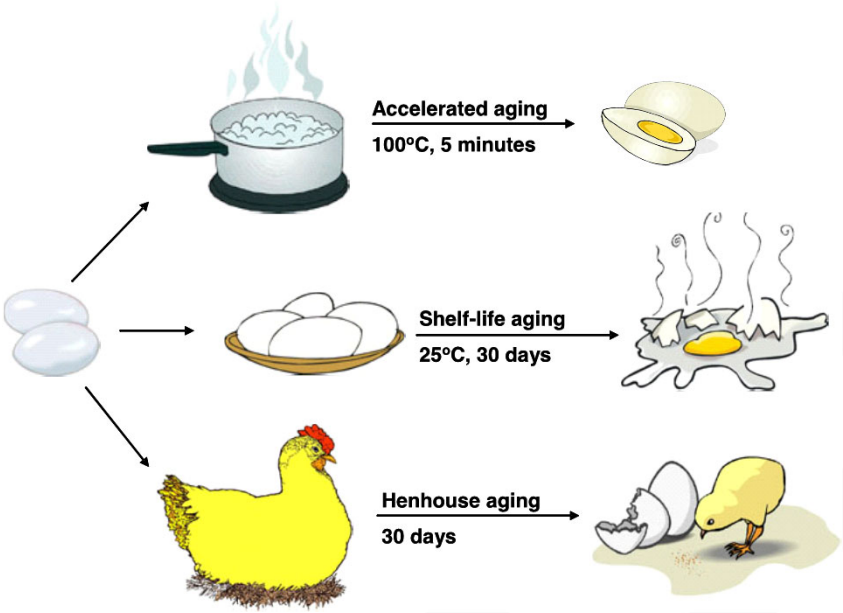


Image: John Wohlgemuth, SunShot Grand Challenge Summit and Peer Review 2014, Anaheim, CA

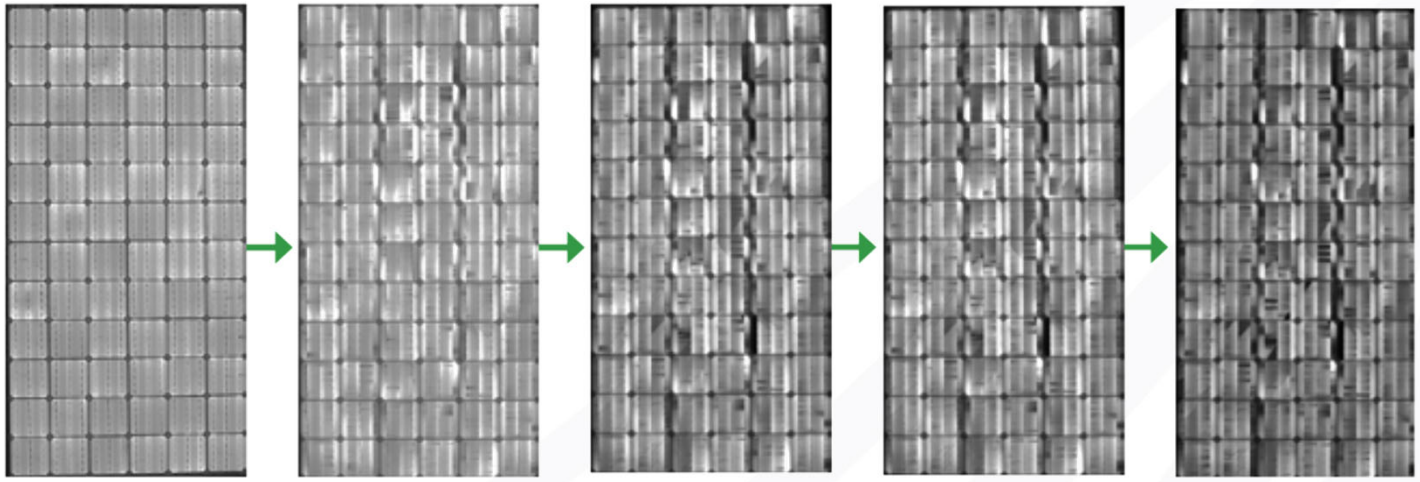
400F for ~30 min

Microwave on high for 4 minutes

Food Network recipe for microwaved bread

Unsurprisingly… Different modules behave differently

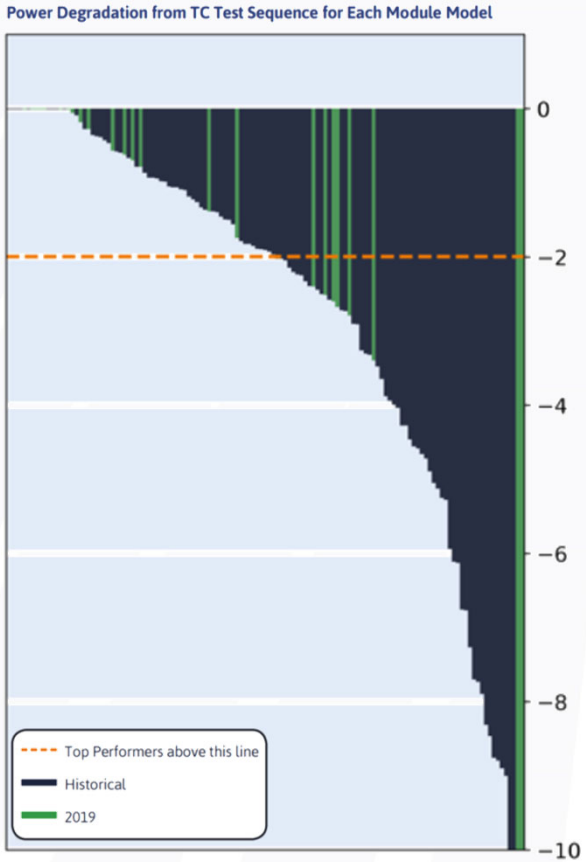
Extended thermal cycling from -40C to 85C



Initial TC200 TC400 TC600 TC800

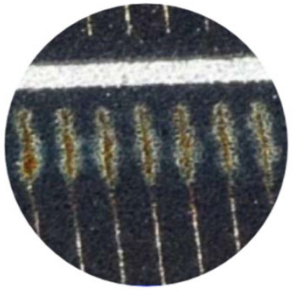
IEC 61215

PVEL 2018
and earlier



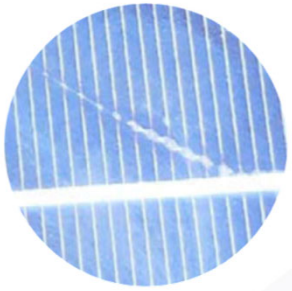
PVEL 2019 PV Module Reliability Scorecard, https://www.pvel.com

And sequential tests don't fully simulate real-word exposure



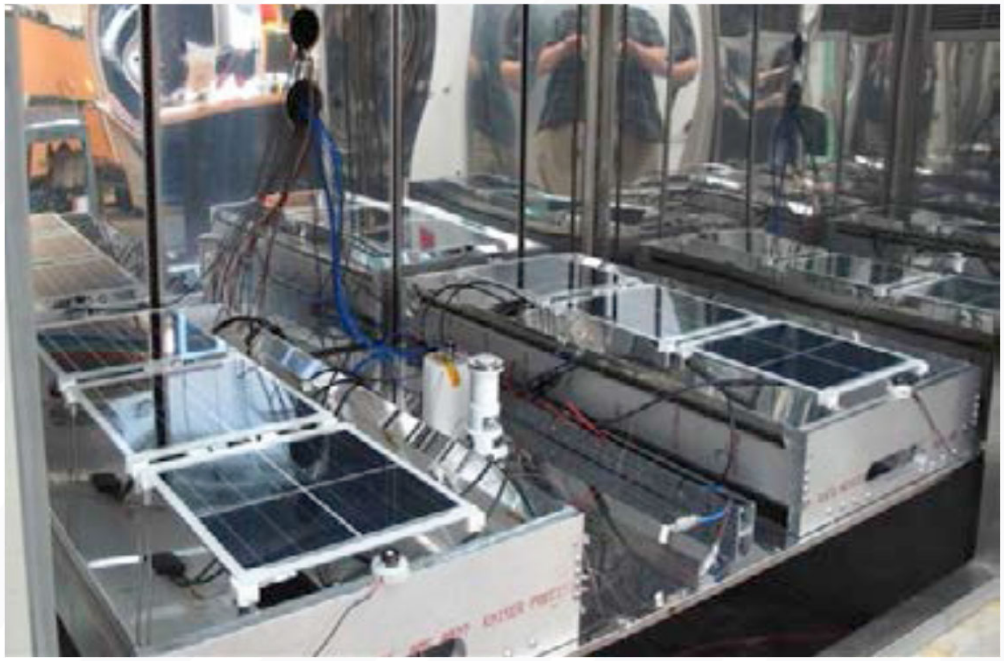
Corrosion

Voltage
Mechanical loading
Humidity
Light
High temperature
Temperature cycling



Delamination

Voltage
Mechanical loading
Humidity
Light
High temperature
Temperature cycling

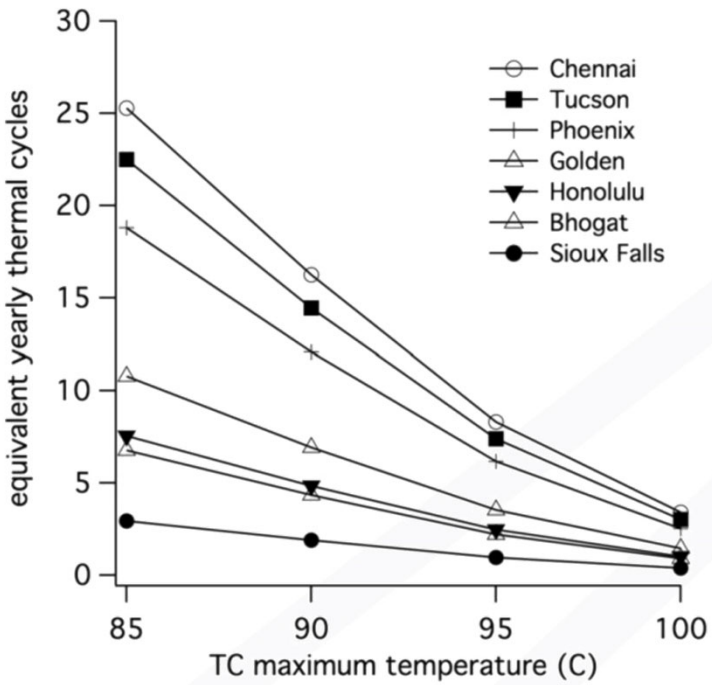


NREL Combined Accelerated Stress Testing (C-AST)

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

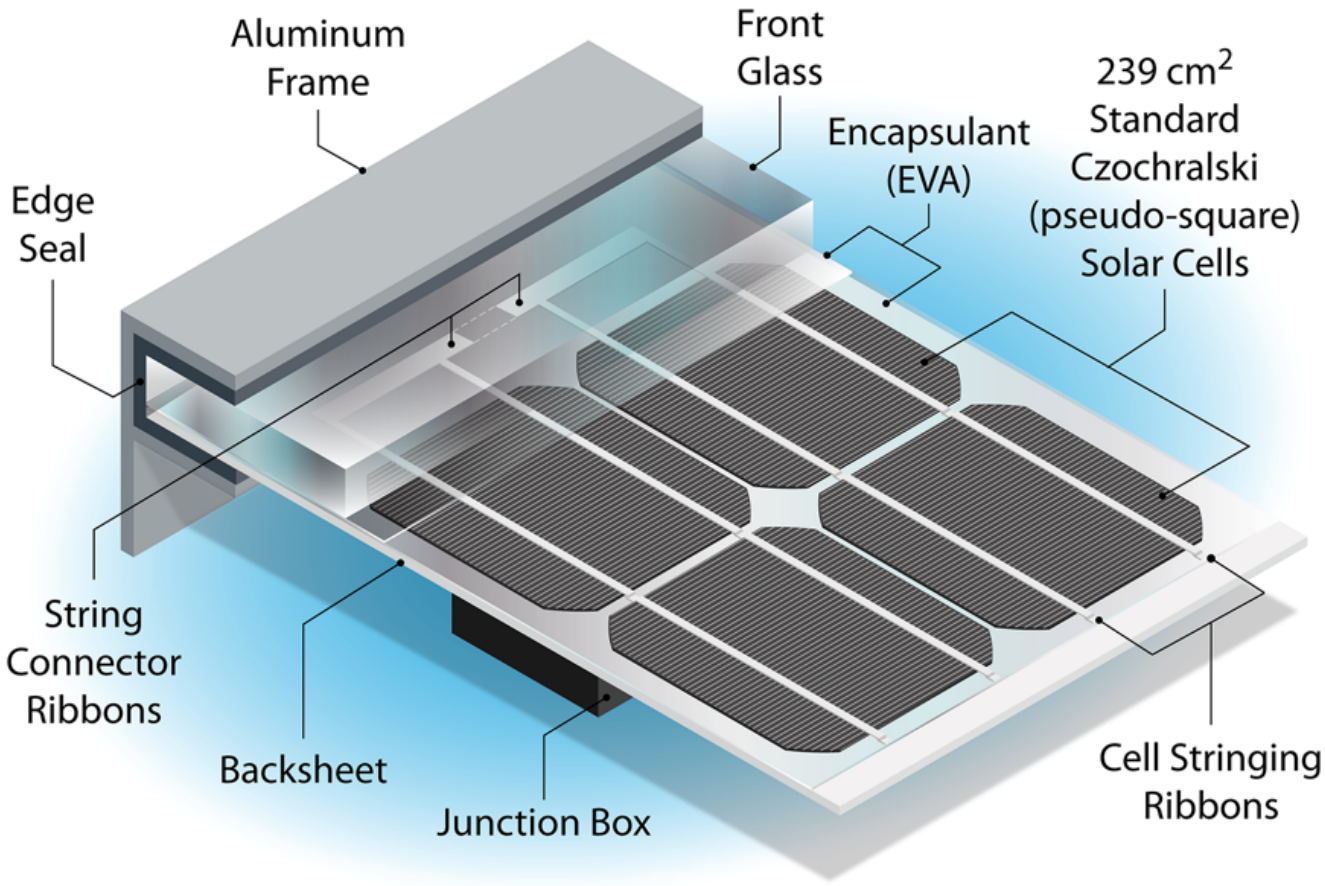
https://www.pvqat.org/project-status/task-group-2.html

Bosco, N.; , Silverman, T.; Kurtz, S., Microelectronics Reliability 62 (2016) 124–129

PV Quality Assurance Task Force (PVQAT)

www.pvqat.org

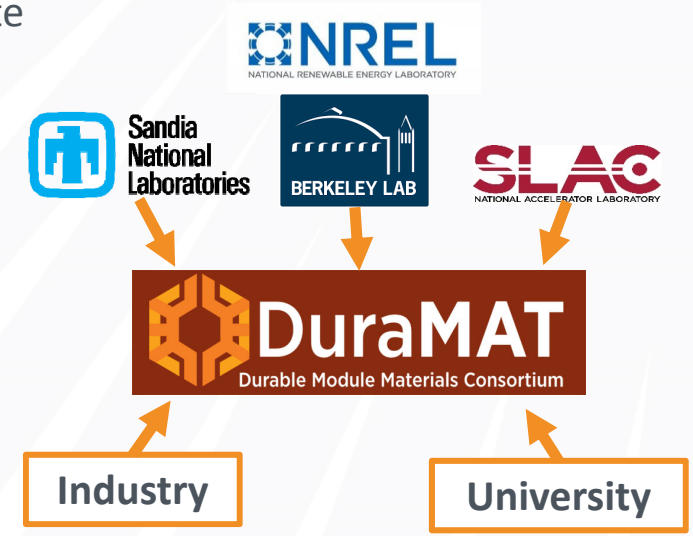
Reliable 50-year Modules?



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					
	Data Management & Analysis	Predictive Simulation	Materials Forensics	Module Phototyping & Test	Outdoor Testing	Techno-economic Analysis
DuraMAT Projects	DataHub	Multi-scale Module Simulation	Material Properties and Aging	Accelerated Testing	Non-Destructive Testing	Quantify LCOE
	Software Development and Machine Learning	Materials Modeling	Correlating Accelerated Testing and Field Data	UV Ionization Damage	Field Aged Module Library	Decision Support
	PVDAQ Upgrade	Flexible Modules	Barrier and Encapsulants	ECA and Contacts	Wind Loading and Structural Materials	Financial Modeling
	Data Visualization	Materials Selection	Cell Cracking	Module Design and Fabrication		Circular Economy
			Front Coating			



Combined accelerated stress testing at NREL to identify PV degradation modes

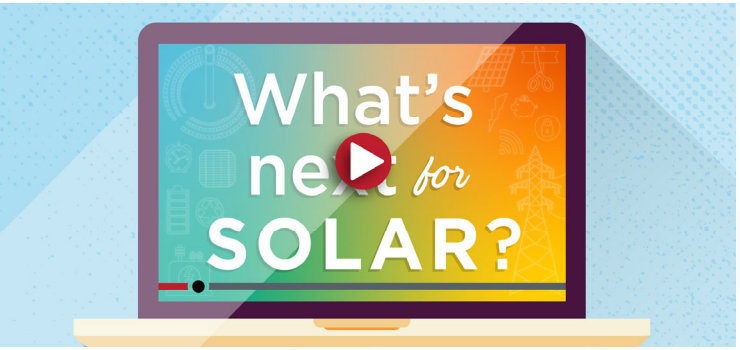
A Quick Recap

- 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?

QUESTIONS?