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<th><strong>DOCKETED</strong></th>
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<tr>
<td><strong>Docket Number:</strong> 19-ERDD-01</td>
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<tr>
<td><strong>Project Title:</strong> Research Idea Exchange</td>
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<td><strong>TN #:</strong> 224676</td>
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<tr>
<td><strong>Document Title:</strong> Presentation - PV Research Priorities</td>
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<tr>
<td><strong>Description:</strong> Presentation by Lenny Tinker DOE/SETO</td>
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<td><strong>Filer:</strong> Silvia Palma-Rojas</td>
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<td><strong>Organization:</strong> Solar Energy Technologies Office, U.S. Department of Energy</td>
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PV Research Priorities:

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

energy.gov/solar-office
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.
A Pathway To 3 Cents per kWh for Utility PV

Labor costs can be reduced by speeding up every step. Example: Self-configuring module electronics reduce installation time.
A Pathway To 3 Cents per kWh for Utility PV

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.

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
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.
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 $V_{OC}$

energy.gov/solar-office
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

• 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 cm² 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

V_{OC} = 1.053 V
J_{SC} = 27.44 mA/cm^2
FF = 84.3%
eff. = 24.34%
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 radiatively 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

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

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<thead>
<tr>
<th>Computation &amp; Analysis</th>
<th>Advanced Module Materials</th>
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<tr>
<td>➢ Data Analytics</td>
<td>➢ Accelerated Testing</td>
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<tr>
<td>➢ Predictive Simulation</td>
<td>➢ Field Deployment</td>
</tr>
<tr>
<td>➢ Technoeconomic Analysis</td>
<td>➢ Materials Characterization</td>
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https://www.duramat.org/
January 2018 Request for Information (RFI)


Technological Research Priorities
Characterization and Modeling Techniques
Module Packaging and Reliability
SETO Portfolio Evaluation
RFI Responses by Institution

89 responses

### Highlighted Technical Challenges Identified in RFI

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

**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.

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

Up For the Challenge?
Visit [americanmadechallenges.org](https://americanmadechallenges.org) to learn more.
Questions?

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