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SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

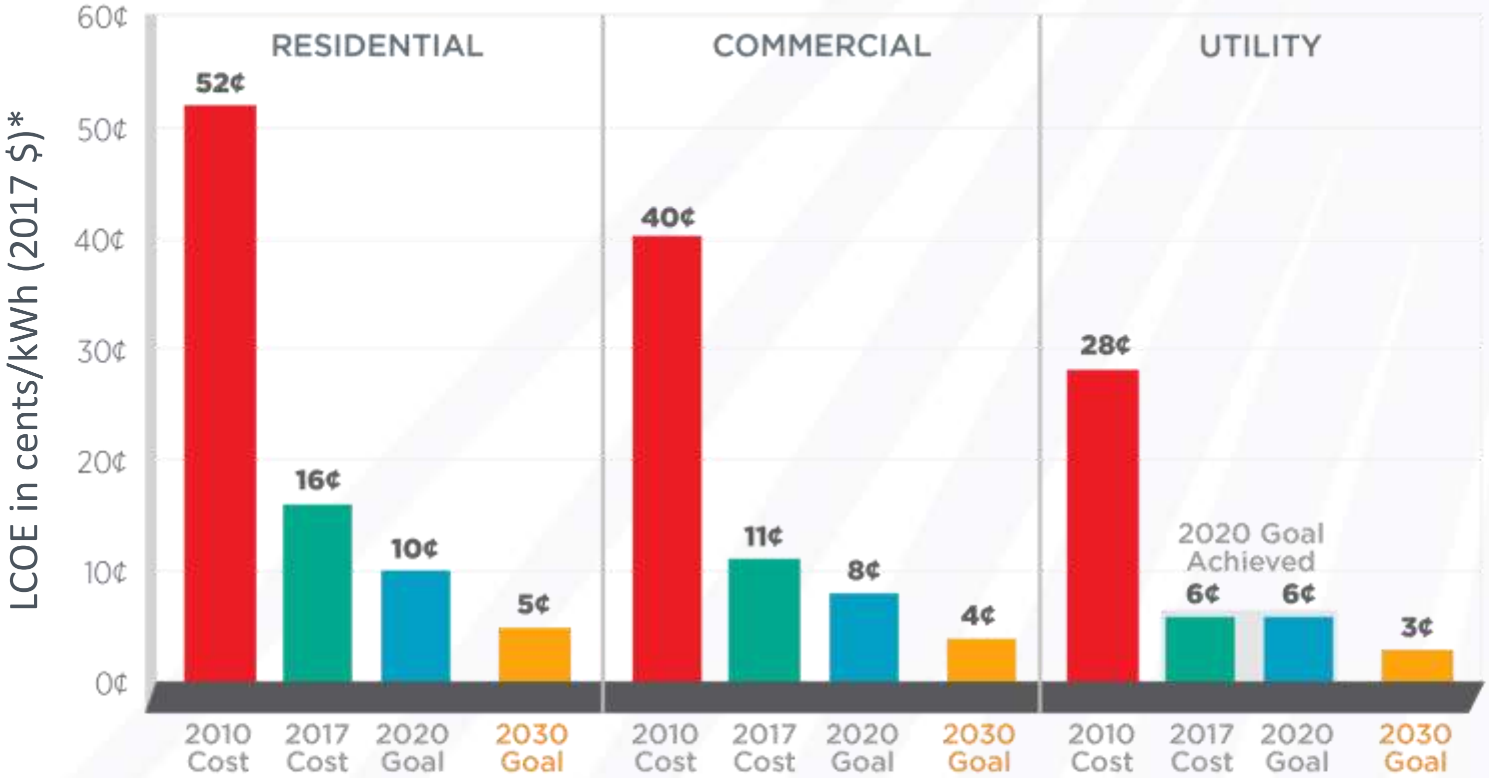
PV Research Priorities:

Enabling widespread use of solar for grid reliability, resilience, and security

Lenny Tinker, PV Program Manager

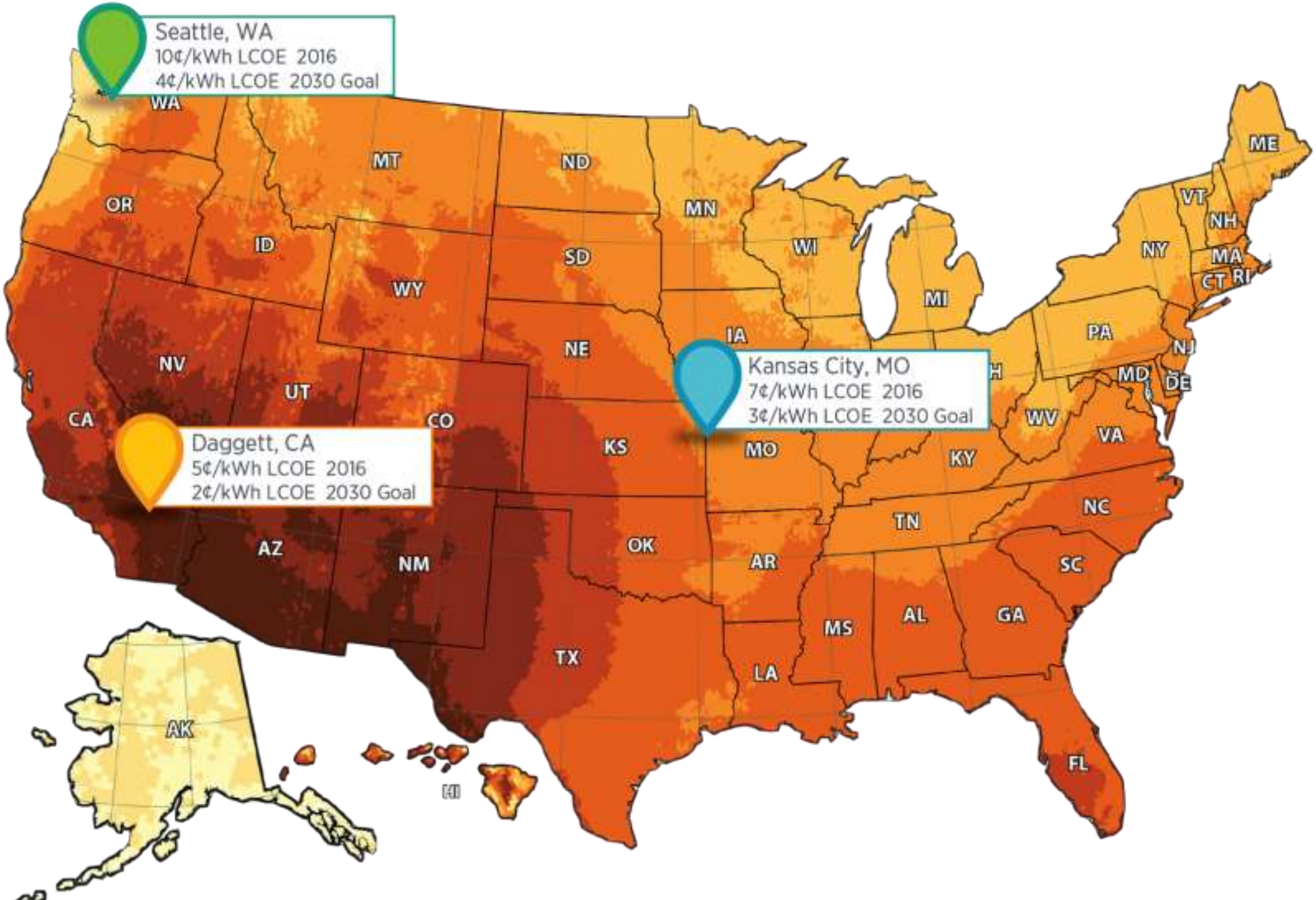
Progress and Goals: 2030 Photovoltaics Goals

The office 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.

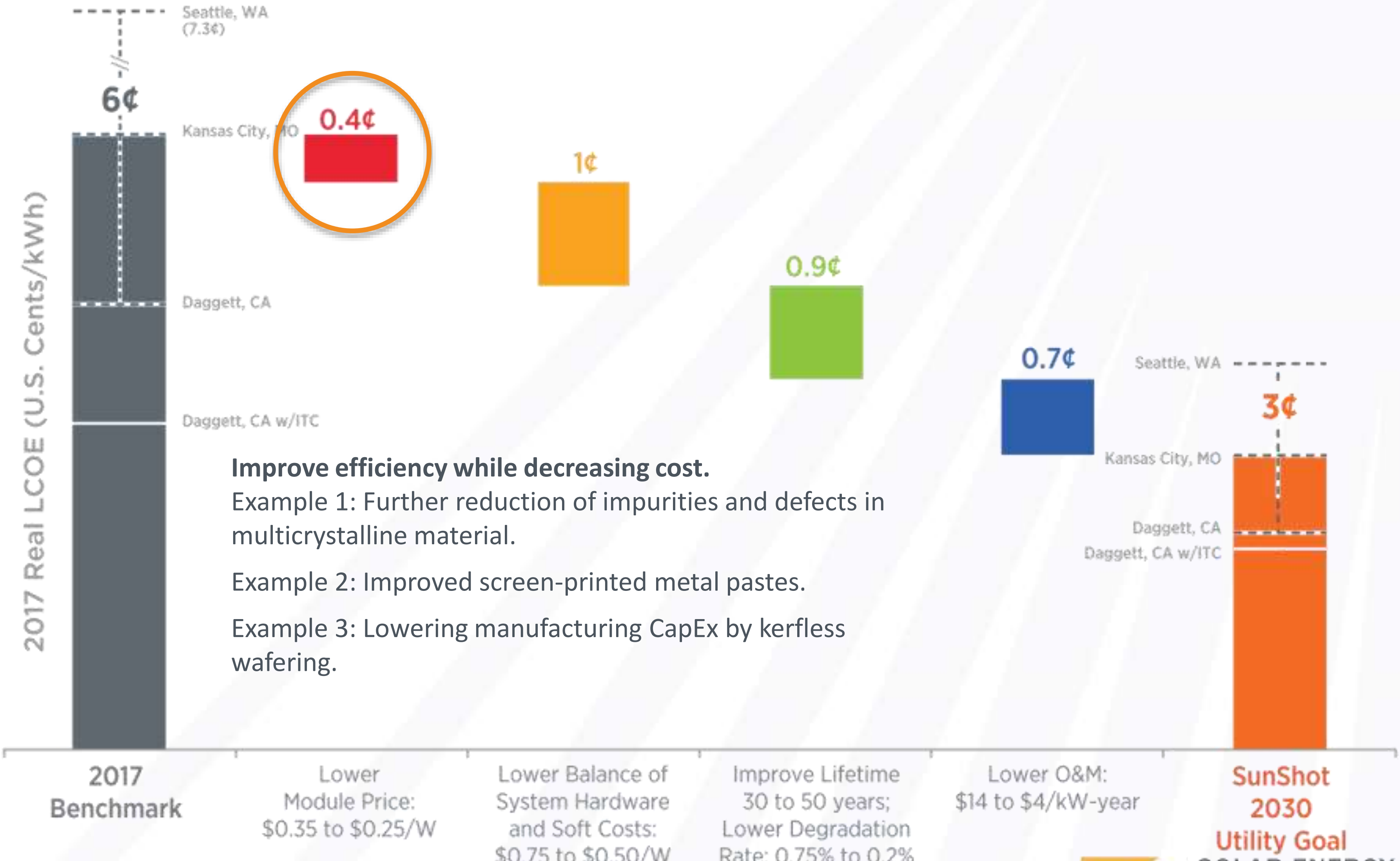


*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010-17.

SETO's 2030 PV Goal Across the U.S.



A Pathway To 3 Cents per kWh for Utility PV



Improve efficiency while decreasing cost.

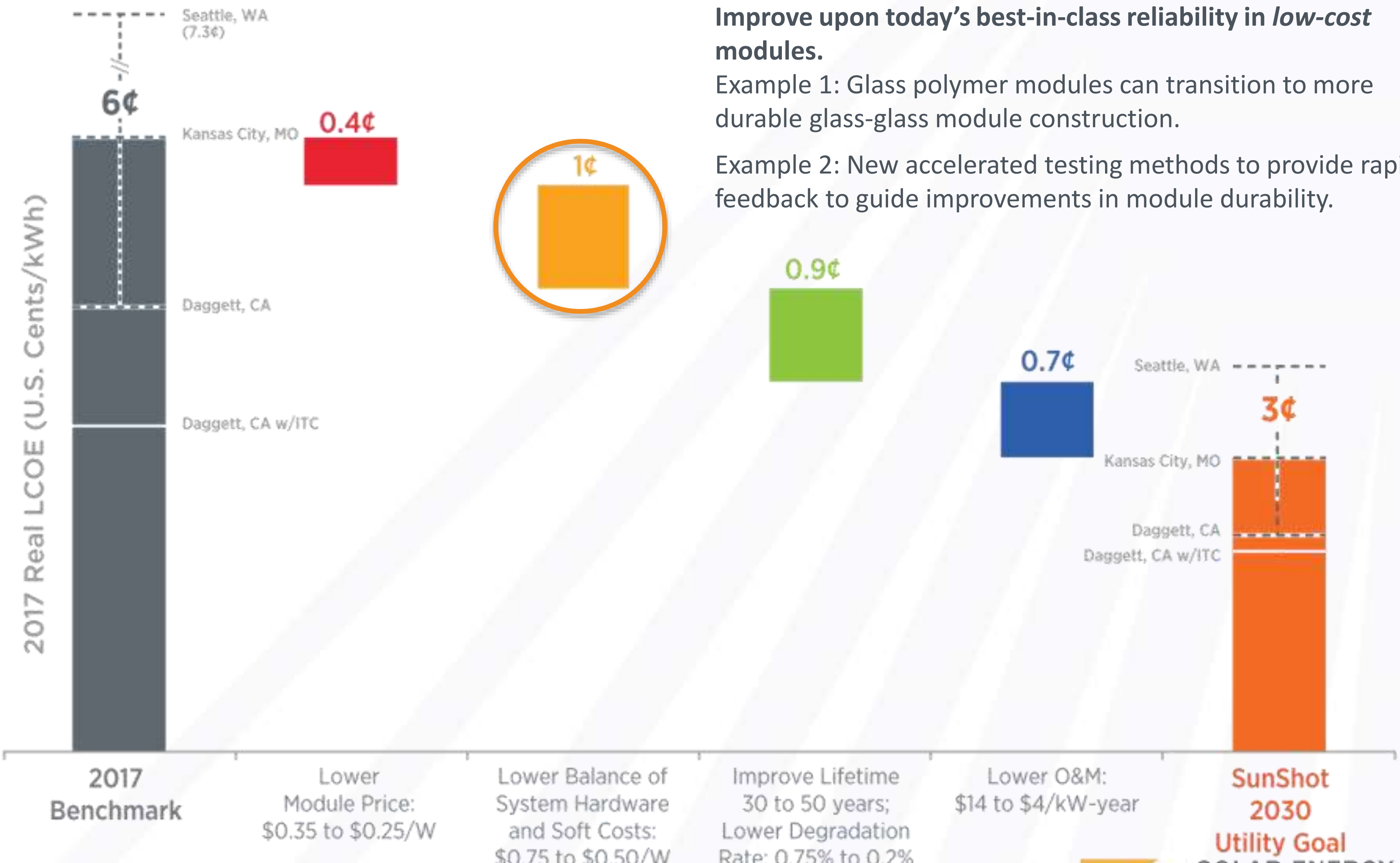
Example 1: Further reduction of impurities and defects in multicrystalline material.

Example 2: Improved screen-printed metal pastes.

Example 3: Lowering manufacturing CapEx by kerfless wafering.

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.

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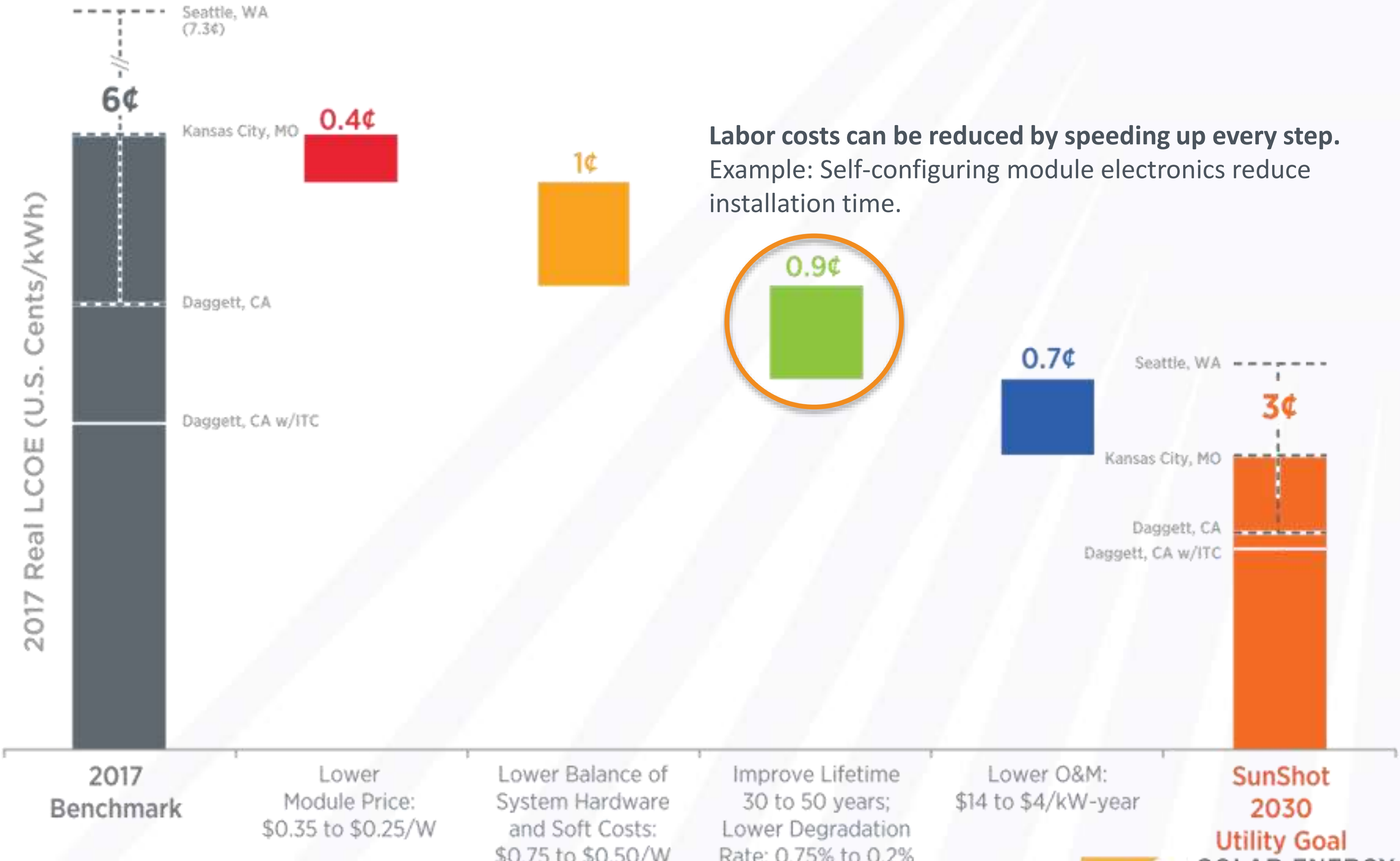

Labor costs can be reduced by speeding up every step. Example: Self-configuring module electronics reduce installation time.

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.

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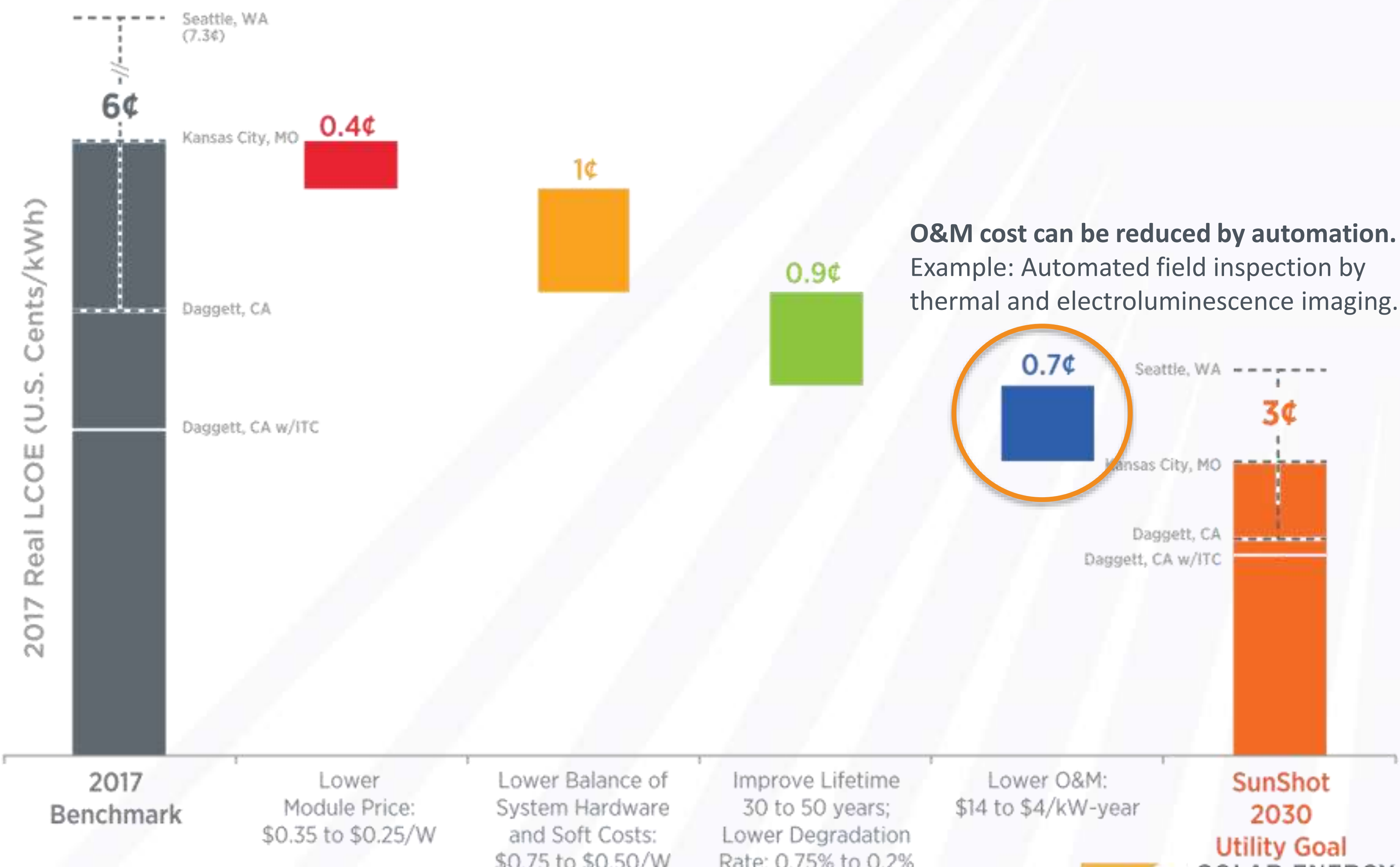
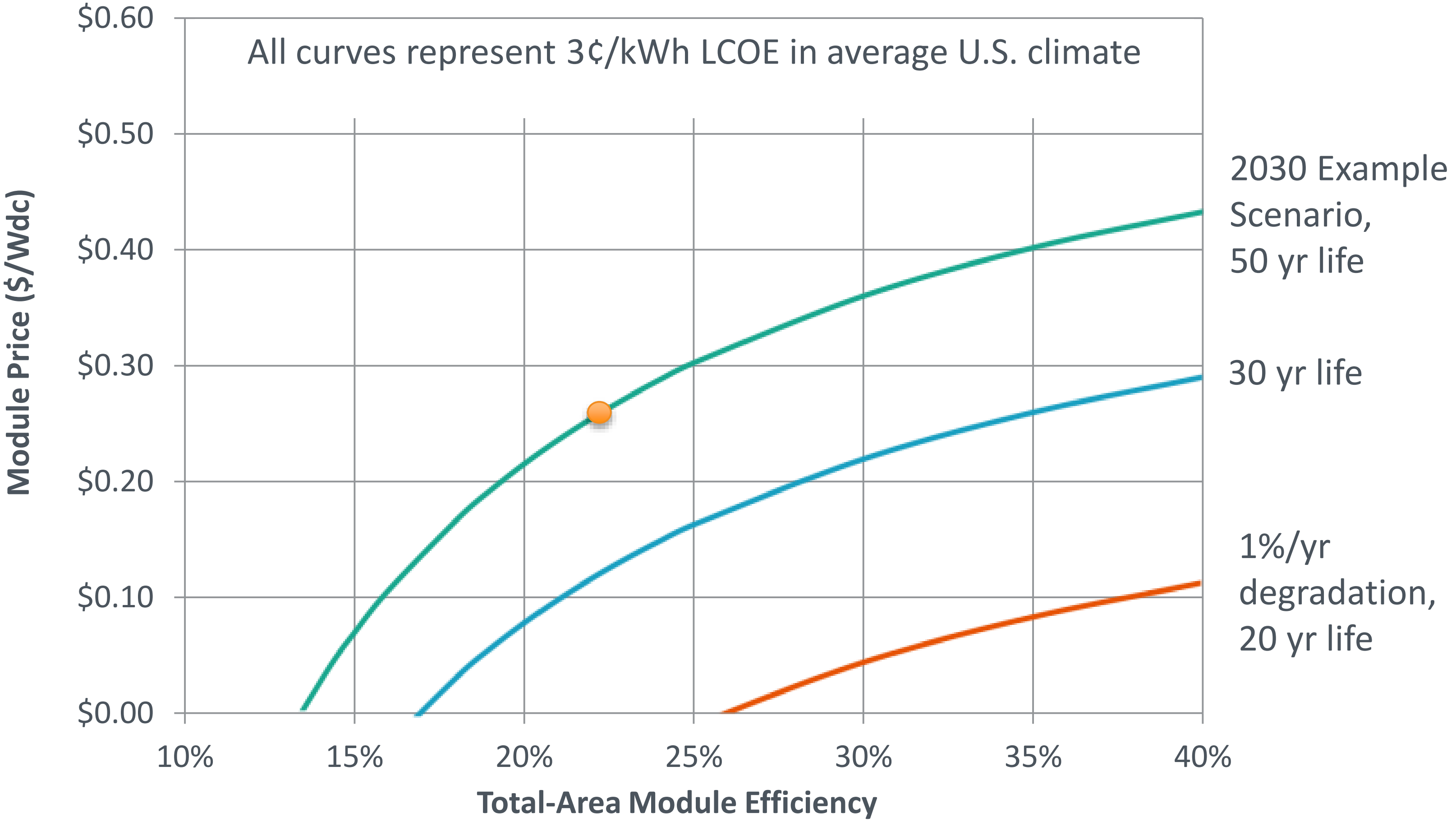


O&M cost can be reduced by automation.
Example: Automated field inspection by thermal and electroluminescence imaging.

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.

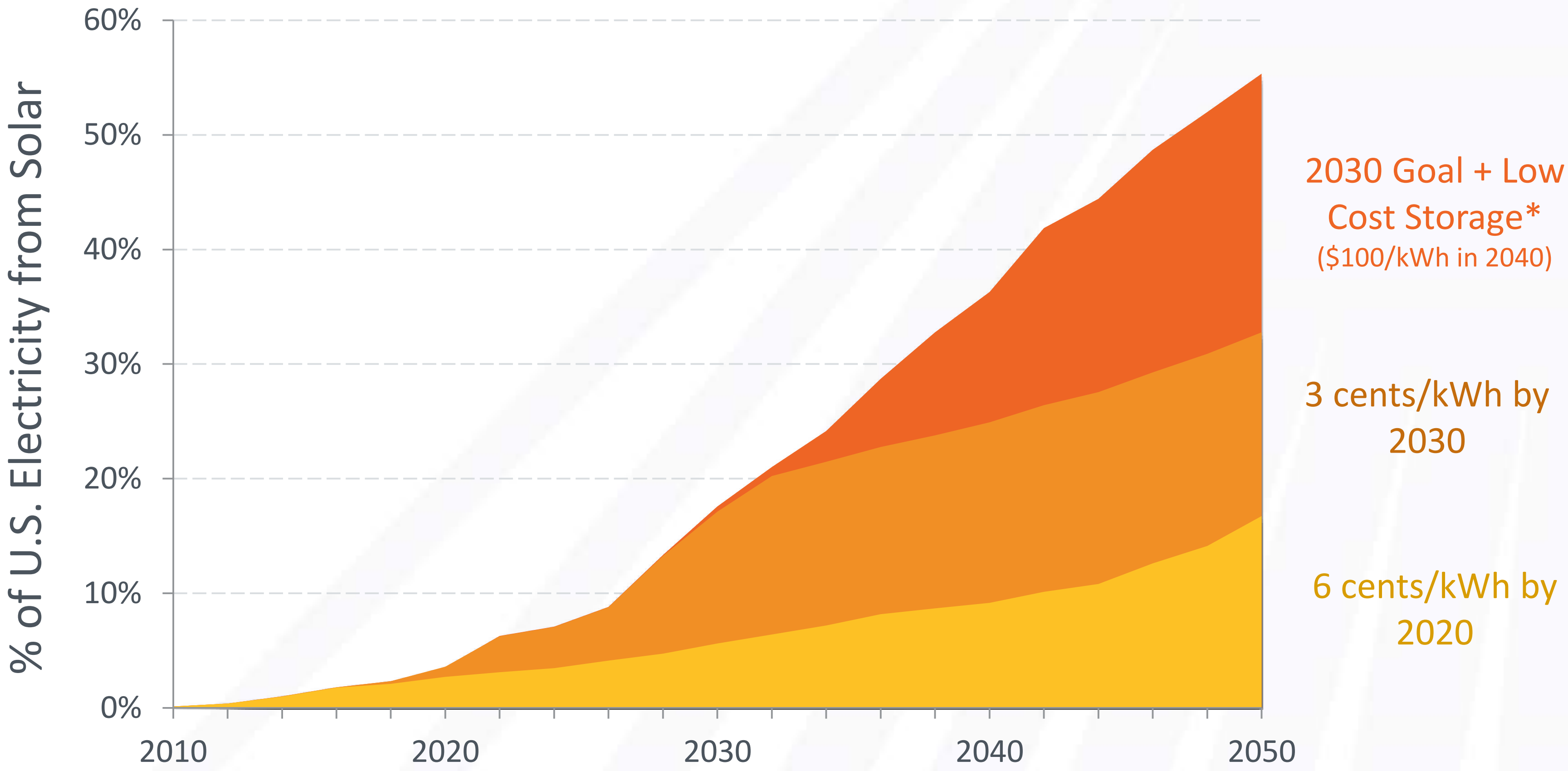
There are Many Technology Pathways

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



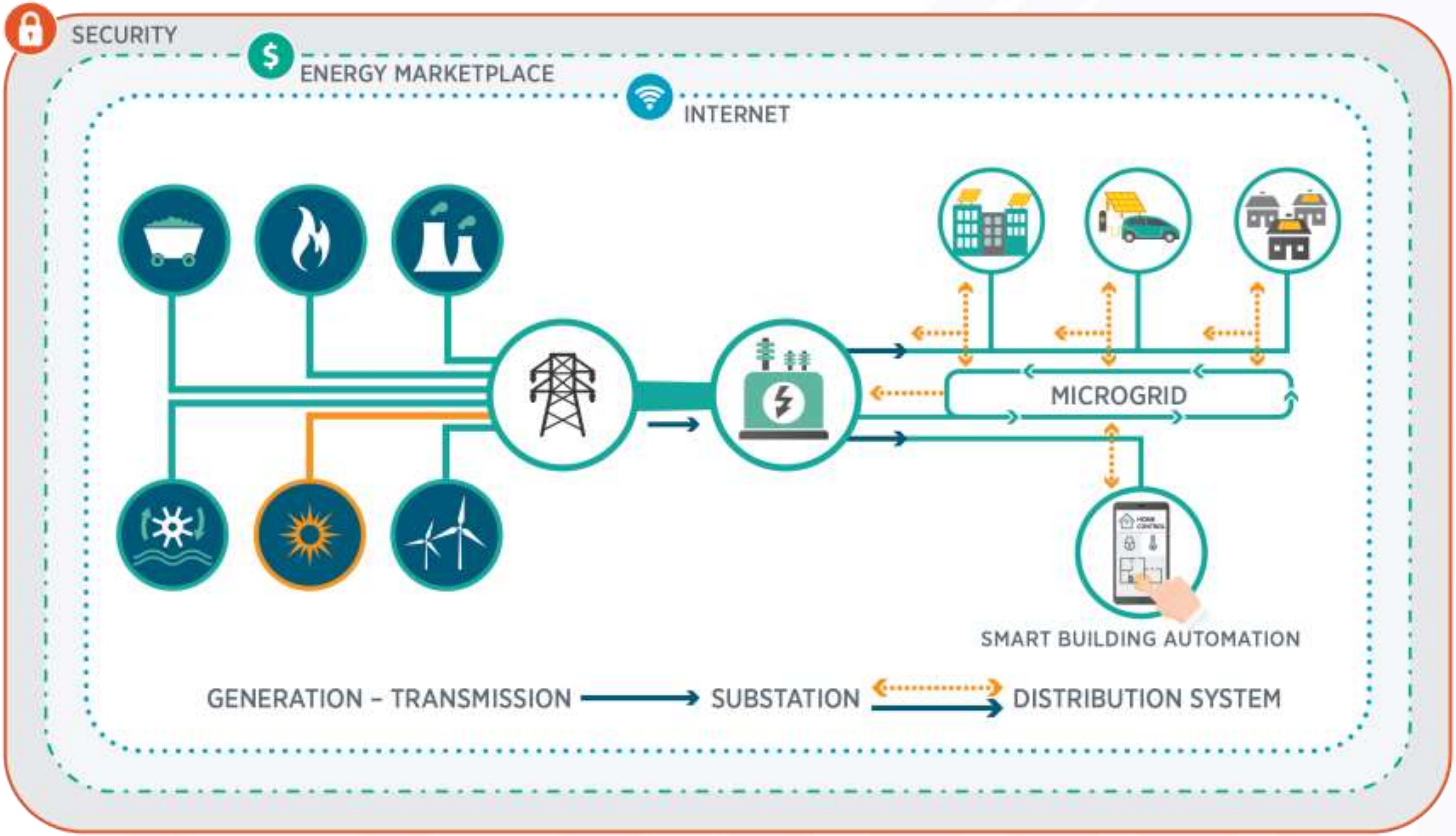
Scenarios assume: 7% WACC, 2.5% inflation, $4/kW-yr O&M, 21% capacity factor

The Great Potential for Solar with Low-Cost Storage



* 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 as solar energy can be stored to better match electricity demand.

Modern Electric Grid: Two Way Energy and Data Flow



Goal: Centralized and distributed generation optimized with finely tuned, 2-way load balancing

Emerging Themes in Current PV R&D Portfolio

Surface passivation to increase carrier lifetime

- Al_2O_3 and a-Si on CdTe and Si
- Molecular passivation of perovskites

Carrier selective contacts to reduce injected current and recombination in Si, CdTe, and perovskite cells

- Electron contacts in TiO_2, SnO_2, ZnO
- Hole contacts in MoO_3, WO_3, V_2O_5, NiO

Tandems to enable high efficiency cells and modules

- Perovskite on Si, thin film, and perovskite
- Thin films or III-Vs on Si
- III-Vs MJ

Rapid low-cost deposition techniques

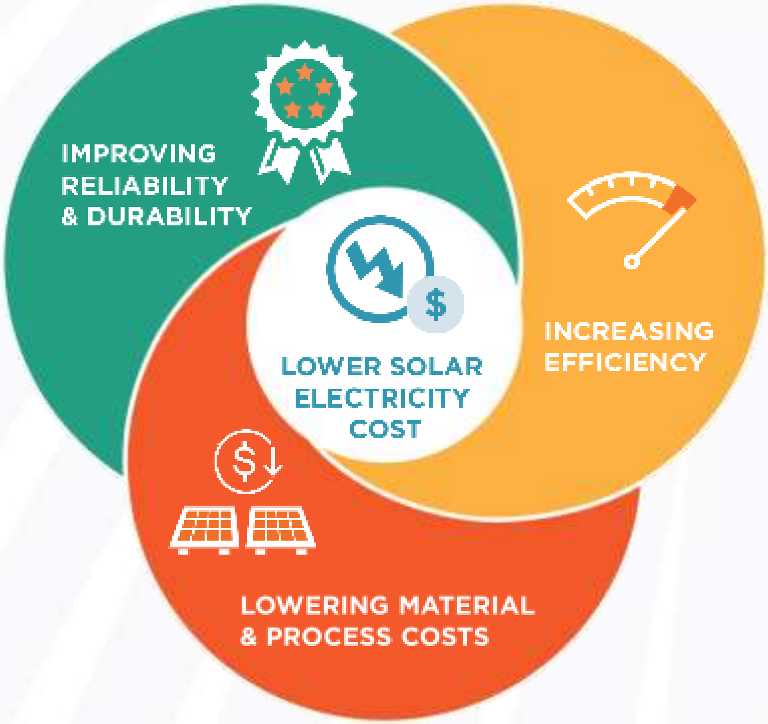
- Solution deposited perovskite cells / modules
- HVPE

Cell, module, and system reliability to enable technologies

- Perovskite stability improvements
- Adhesion of module components

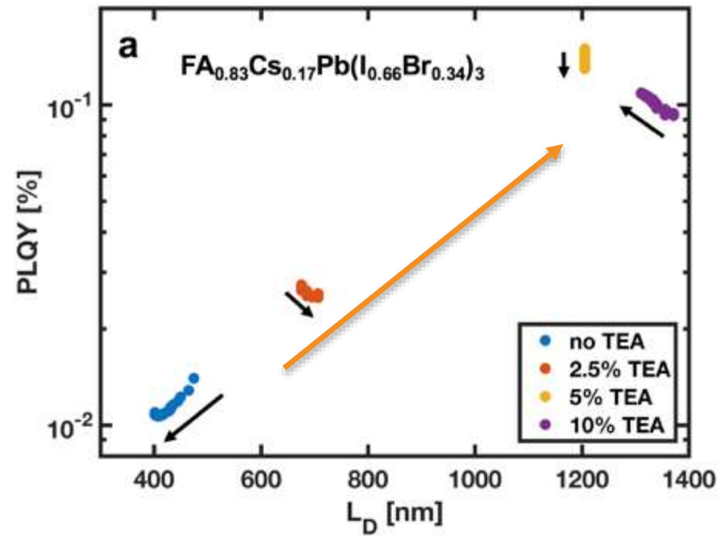
Defect characterization and mitigation to increase performance and reliability

Metallization and interconnection to lower cost and CapEx

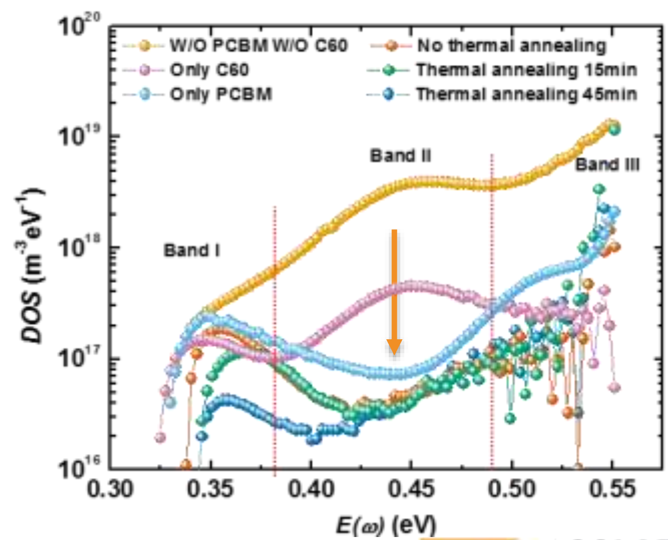


Surface Passivation: Increase Carrier Lifetime and V_{OC}

- Univ. of Washington
  Hugh Hillhouse
  - Molecular passivation of perovskite active layers
  - Increase in carrier diffusion length and PL quantum yield

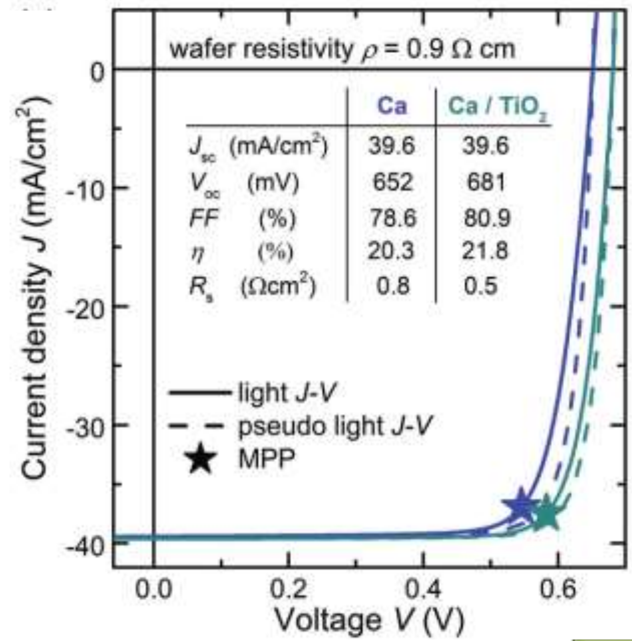


- Univ. Nebraska - Lincoln
  Jinsong Huang
  - Fullerene passivation of perovskite active layers
  - Reduce trap density to increase V_{OC}

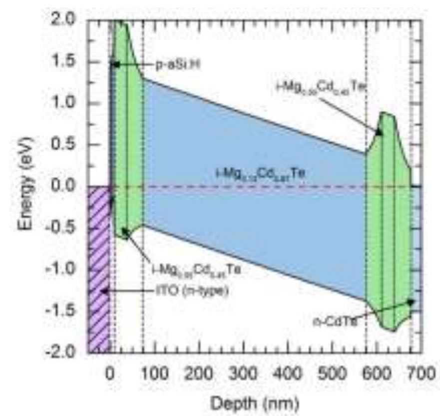


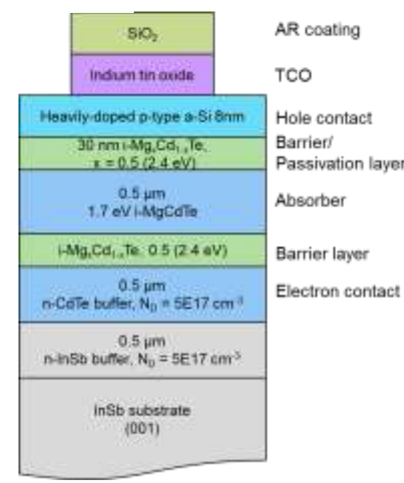
Selective Contacts: Metal Oxides on Si, a-Si on CdTe

- Univ. California Berkeley
  Ali Javey
  - Dopant-free asymmetric heterocontact (DASH) silicon solar cells
  - Utilizing TiO_2/Ca electron contact
  - MoO_3 hole contact, a-Si passivation



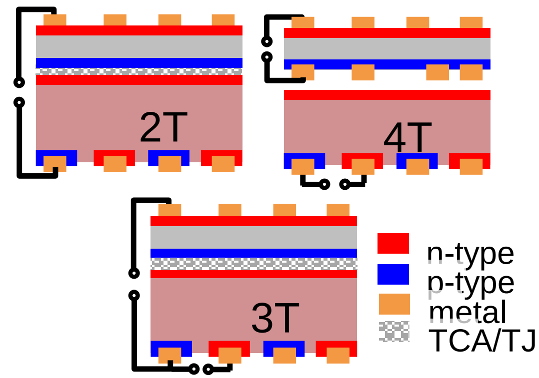
- Arizona State Univ.
  Zack Holman
  - Doped a-Si hole contact on CdTe
  - Utilizing doped MgCdTe passivation

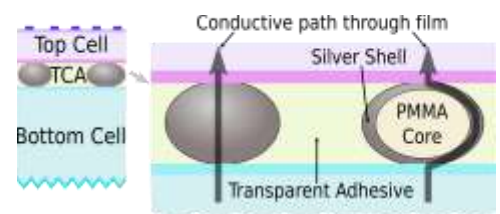




Tandems for High-Efficiency Cells

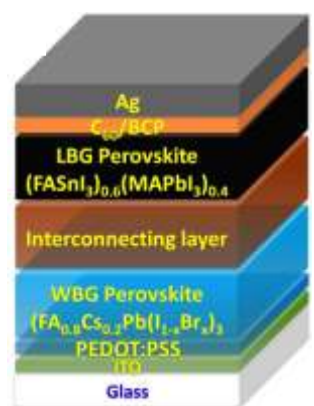
- National Renewable Energy Lab
  Adele Tamboli
  - Developing 3T III-V/Si cells
  - Initial 3T GaInP/Si dual junction cells demonstrating 25.3%
  - Flexible microspheres in adhesive for electrical connection

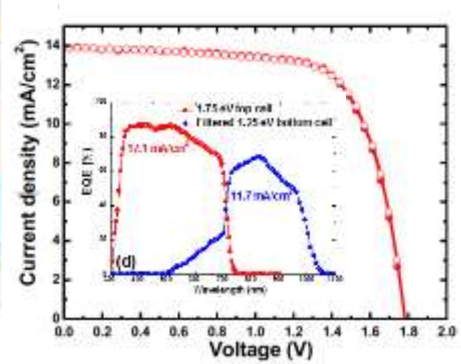




Flexible Microspheres Provide Electrical Conection Between Surfaces Without Lateral Conduction

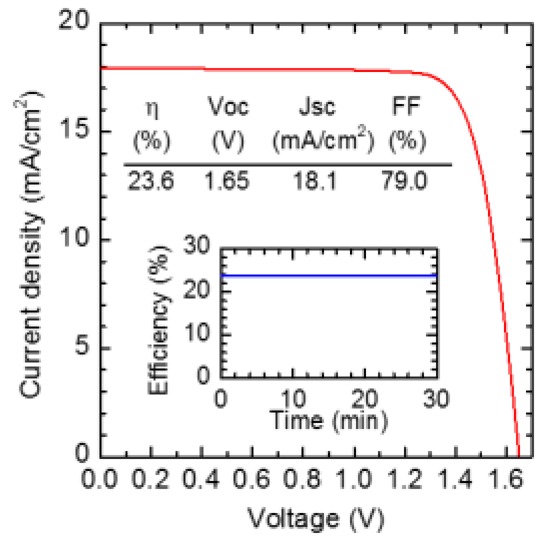
- National Renewable Energy Lab
  Kai Zhu
  - Low gap perovskite of 1.25 eV
  - Wide gap perovskite of 1.75 eV
  - Full perovskite tandem

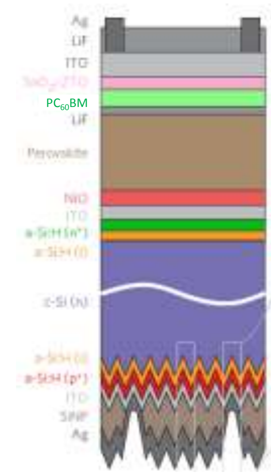




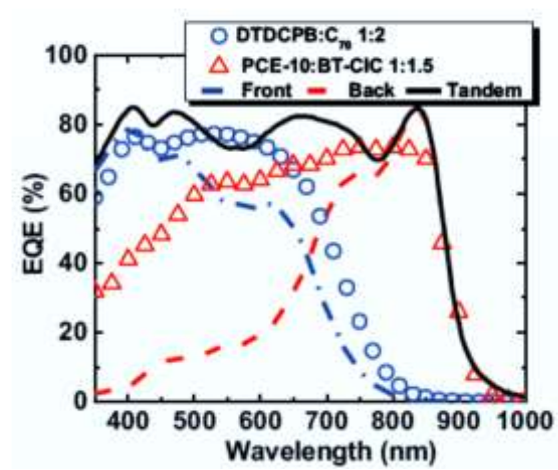
Tandems for High-Efficiency Cells

- Stanford
  Michael McGehee
  - 1 cm^2 perovskite on n-type Si
  - Stable performance over test time
  - Developing tandems on n- and p-type Si



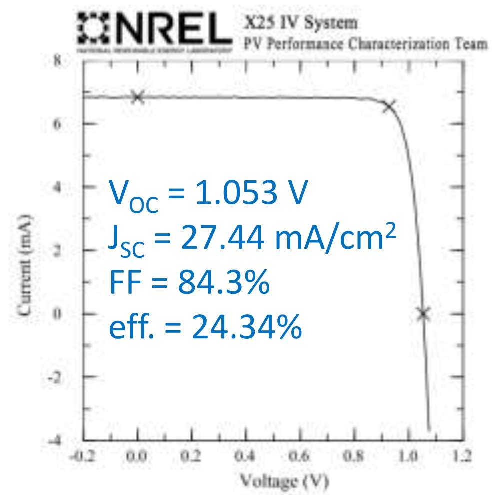


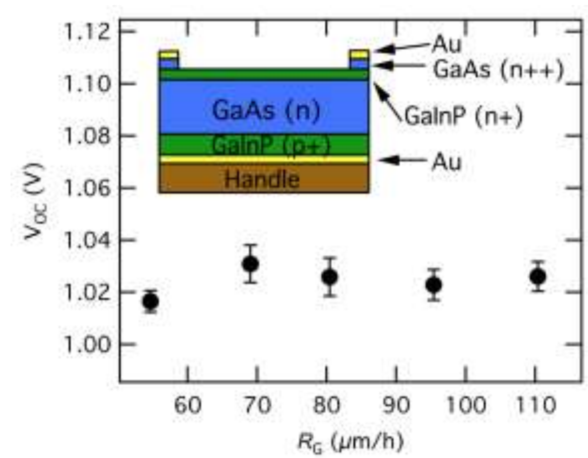
- Univ. of Michigan
  Stephen Forrest
  - Low gap polymer with non-fullerene acceptor
  - Tandem achieved 15% PCE
  - Semitransparent devices for BIPV applications

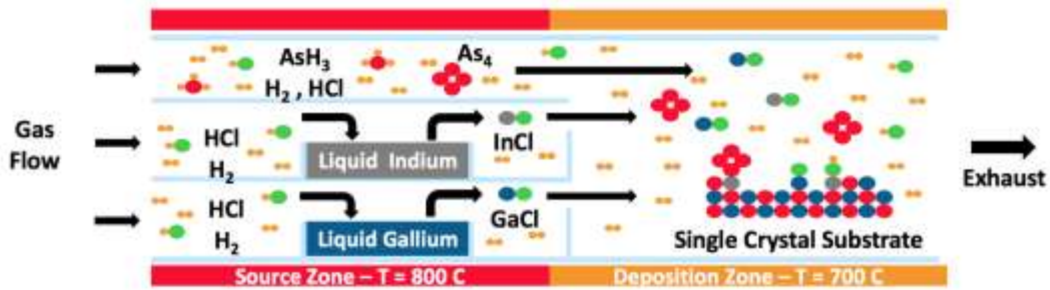


Rapid Low-Cost Deposition

- National Renewable Energy Lab
  Aaron Ptak
  - Dynamic Hydride Vapor Phase Epitaxy (D-HVPE) is a rapid growth technique to lower the costs of III-V cells
  - Atomically- and chemically-abrupt interfaces
  - Greatly expanded the growth temperature range
  - Solar cell quality is insensitive to growth rate, which has implications on throughput and cost

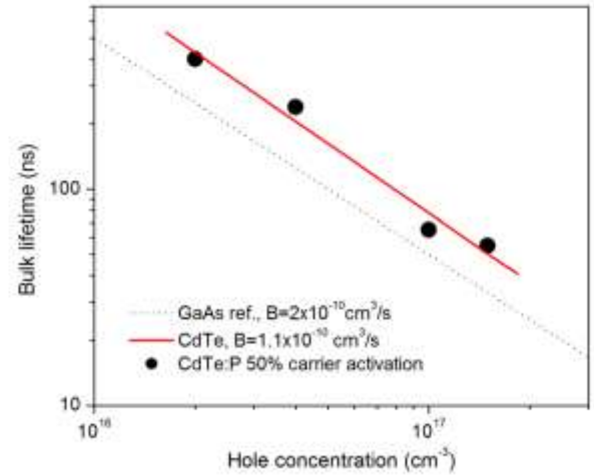


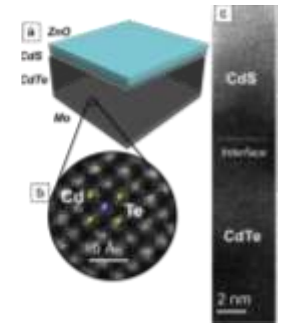




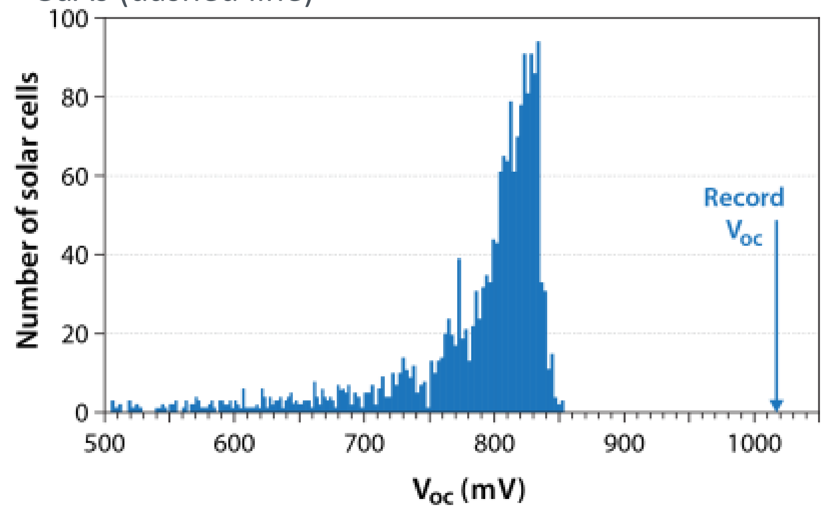
Defect Characterization and Mitigation

- National Renewable Energy Lab
  Wyatt Metzger
  - Moving away from standard Cu doping on Cd sites, and placing Group V elements such as P on Te lattice sites
  - Techniques and dopants explored: VTD at IEC / NREL, CSS, N cracking, P, As, and Sb dopants, Bridgman material from WSU, Zn alloying…
  - Radiatively limited lifetimes and 2 orders of magnitude greater hole density were achieved in single crystals
  - Improved absorber properties lead to world record V_{oc} relative to standard processes (histogram)



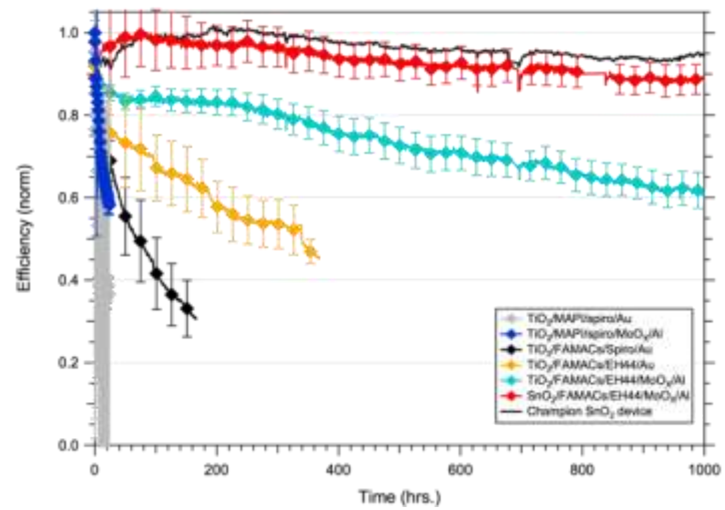


CdTe (circles) can achieve hole density and radiatvely limited lifetimes commensurate with high-performance GaAs (dashed line)

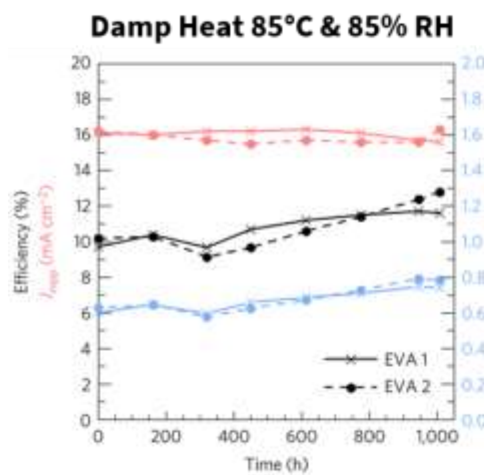


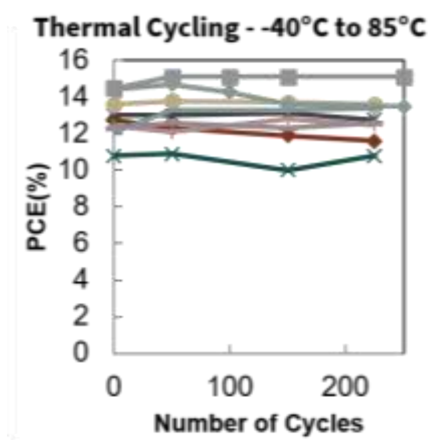
Perovskite Cell Reliability

- National Renewable Energy Lab
  Joe Berry
  - Show substantial stability improvements for devices without encapsulation
  - 94% of T_0 after 1000 hours under illumination and load in air



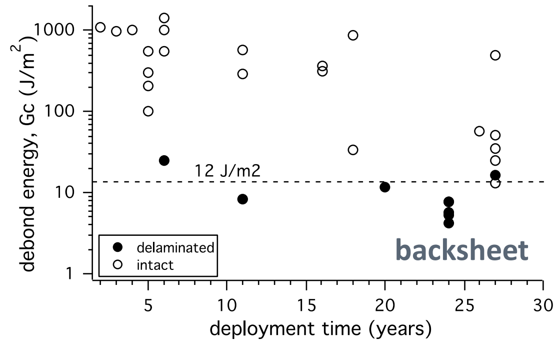
- Stanford
  Michael McGehee
  - Encapsulated perovskite devices passed qualification tests
  - Damp heat, thermal cycling, UV illumination





PV Module and System Reliability

- National Renewable Energy Lab
  Nick Bosco
  - Adhesion testing setup and test developed with Stanford
  - Testing delamination in encapsulants and backsheets



- National Renewable Energy Lab
  Peter Hacke
  - Combined Accelerated Stress Testing (CAST) system
  - Study the role that combinations of different stresses have on accelerating degradation modes

DuraMat: Durable Module Materials Consortium

- Bring *national laboratory* and *university* infrastructure together with photovoltaic (PV) *supply chain and manufacturing industry* to accelerate development of durable packaging materials and technology transfer
- 6 national laboratory capability development projects, 8 university projects, and 3 collaborative industry-lab projects, funded in FY17
- 13-member PV Industry Advisory Board guides strategic and technical direction of consortium

NREL · Sandia National Laboratories · Berkeley Lab · SLAC → DuraMAT (Durable Module Materials Consortium) ← Industry · University

Research strategy integrates **six capability areas** across DuraMat that accelerate PV material design, informed by industry partners to meet SETO technology goals

Computation & Analysis	***Advanced Module Materials***
➢ **Data Analytics**	➢ **Accelerated Testing**
➢ **Predictive Simulation**	➢ **Field Deployment**
➢ **Technoeconomic Analysis**	➢ **Materials Characterization**

Combined accelerated stress testing at NREL to identify PV degradation modes

https://www.duramat.org/

January 2018 Request for Information (RFI)

SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

Photovoltaics Innovation Roadmap
Request for Information Summary
Solar Energy Technologies Office
January 2018

Download RFI summary report on SETO website:
https://energy.gov/eere/solar/downloads/pv-innovation-roadmap

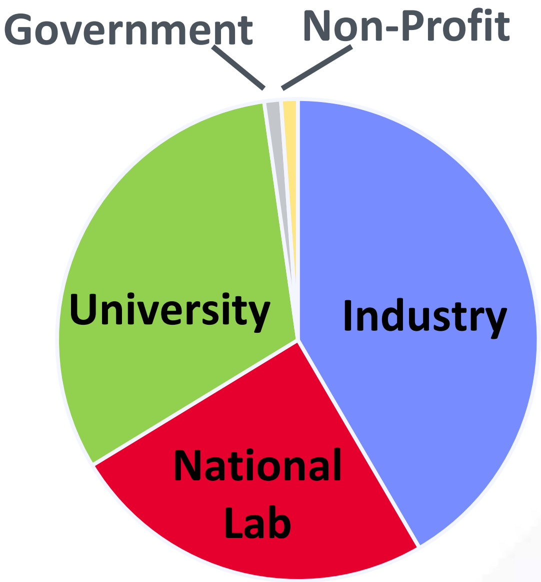
Technological Research Priorities

Characterization and Modeling Techniques

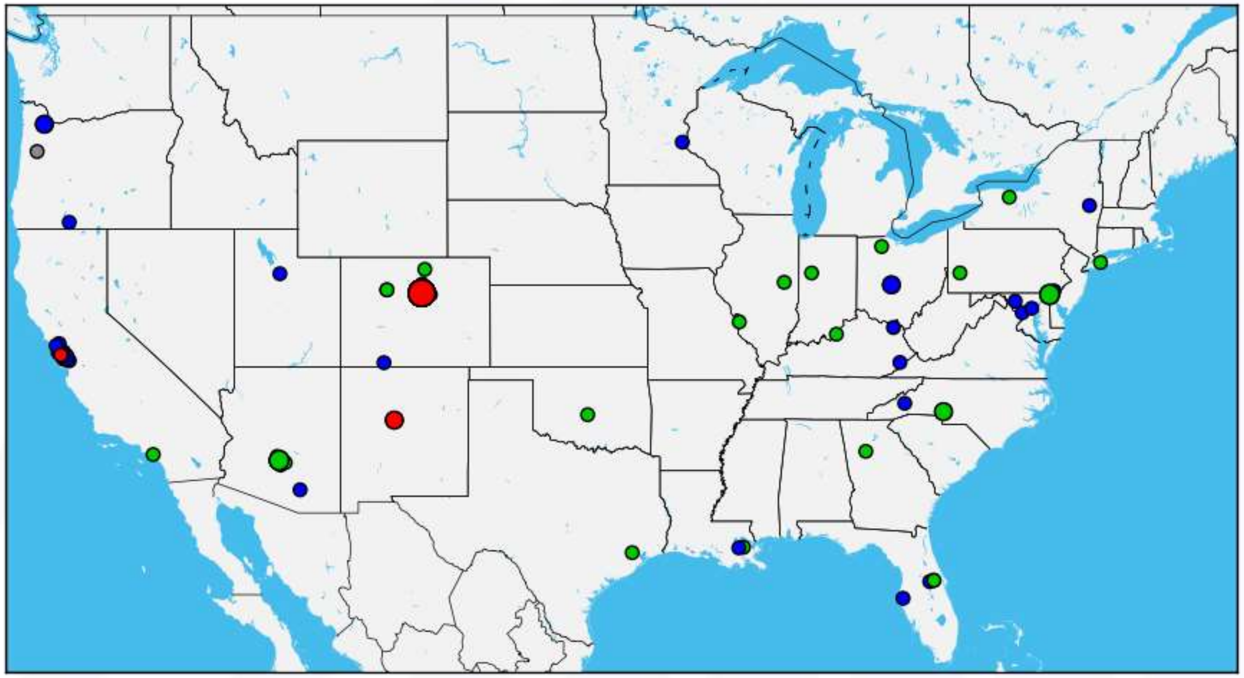
Module Packaging and Reliability

SETO Portfolio Evaluation

RFI Responses by Institution



89 responses



https://energy.gov/eere/solar/downloads/pv-innovation-roadmap

Highlighted Technical Challenges Identified in RFI

Silicon • **Wafering**: crucible, kerfless, gas-to-wafer • **Light-, potential-induced** degradation • **Tandems**: top cell, 3/4-terminal design	**CdTe** • **CdSeTe** defect/doping behavior • **Back contact** passivation • **Polycrystalline interfaces**
CIGS • **Metastability response** to heat and light • **Alkali role** in degradation, passivation • New **wide-band-gap buffer layers**	**Perovskites** • **Stability:** separating moisture and light • **Architectures**: lightweight, glassless • **Defect and dopant control**
III-V • Low-cost **substrate reuse** • Low-cost **epitaxial lift-off** • **Multijunction** efficiency, optical gains	**Module** • High-performance **glass alternatives** • Improved **edge seals** • **Durability** of coatings, encapsulants

https://energy.gov/eere/solar/downloads/pv-innovation-roadmap

American-Made Solar Prize

The **American-Made Solar Prize** is a $3 million prize competition designed to accelerate and sustain American solar innovation through a diverse and powerful support network of resources.

IDEATE

An ongoing ideation process to propose, discuss, and rate solutions for technical challenges in the solar industry.

SUBMIT BY OCTOBER 2

COMPETE

Entrepreneurial individuals and teams compete in contests to solve difficult challenges in the solar industry and can win cash prizes and valuable resources needed to succeed.

SUBMIT BY OCTOBER 5

EMPOWER

Partners join the **American-Made Network** to support competitors as they rapidly develop solutions and can win performance payments.

ONGOING

Up For the Challenge?

Visit **americanmadechallenges.org** to learn more

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Questions?

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