DOCKETED	
Docket Number:	19-ERDD-01
Project Title:	Research Idea Exchange
TN #:	224675
Document Title:	Presentation - Research Needs for Thin-Film Photovoltaic Technologies
Description:	Staff Presentation
Filer:	Silvia Palma-Rojas
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	9/8/2018 4:38:22 PM
Docketed Date:	9/8/2018

California
Energy Commission
Research & Development

Research Needs for Thin-film Photovoltaic Technologies

Rizaldo Aldas, PhD
Energy Research and Development Division

September 7, 2018
Sacramento, CA

Housekeeping

- ✓ Facilities
- ✓ Emergency Exit
- ✓ Sign-In Sheet

Workshop Objective

- ✓ Examine ways to advance the science and manufacturing of thin-film photovoltaic (PV) technologies and possibilities for reducing associated costs.
- ✓ Determine research needs that would enable improvements to materials science and manufacturing to create high value market applications for selected thin-film PV technologies.
- ✓ Obtain feedback from interested parties and experts on the objective, groups, metrics of our planned grant solicitation.

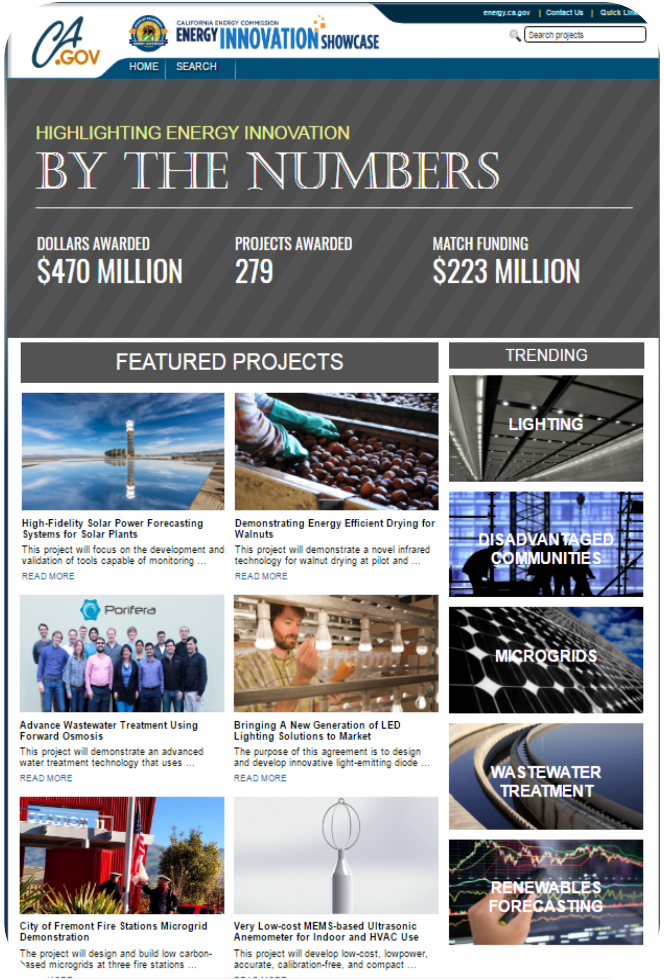
Agenda

9:10 – 9:40 AM: **Overview of Research Initiative for Solar R&D under 2018-2020 EPIC Program and Planned Solicitation**

9:40-10:00 AM: **Presentation on DOE Solar Energy Technologies Office (SETO)'s Research and Development on PV Technology**

10:00 – 11:30 AM: **Panel Discussion on State of the Art and Research Needs for Conventional and Emerging Thin-film Photovoltaics**

11:30-12:00 PM: Discussion and Public Comments



Enhanced Outreach & Engagement Opportunities

EPIC Innovation Showcase

- http://innovation.energy.ca.gov

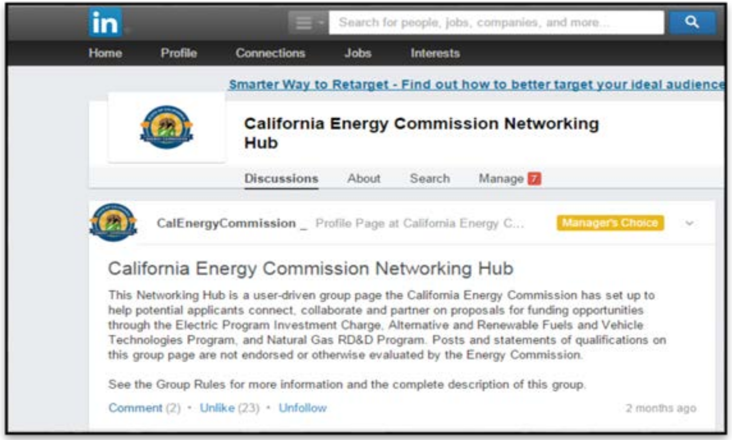
Social Media

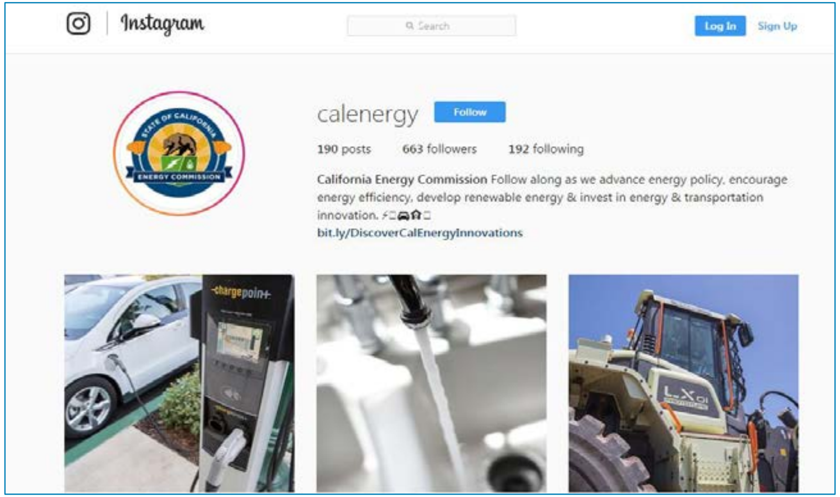
- Blogs, tweets and video features of research projects

Extensive public workshops on research scope, technology advancements, and market opportunities

Participating in meetings and events with diverse organizations

Connecting With Us





Instagram

California
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Research & Development

CREATE Solar

Silvia Palma-Rojas, PhD
Energy Research and Development Division

September 7, 2018

Sacramento, CA

Electric Program Investment Charge (EPIC)
The Science of Innovation


Create


Inspire


Collaborate

Background

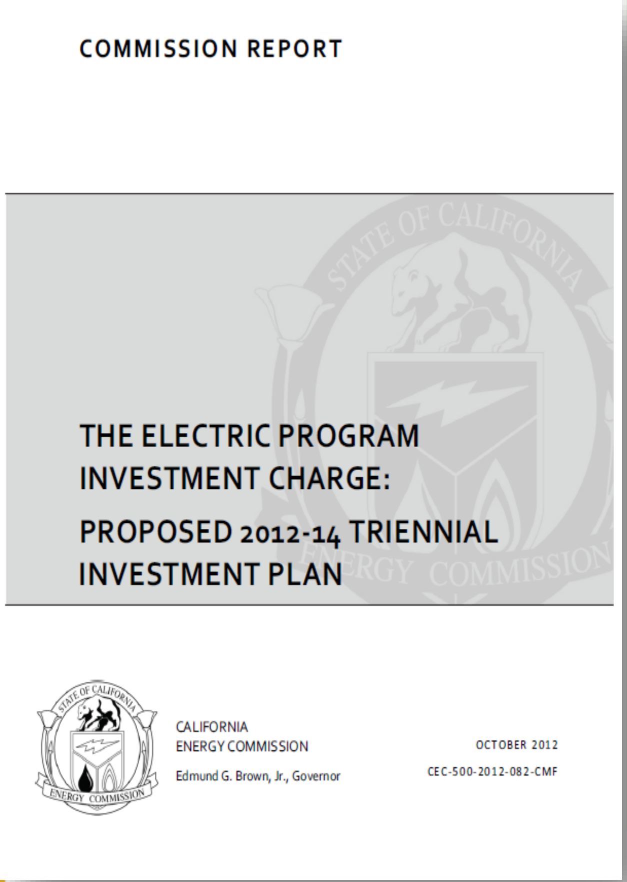
The Electric Program Investment Charge (EPIC) is funded by an electricity ratepayer surcharge established by the California Public Utilities Commission (CPUC) in 2011.

- Annual program funds total $162 million per year (adjusted for inflation) with 80% administered by the California Energy Commission.

The purpose of EPIC is to:

- Benefit the ratepayers of the three largest electric investor-owned utilities, Pacific Gas and Electric Co., San Diego Gas and Electric Co., and Southern California Edison
- Funds clean energy technology projects and Encourage technological advancement and breakthroughs.

EPIC Program: Triennial Investment Plans


COMMISSION REPORT

THE ELECTRIC PROGRAM INVESTMENT CHARGE:

PROPOSED 2012-14 TRIENNIAL INVESTMENT PLAN

CALIFORNIA ENERGY COMMISSION

Edmund G. Brown, Jr., Governor

OCTOBER 2012

CEC-500-2012-082-CMF

EPIC Program released:

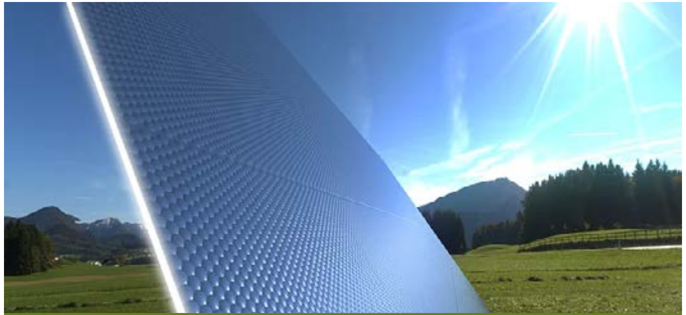
- 2012-2014:Triennial Investment Plan with 11 funding areas
- 2015-2017:Triennial Investment Plan with 11 funding areas

- Funding initiatives on applied R&D for solar energy:
  - Develop Emerging Utility-Scale Renewable Energy Generation Technologies and Strategies to Improve Power Plant Performance and Reduce Costs.
  - Develop Innovative Tools and Strategies to Increase Predictability and Reliability of Wind and Solar Energy Generation.

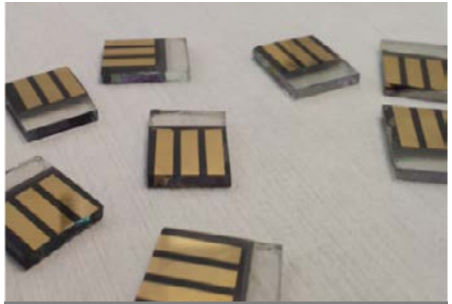
www.energy.ca.gov/research/annual_reports.html

Current Solar Portfolio

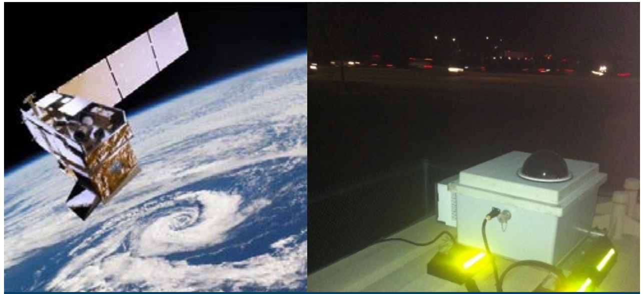
Air-driven tracking system



Self-Tracking Concentrator PV System



Manufacturing Approach for Perovskite Cells



Improving Accuracy of Solar Forecasting

Developing a Next Generation Manufacturing Tools

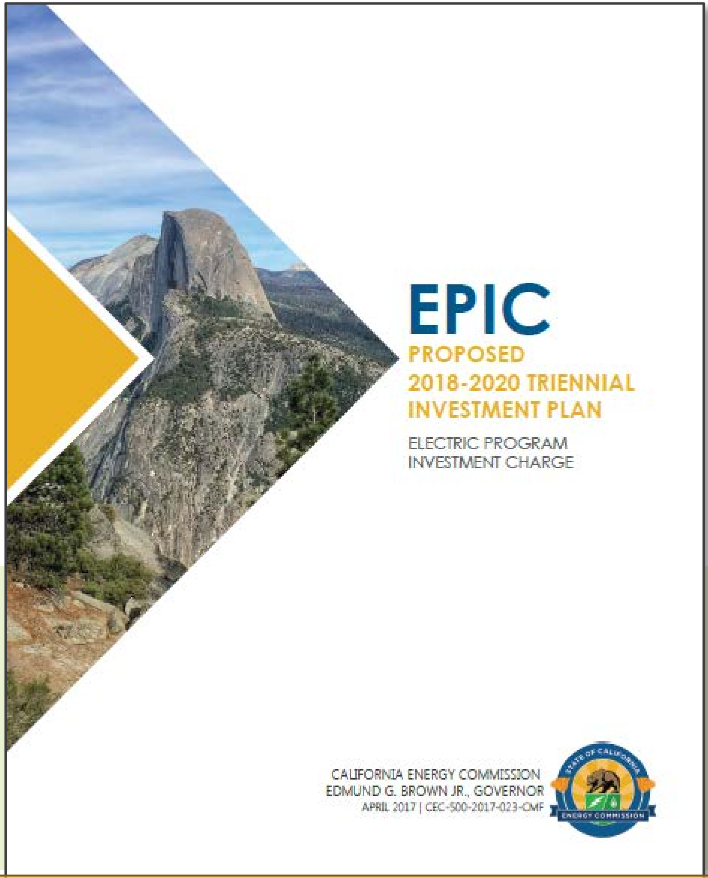
All terrain tracking system

Going Forward

The Energy Commission submitted its EPIC 2018 – 2020 Proposed Investment Plan to the CPUC on May 1, 2017.

Strategic Initiative 4.1.1 "**Advance the Material Science, Manufacturing Process, and In-Situ Maintenance of Thin-film PV Technologies**" identified the need to:

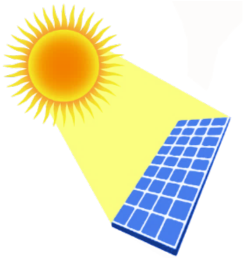
- Advance the material science associated with emerging thin-film PV technologies
- Develop novel encapsulating materials and techniques that will prevent module failures and pave the pathway for large-scale application.
- Identify innovative high value applications.



www.energy.ca.gov/research/annual_reports.html

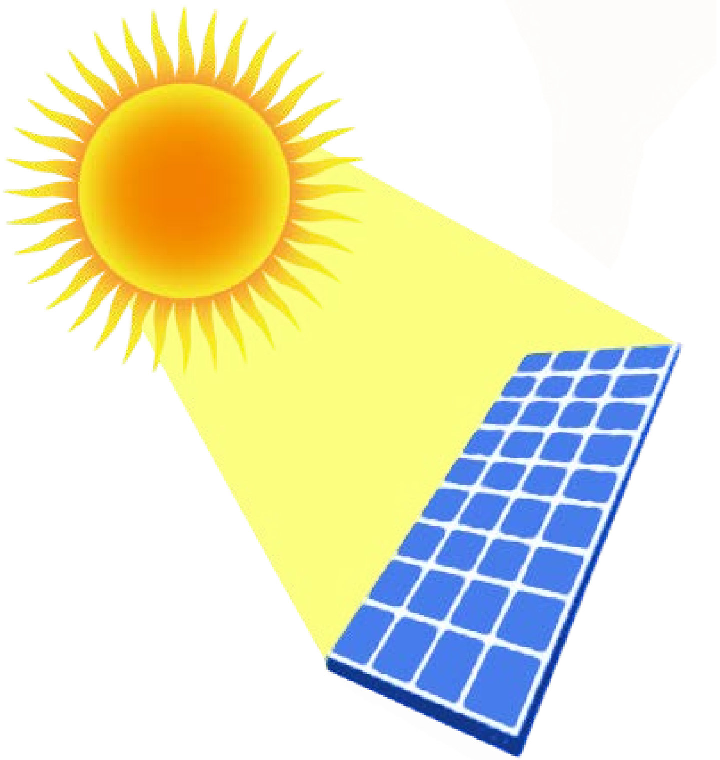
Cost Reductions, Advanced Technology for Solar Photovoltaics (CREATE Solar)

- Facilitate technological advancements in thin-film solar photovoltaic (PV) systems for distributed level applications.
- Enable scaling while addressing constraints in cell efficiency, supply chain, materials scarcity and toxicity
- Create new market applications for thin-film PV technologies with unique properties to increase renewables penetration and to lower the levelized cost of energy (LCOE) at distributed level.



Policy Drives Thin-Film PV Innovation

- Increase RPS to 50% by 2030
- Reduce GHG to 40% below 1990 levels by 2030
- Title 24 requires residential solar PV systems in new construction starting in 2020.

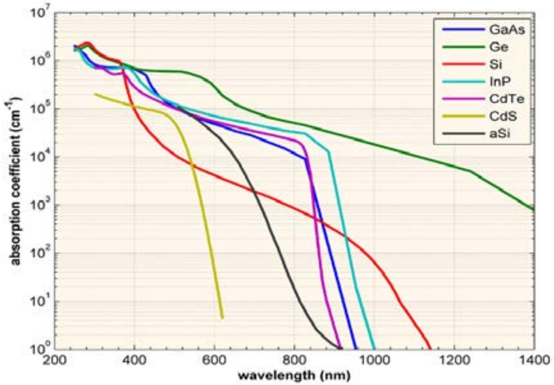


- Double energy efficiency savings by 50%
- 12,000 MW of distributed generation by 2020
- Increase access to clean energy in disadvantaged communities

Solar PV Market Context

- Cumulative installed capacity of distributed solar PV increased 360% from 2012-2017.
- Behind-the-meter (BTM) PV shares approximately 51 percent of the total distributed generation sources, with an installed capacity nearly to 6,000 MW.
- Wafer-based silicon solar PVs dominate the solar energy landscape with a market share of about 90 percent.
- Thin-film PV technologies market share is growing, but currently it is about 10 percent.

Advantages



Absorption coefficient of semi-conductor materials

Disadvantages

- Less material used, potential cost reduction.
- Potential for lower thermal budget, potential cost reduction
- Thin, light, flexible, transparent make thin-film technology suitable for building-integrated PV applications.
- Potential for roll-to-roll application due to its flexibility, which may reduce installation costs

- ❑ Lower efficiency than c-Si, potentially larger module costs
- ❑ Potential for capital-intensive production equipment
- ❑ Use of scarce, toxic materials, degradation rates

Source: Yang H, Burnett J, Ji J. Simple approach to cooling load component calculation through PV walls. Energy and Buildings, 31, 2000. https://www.pveducation.org/pvcdrom/absorption-coefficient https://ocw.mit.edu/courses/mechanical-engineering/2-627-fundamentals-of-photovoltaics-fall-2013/lecture-videos-slides/2011-lecture-12-thin-films-materials-choices-and-manufacturing-part-i/

What is the goal of CREATE Solar?

- Fund applied research and development projects that catalyze achieved breakthroughs in materials science and manufacturing process.
- Fund Projects that go beyond the state-of-the-art PV technology to support the development of innovative market application at distributed level.
- Ensure market readiness and higher penetration of solar generation at distributed level.

Group 1: Conventional Thin-film Photovoltaics

- Challenges faced by conventional thin-film PV technologies, including cadmium telluride (CdTe), copper indium gallium selenide (CIGS), Gallium Arsenide (GaAS).
- Pilot Technology demonstration projects should reach at least a technology readiness level of TRL 6-7 at the end of the project.

Research Areas

1) Improvement of material properties to increase voltage, diode quality, and efficiency.

2) Development of novel cell architecture to improve cell performance and address the short lifetimes of photo-excited electrons in cells.

3) Advancement of high-quality interfaces for high performance solar cells with increased current, reproducibility and stability.

4) Development and demonstration of four-terminal tandem systems.

5) Advanced manufacturing processes to address challenges to produce high performance modules in large-scale manufacturing.

Group 2: Emerging Thin-film Photovoltaics

- Challenges faced by emerging thin-film PV technologies that include perovskites, organic/polymer, III-V multi-junction solar cells, and quantum dots.
- Technology development projects should reach at least a technology readiness level of TRL 4-5 at the end of the project.

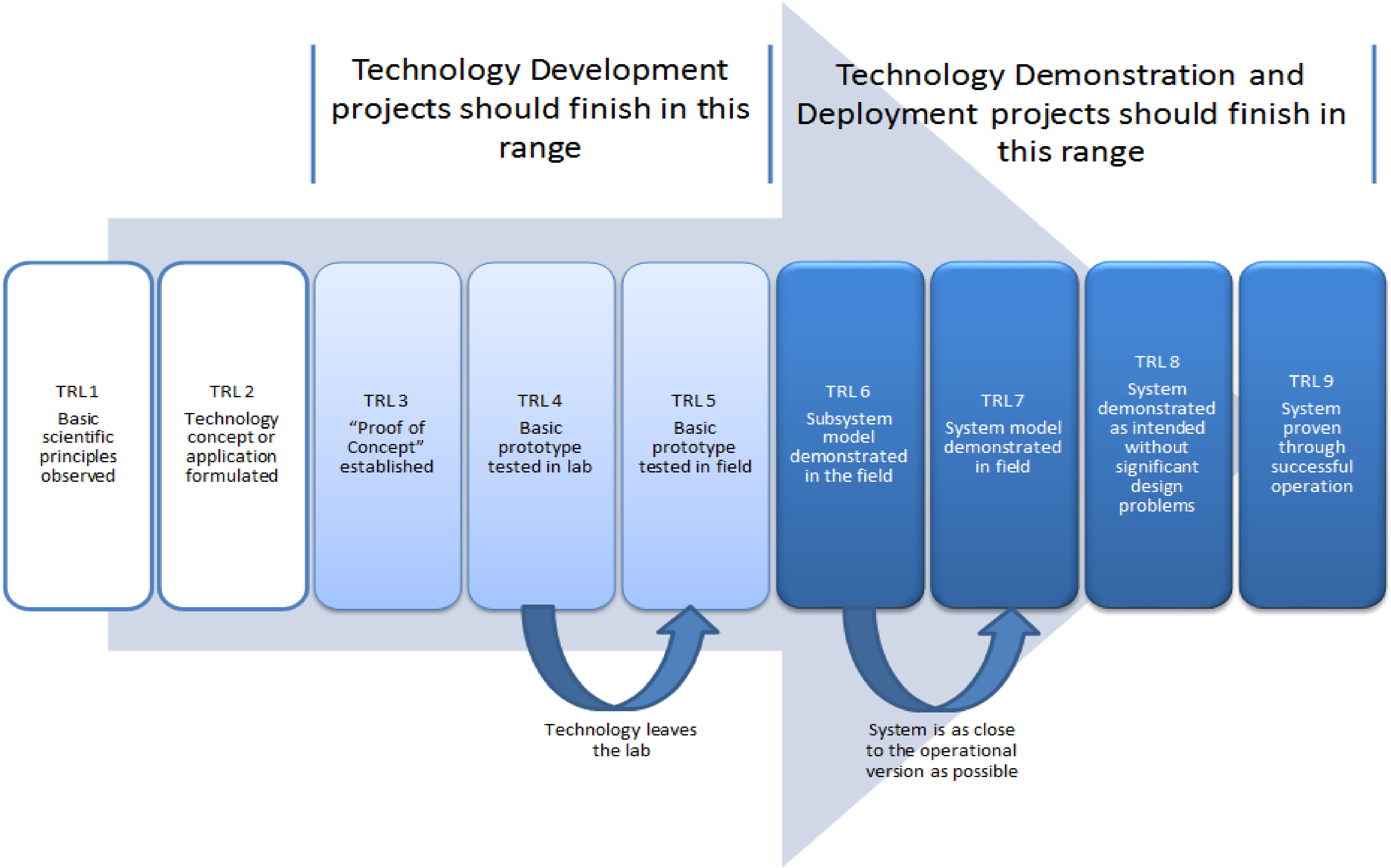
Research Areas

1) Development of novel absorber, contact materials, and device architectures for increased lifetime and device performance.

2) Advancement of structural, compositional, and/or interface engineering to improve the perovskite solar cell operational stability and to reduce eco-toxicological problems.

3) Improvements in process/manufacturing .

4) Improvement of precision optics and solar tracking systems to enhance cost competitiveness of III-V multi-junction solar cells.


Technology Development projects should finish in this range
Technology Demonstration and Deployment projects should finish in this range
TRL 1
Basic scientific principles observed
TRL 2
Technology concept or application formulated
TRL 3
“Proof of Concept” established
TRL 4
Basic prototype tested in lab
TRL 5
Basic prototype tested in field
TRL 6
Subsystem model demonstrated in the field
TRL 7
System model demonstrated in field
TRL 8
System demonstrated as intended without significant design problems
TRL 9
System proven through successful operation
Technology leaves the lab
System is as close to the operational version as possible

Metrics: Group I

PV TECHNOLOGY	Metrics Module Efficiency Cell Efficiency LCOE
CdTe	>19.1 % >22.6% ≤$0.04/kWh
CIGS	>19.7 % >23.1% ≤$0.04/kWh
GaAs	>25.9% >34% ≤$0.04/kWh

Source: Confirmed single junction terrestrial cell and submodule efficiencies measured under the global AM1.5 spectrum (1000 W/m2) at 25°C (IEC 60904-3: 2008, ASTM G-173-03 global); Green et al. Progress in Photovoltaics, Res Appl. 26, p. 3-12, 2018. https://doi.org/10.1002/pip.2978 ttps://www.energy.gov/eere/solar/sunshot-2030 PV Innovation Roadmap RFI Summary, U.S. Department of Energy. 2018. https://www.nrel.gov/pv/materials-devices.html PV Innovation Roadmap RFI Summary, U.S. Department of Energy. 2018. https://www.nrel.gov/pv/materials-devices.html https://aip.scitation.org/doi/pdf/10.1063/1.5001441

Metrics: Group II

PV TECHNOLOGY	Metrics Module Efficiency Cell Efficiency LCOE
Perovskite	>16.4 % >23.5% or >26% for tandem cells N/A
Organic/Polymer	>10.0 % >12.4% N/A
Multi-junction (III-V)	>40 % ≤$0.04/kWh

Source: Confirmed single junction terrestrial cell and submodule efficiencies measured under the global AM1.5 spectrum (1000 W/m2) at 25°C (IEC 60904-3: 2008, ASTM G-173-03 global); Green et al. Progress in Photovoltaics, Res Appl. 26, p. 3-12, 2018. https://doi.org/10.1002/pip.2978 ttps://www.energy.gov/eere/solar/sunshot-2030 PV Innovation Roadmap RFI Summary, U.S. Department of Energy. 2018. https://www.nrel.gov/pv/materials-devices.html PV Innovation Roadmap RFI Summary, U.S. Department of Energy. 2018. https://www.nrel.gov/pv/materials-devices.html https://aip.scitation.org/doi/pdf/10.1063/1.5001441

Life Cycle Performance

- Proposals under this solicitation must demonstrate how they will meet the efficiency and Sunshot's LCOE targets shown in table 1
- Project must include a life cycle assessment of such thin-film solar technology, showing how the technology will address the life cycle constraints, including but not limited to material supply, toxicity and recyclability.

Thank You!

Please submit your comments by September 14, 2018

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DOE Solar Energy Technologies Office (SETO)'s Research and Development on PV Technology

LENNY TINKER, PROGRAM MANAGER
DOE/SETO

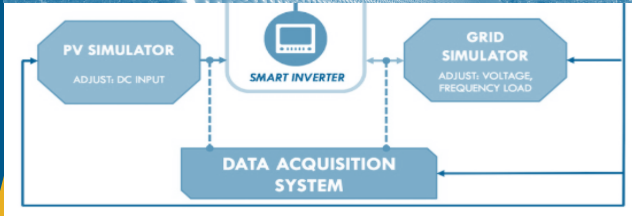
California
Energy Commission
Research & Development

Discussion Panel

Katharina Snyder, PhD
Energy Research and Development Division

September 7, 2018

Sacramento, CA



Panel Discussion on State of the Art and Research Needs for Conventional and Emerging Thin-film Photovoltaics

DR. ELI YABLONOVITCH, UNIVERSITY OF CALIFORNIA, BERKELEY
DR. MICHAEL MCGEHEE, UNIVERSITY OF COLORADO, BOULDER
DR. DAVID FENNING, UNIVERSITY OF CALIFORNIA, SAN DIEGO
DR. WEN MA, SUNPREME INC.
DR. CHENLEI WANG, SUNPREME INC.
DR. MICHAEL WOODHOUSE, NATIONAL RENEWABLE ENERGY LABORATORY

Question?
Comments?

Thank You!

Please submit your comments by September 14, 2018

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