DuraMAT
Durable Module Materials Consortium

DuraMAT Capability 5
Field Testing:
Overview and Capability Development Activities

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DuraMat Workshop

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Energy Materials Network
U.S. Department of Energy
NREL
Sandia National Laboratories
BERKELEY LAB
SLAC NATIONAL ACCELERATOR LABORATORY

Motivation for Field Deployment

- Field deployment is a key aspect of confirming the durability of new module materials and module designs
- Support DuraMat capabilities:
  - *Accelerated Module Testing* - Validates the results by confirming the field relevance of degradation mechanisms and acceleration factors
  - *Predictive Simulation* and *Materials Discovery* - Demonstrates the bankability of new materials
- Facilitates technology transfer and commercialization of the most promising materials

Approach: Leverage DOE-RTCs

Regional Test Centers
Differentiating PV Quality

Regional Test Centers for Photovoltaic Technologies

Powered by SunShot
U.S. Department of Energy

www.pvrtc.org

The five DOE Regional Test Centers conduct extensive field-testing to:

- Assess and validate the performance and reliability of new PV technologies and increase the confidence of manufacturers, integrators and the financial community in the bankability of those technologies.
- Better understand validation standards
- Support the DOE SunShot Initiative goals by helping accelerate innovation in the solar sector.

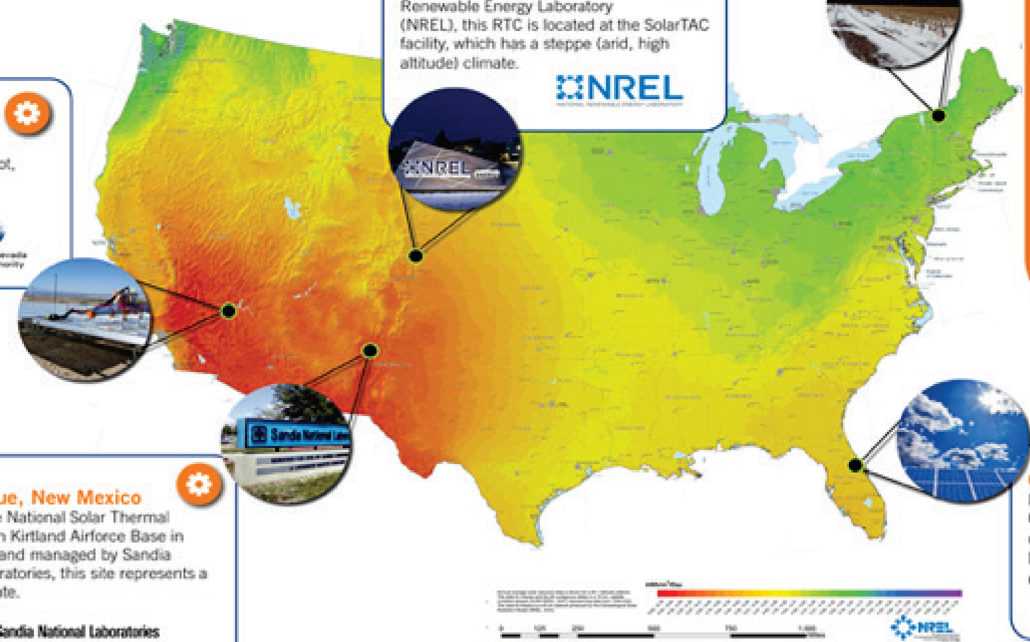
Develop predictive performance models, collect detailed operations and maintenance data, and quantify performance in four areas:

- Design Evaluation and Baseline Testing
- Performance and System Monitoring
- Analysis and Modeling
- Reliability and Safety Key

Williston, Vermont
This site is located at an IBM facility outside Burlington and will provide important data on PV performance under harsh, winter conditions.
Green Mountain Power · IBM · The University of Vermont

Denver, Colorado
Managed by the National Renewable Energy Laboratory (NREL), this RTC is located at the SolarTAC facility, which has a steppe (arid, high altitude) climate.
NREL

Las Vegas, Nevada
Located at a site managed by Southern Nevada Water Authority this site represents a hot, arid climate.
UNLV · Southern Nevada Water Authority



Vermont Photovoltaic Regional Test Center

Albuquerque, New Mexico
Located at the National Solar Thermal Test Facility on Kirtland Airforce Base in Albuquerque and managed by Sandia National Laboratories, this site represents a hot, arid climate.
Sandia National Laboratories

Orlando, Florida
Managed by the Florida Solar Energy Center and located at the University of Central Florida, this RTC will test PV performance in a hot tropical environment.
FSEC

Project Synergies

PV Lifetime

- Assess lifetime and durability of commercially available PV modules.
- Multi-year, multi-climate effort conducted at the RTC's
- Grid-tied PV systems that reflect U. S. commercial market share.
- 10kW minimum system size (30+ modules).
- 100% pre-deployment flash testing
- In-situ IV sweeps using novel hardware (Pordis LLC)
- Data obtained from these systems will be used to construct degradation rate curves with high degree of fidelity.

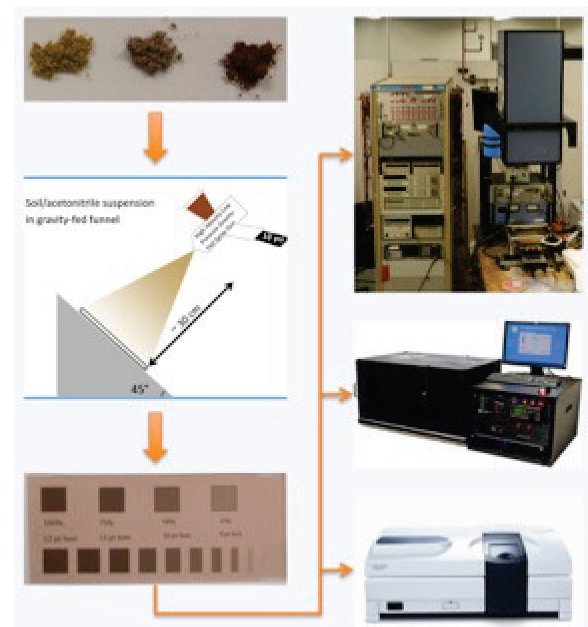
Soiling

Outdoor:

- Performance loss stations in operation at most RTC sites

Laboratory:

- Tools to study fundamental impacts to PV performances
    - Artificial soiling capability
    - Analytical methods to quantify loss, characterize interaction of incident light with surface soil



Scalable Deployments from Components to Systems

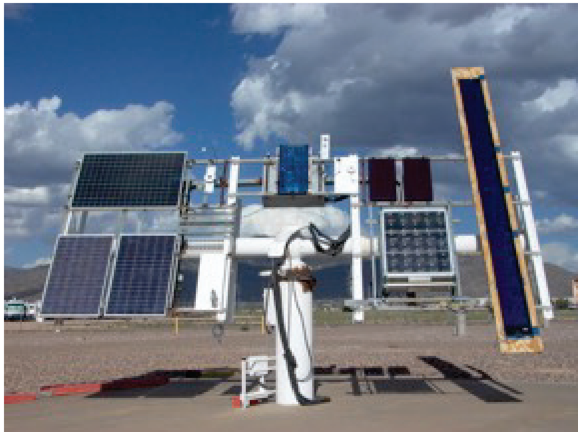
Component Level: Connector Reliability Study

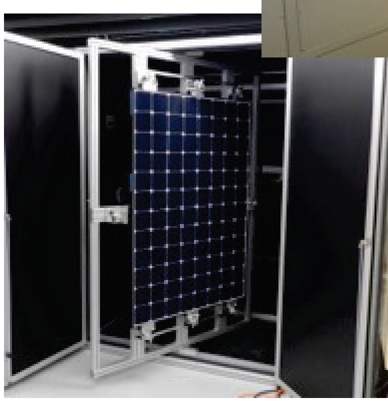
System Level: Prototype flexible CIG modules installed on roof pans

- 1-month to multi-year installations
- Evaluate materials and component reliability and degradation rates
- Flexible, stand-alone platforms at any orientation
- Tracker-mounted for maximum sun exposure
- Can be set up to be completely autonomous
- Configured per experimental needs

- Minimum 1-year installations typical
- Evaluate system reliability and degradation rates
- Validate energy yield calculations
- DC Voltage and Current (string and combiner)
- Module Temperature
- Localized Irradiance Sensors

Characterization: Linking Outdoor Performance with Laboratory Diagnostics





Outdoor Capabilities

- Two fully programmable Two-Axis trackers
- Large, flexible mounting surfaces
- Single cell packages to full scale modules, complicated form factors
- Full electrical performance (IV curves, temperature coefficients, angle of incidence)

Indoor Module Lab

- Industry standard AAA 1-sun flash tester
- Custom Electroluminescence (EL) enclosure, mini-modules to full-size
- Temperature controlled light-soaking chamber, integrated IV sweep capability

Cell and Device Lab

- Reflectance and transmission measurements, Cary Spectrophotometer
- Solar cell spectral response/quantum efficiency measurements
- 2 1-sun cell testers

CAPABILITY DEVELOPMENT PROJECTS

1. Non-Destructive module evaluation methods
2. Data collection development

Non-destructive module evaluation methods

Motivation:

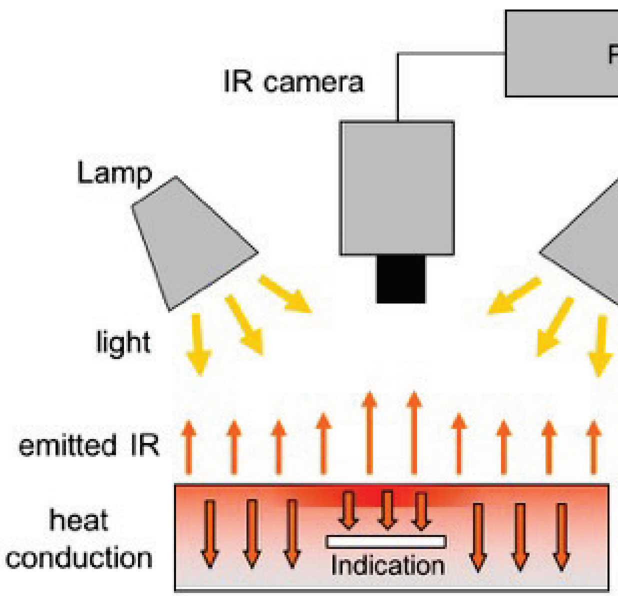
- Challenge: Identification and characterization of manufacturing defects and field failures
  - Size - too large to fit in most common laboratory inspection instruments.
  - Packaging – designed to last 25+ years, extraction of smaller samples is difficult without creating additional damage (and is destructive)
  - Existing techniques (Electroluminescence and Lock-in Infrared Thermography) more suited to identifying cell failures, not package failures.

Project Goals:

- Develop a suite of non-destructive module field evaluation methodologies.
- Address mechanical degradation of the module package (delamination, cracking, etc) and physical/chemical materials degradation (embrittlement, oxidation, etc).
- Candidate methods include;
  - Pulsed IR Thermography, Ultrasonic Diagnostics, FTIR, Raman Spectroscopy, Reflectance, Wet leakage current.
- Where possible, leverage existing methods established in other industries, e.g. Aerospace.

Example Capabilities: Pulsed Thermography

- A brief pulse of light is applied to the target
- High frequency IR imaging allows the thermal wave to be observed as it propagates through the target
- Internal flaws such as debonding, voids or inhomogeneous materials impede the thermal wave, creating thermal contrast.
- Can be applied in the field
- Established method for aerospace applications



Designation: E2582 – 07 (Reapproved 2014)

Standard Practice for
Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications[1]

This standard is issued under the fixed designation E2582; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This practice describes a procedure for detecting subsurface flaws in composite panels and repair patches using Flash Thermography (FT), in which an infrared (IR) camera is used to detect anomalous cooling behavior of a sample surface after it has been heated with a spatially uniform light pulse from a flash lamp array.

1.2 This practice describes established FT test methods that are currently used by industry, and have demonstrated utility in quality assurance of composite structures during post-manufacturing and in-service examinations.

1.3 This practice has utility for testing of polymer composite panels and repair patches containing, but not limited to, bismaleimide, epoxy, phenolic, poly(amide imide), polybenzimidazole, polyester (thermosetting and thermoplastic), poly(ether ether ketone), poly(ether imide), polyimide (thermosetting and thermoplastic), poly(phenylene sulfide), or polysulfone matrices; and alumina, aramid, boron, carbon, glass, quartz, or silicon carbide fibers. Typical as-fabricated geometries include uniaxial, cross ply and angle ply laminates; as well as honeycomb core sandwich core materials.

1.4 This practice has utility for testing of ceramic matrix composite panels containing, but not limited to, silicon carbide, silicon nitride and carbon matrix and fibers.

1.5 This practice applies to polymer or ceramic matrix composite structures with inspection surfaces that are sufficiently optically opaque to absorb incident light, and that have sufficient emissivity to allow monitoring of the surface temperature with an IR camera. Excessively thick samples, or samples with low thermal diffusivities, require long acquisition periods and yield weak signals approaching background and noise levels, and may be impractical for this technique.

1.6 This practice applies to detection of flaws in a composite panel or repair patch, or at the bonded interface between the panel and a supporting sandwich core or solid substrate. It does not apply to discontinuities in the sandwich core, or at the interface between the sandwich core and a second panel on the far side of the core (with respect to the inspection apparatus).

1.7 This practice does not specify accept-reject criteria and is not intended to be used as a basis for approving composite structures for service.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
D3878 Terminology for Composite Materials
E1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions*—Terminology in accordance with Terminologies D3878 and E1316 and shall be used where applicable.

3.2 *Definitions of Terms Specific to This Standard:*
3.2.1 *aspect ratio*—the diameter to depth ratio of a flaw. For irregularly shaped flaws, diameter refers to the minor axis of an equivalent rectangle that approximates the flaw shape and area.

3.2.2 *discrete discontinuity*—a thermal discontinuity whose projection onto the inspection surface is smaller than the field of view of the inspection apparatus.

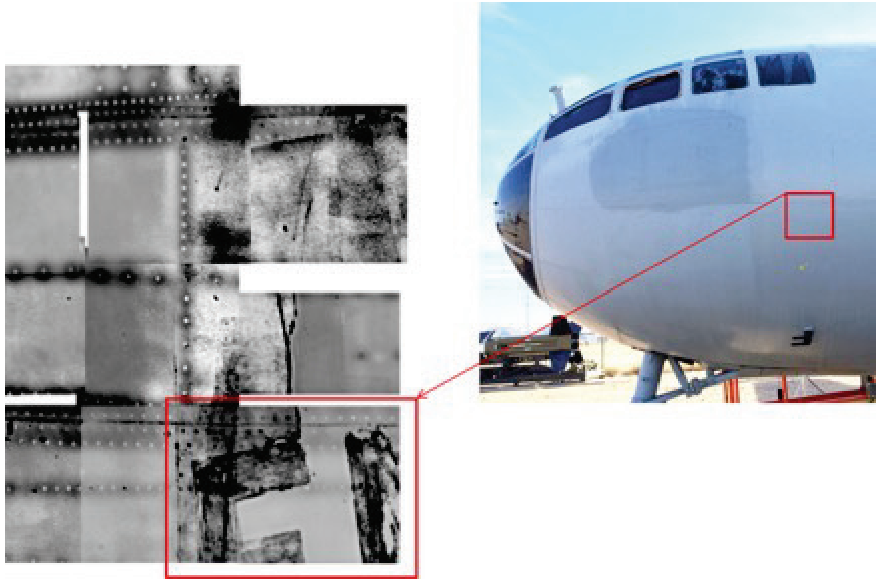
3.2.3 *extended discontinuity*—a thermal discontinuity whose projection onto the inspection surface completely fills the field of view of the inspection apparatus.

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.10 on Specialized NDT Methods.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Pulsed Thermography: Example Application

- Field inspection of a WWII B-29 Superfortress during restoration
- Subsurface structural elements are easily visible along with details of painting history.



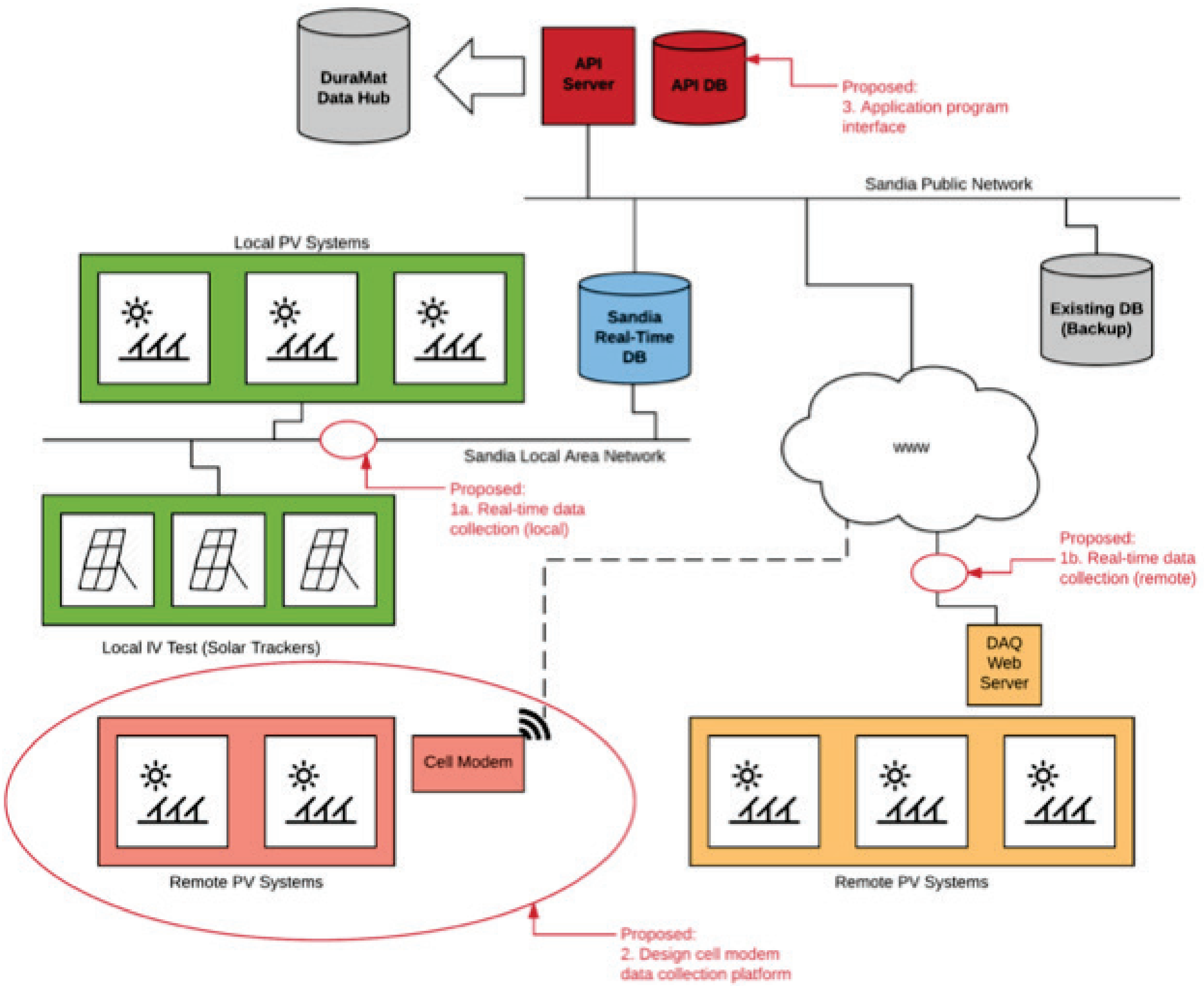
Data Collection Development

Key Tasks:

1. Data Collection upgrades
   - Local and remote sites
   - Reliability
   - Transmission frequency
   - Quality control checks

2. Remote Cell modem platform

3. Ingestion into DuraMat data hub



Thank You

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