DOCKETED	
Docket Number:	25-EPIC-01
Project Title:	Electric Program Investment Charge 2026–2030 Investment Plan (EPIC 5)
TN #:	266762
Document Title:	Swift Solar Inc Comments - Metrology tool validation for large scale manufacturing of Pervoskite PV
Description:	N/A
Filer:	System
Organization:	Swift Solar Inc
Submitter Role:	Public
Submission Date:	10/22/2025 6:01:44 PM
Docketed Date:	10/23/2025

Comment Received From: Swift Solar Inc
Submitted On: 10/22/2025
Docket Number: 25-EPIC-01

Metrology tool validation for large scale manufacturing of Pervoskite PV

Additional submitted attachment is included below.

CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

Electric Program Investment Charge 2026–2030 (EPIC 5) Research Concept Proposal Form

The California Energy Commission (CEC) is currently soliciting research concept ideas and other input for the Electric Program Investment Charge 2026–2030 (EPIC 5) Investment Plan. For those who would like to submit an idea for consideration, please complete this form and submit it to the CEC by **August 8, 2025**. More information about EPIC 5 is available below.

To submit the form, please visit the e-commenting link: https://efiling.energy.ca.gov/EComment/ECommentSelectProceeding.aspx and select the Docket **25-EPIC-01**. Enter your contact information and then use the "choose file" button at the bottom of the page to upload and submit the completed form. Thank you in advance for your input.

1. *Please provide the name, email, and phone number of the best person to contact should the CEC have additional questions regarding the research concept:*

   Bijan Moslehi, Bijan.moslehi@swiftsolar.com

2. *Please provide the name of the contact person's organization or affiliation:*

   Swift Solar Inc.

3. *Please provide a brief description of the proposed concept that you would like the CEC to consider as part of the EPIC 5 Investment Plan. What is the purpose of the concept, and what would it seek to do? Why are EPIC funds needed to support the concept?*

   We propose to develop a Manufacturing Reliability Toolkit for Perovskite and Perovskite–Silicon Tandem Photovoltaic (PV) Modules to accelerate the transition of laboratory-scale innovations into California-ready manufacturing.

   The toolkit will integrate non-destructive, in-line optical and electrical metrology—including photoluminescence (PL) and electroluminescence (EL) mapping, and optical coherence/ellipsometric imaging—to detect process-critical defects such as nonuniformities, shunts, and incomplete encapsulation.

We will correlate these signals to IEC 61215/61730 reliability outcomes through a failure analysis (FA) protocol incorporating potential-induced degradation (PID; IEC TS 62804-1:2025), dynamic mechanical load (DML; IEC TS 62782), and extended stress (IEC TS 63209-1) sequences.

Validated methods will be deployed on a pilot manufacturing line (Technology Readiness Level (TRL) 4→6) to increase yield by ≥15% and reduce scrap by ≥20%. EPIC funding is essential because these tools—reliability correlations, datasets, and metrology standards—are pre-competitive public goods that directly improve PV reliability and lower costs for California ratepayers.

4. *In accordance with Senate Bill 96[1], please describe how the proposed concept will "lead to technological advancement and breakthroughs to overcome barriers that prevent the achievement of the state's statutory energy goals." For example, what technical and/or market barriers or customer pain points would the proposed concept address that would lead to increased adoption of clean energy technology or innovation? Where possible, please provide specific cost and performance targets that need to be met for increased industry and consumer acceptance. For scientific analysis and tools, provide more information on what data and information gaps the proposed concept would help fill, and which specific parties or end users would benefit from the results, and for what purpose(s)?*

Advancement of State Goals

This project advances California's Distributed Energy Resource Integration, Building Decarbonization, and Climate Adaptation goals by:

- Providing standardized reliability assurance for emerging perovskite technologies, reducing qualification barriers for DER deployment.
- Increasing module lifetime and reducing embodied carbon through higher yield and lower failure rates.
- Incorporating wildfire smoke and heat stress data into reliability modeling, ensuring modules perform predictably under California-specific environmental conditions.

Barriers and Targets

[1] See section (a) (1) of Public Resources Code 25711.5 at: https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PRC&sectionNum=25711.5.

Current Barriers:

- Lack of standardized in-line QA methods for perovskite thin films.
- Weak linkage between metrology signals and module reliability.
- Sparse data on California-specific environmental stressors (smoke aerosols, thermal cycling).
- Limited availability of independent engineer (IE) and lender-validated bankability data.

Targets:

Domain	Metric	Target
Metrology	Defect detection accuracy	≥90% vs. destructive FA
Throughput	In-line measurement speed	≥1 m²/min
Reliability correlation	R^2 between metrology and IEC outcomes	≥0.90
Pilot line yield	Improvement	≥15%
Scrap rate	Reduction	≥20%
Uncertainty quantification	Measurement System Analysis (GR&R)	<10%

5. *Please describe the anticipated outcomes if this research concept is successful, either fully or partially. For example, to what extent would the research reduce technology or ratepayer costs and/or increase performance to improve the overall value proposition of the technology? What is the potential of the innovation at scale? How will the innovation lead to ratepayer benefits in alignment with EPIC's guiding principles to improve safety,[2] reliability,[3] affordability,[4] environmental sustainability,[5] and equity?[6]*

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[2] EPIC innovations should improve the safety of operation of California's electric system in the face of climate change, wildfire, and emerging challenges.
[3] EPIC innovations should increase the reliability of California's electric system while continuing to decarbonize California's electric power supply.
[4] EPIC innovations should fund electric sector technologies and approaches that lower California electric rates and ratepayer costs and help enable the equitable adoption of clean energy technologies.
[5] EPIC innovations should continue to reduce greenhouse house gas emissions, criteria pollutant emissions, and the overall environmental impacts of California's electric system, including land and water use.
[6] EPIC innovations should increasingly support, benefit, and engage disadvantaged vulnerable California communities (DVC). (D.20-08-046, Ordering Paragraph 1.) DVCs consist of communities in the 25 percent highest scoring census tracts according to the most recent version of the California Communities Environmental Health Screening Tool (CalEnviroScreen), as well as all California tribal lands, census tracts with median household incomes less than 60 percent of state median income, and census tracts that score in the highest 5 percent of Pollution Burden

Technical Outputs: Open, validated in-line metrology suite; failure library for ≥5 dominant degradation modes.
Economic Impact: Yield ↑ ≥15%, scrap ↓ ≥20%, translating to 4% cost reduction.
Public Benefit:

- Ratepayer savings through longer module lifetimes and fewer replacements.
- Lower embodied carbon and hazardous waste.
- Open datasets enabling California SMEs to enter the PV manufacturing value chain.

Partial success: Even if some tools remain lab-scale, deliver **benchmarked datasets, models, and mitigations** that measurably reduce manufacturing and deployment risk for next iterations — consistent with EPIC RD&D public good.

6. *Describe what quantitative or qualitative metrics or indicators would be used to evaluate the impacts of the proposed research concept.*

- ≥3 validated metrology techniques; ≥90% correlation to destructive FA.
- Pilot-line yield ↑ ≥15% / scrap ↓ ≥20%.
- One independent engineer (IE) letter verifying bankability alignment with PV Evolution Labs (PVEL) Product Qualification Program (PQP) and Renewable Energy Test Center (RETC) PV Module Index (PVMI) standards.

7. *Please provide references to any information provided in the form that supports the research concept's merits. This can include references to cost targets, technical potential, market barriers, equity benefits, etc.*

- **IEC 61215-1:2021** — design qualification/type approval; notable changes include DML & PID integrations.
- **IEC 61730-1:2023** — module safety (construction).
- **IEC TS 63209-1:2021** — extended-stress testing for modules.
- **IEC TS 62804-1:2025** — PID test methods (latest ed.).
- **IEC TS 62782:2016** — cyclic (dynamic) mechanical load test.
- **ISOS perovskite stability consensus (Nature Energy, 2020).**
- **Kiwa PVEL PV Module Reliability Scorecard 2024** (PQP & bankability context).
- **RETC PV Module Index 2025** (beyond-certification practice).
- **DNV — IE/technical bankability expectations** (slides & service briefs).
- **Wildfire smoke & PV in CA (EIA/NREL/UCAR).**

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within CalEnviroScreen, but do not receive an overall CalEnviroScreen score due to unreliable public health and socioeconomic data.

8. *The EPIC 5 Investment Plan must support at least one of five Strategic Goals:*[7]
    a. *Transportation Electrification*
    b. *Distributed Energy Resource Integration*
    c. *Building Decarbonization*
    d. *Achieving 100 Percent Net-Zero Carbon Emissions and the Coordinated Role of Gas*
    e. *Climate Adaptation*

    Please describe in as much detail as possible how your proposed concept would support these goals.

- **DER Integration & Building Decarbonization:** QA methods ensure modules entering CA DER/building markets meet **61215/61730-anchored** expectations, easing interconnection and lowering lifecycle costs.
- **Achieving 100% Net-Zero:** Higher yield & reliability reduce LCOE and accelerate deployment of high-efficiency PV.
- **Climate Adaptation:** Explicitly incorporates **wildfire-smoke/heat** into modeling and qualification-adjacent testing for CA resilience.

California ratepayers benefit through **greater reliability, lower costs, and improved safety** of solar energy systems. By ensuring that perovskite modules manufactured for the state's grid meet stringent quality standards, this project:

- Reduces module failures and replacement costs, lowering levelized cost of electricity (LCOE).
- Improves manufacturing yields and resource efficiency, reducing embodied carbon and waste.
- Creates technical foundations for domestic manufacturing jobs and supply-chain resilience.
- Provides open data and standardized practices that enhance equity by lowering entry barriers for smaller solar manufacturers and project developers.
- The project will engage California small manufacturers and technical colleges for technician training in advanced PV metrology and reliability testing, contributing to a skilled local workforce.

[7] In 2024 the CPUC adopted five Strategic Goals to guide development of the EPIC 5 Investment Plan. A description of the goals can be seen in Appendix A of CPUC Decision 24-03-007 available at:
https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M527/K228/527228647.PDF

About EPIC

The CEC is one of four EPIC administrators, funding research, development, and demonstrations of clean energy technologies and approaches that will benefit electricity ratepayers of California's three largest investor-owned electric utilities.

EPIC is funded by California utility customers under the auspices of the California Public Utilities Commission.

To learn more about EPIC, visit:
https://www.energy.ca.gov/programs-and-topics/programs/electric-program-investment-charge-epic-program

EPIC 5 documents and event notices will be posted to:
https://www.energy.ca.gov/proceeding/electric-program-investment-charge-2026-2030-investment-plan-epic-5

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