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Discover, Develop, and De-Risk module materials, architectures, accelerated testing protocols,data analytics, and financial models to reduce the LCOE of solar energy

Field-Aged Module Library

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SAND2020-xxxx C

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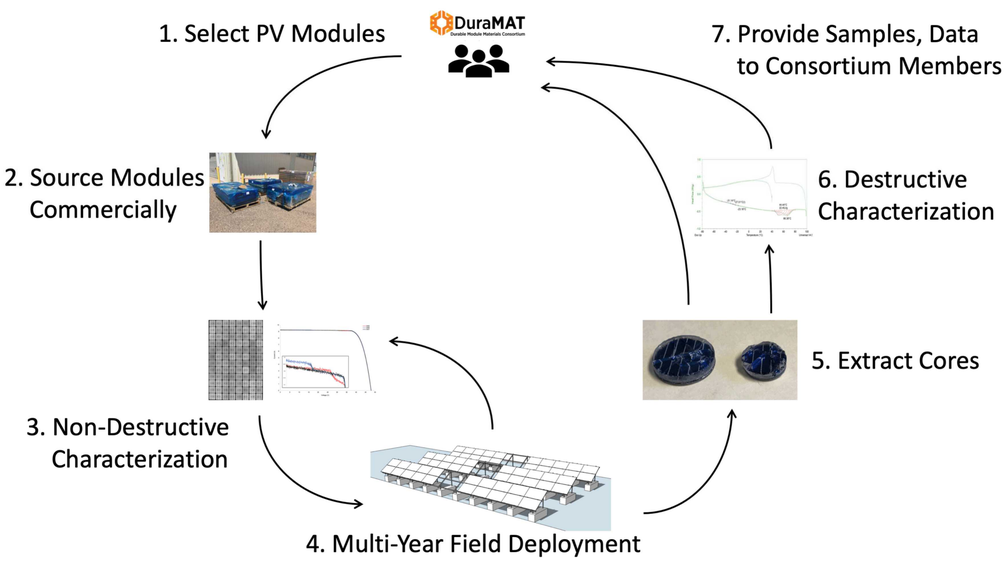
Capability Goal: Characterize material degradation from natural aging in commercially relevant PV modules

- Acquire commercially available PV modules from independent vendors
- Deploy alongside existing operational systems for extended timeframe (upwards of 10 years)
- Remove single modules of each type at a fixed interval for destructive characterization to track changes in packaging materials
- Utilize breadth of modules to develop and validate new field forensics methods

Manufacturer	Model	Cell Type
Canadian Solar	CS6K-300MS Quintech	Mono-Si
Hanwa Q-Cells	Q.Peak-G4.1 300	Mono-Si
Jinko	JKM270PP-60	Multi-Si
LG	LG320N1K-A5	Mono (N)
Mission Solar	MSE300SQ5T	Mono PERC
Panasonic	VBHN330SA17 HIT	HIT N-type



Characterization Methods

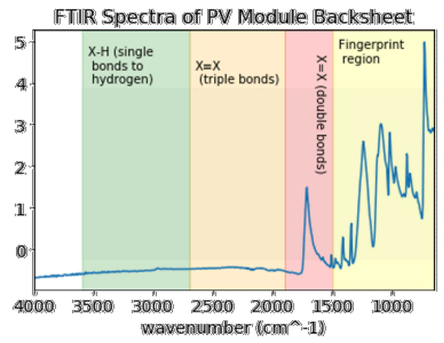
Laboratory Non-Destructive
- Indoor Flash Test
- Electroluminescence
- Infrared thermography
- Visual

ND Field Forensics
- FT-IR
- UV Fluorescence
- *Yellowness Index (YI)*
- *Gloss*
- *Field Raman*
- *Near IR spectroscopy*

Laboratory Destructive
- Differential Scanning Calorimetry (DSC)
- FT-IR
- Thermal Gravimetric Analysis (TGA)
- X-ray Fluorescence
- SAXS/WAXS
- Raman Spectroscopy

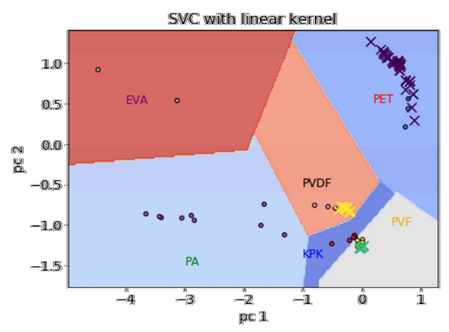
Non-Destructive Field Forensics - FTIR

- Transform measured spectra using standard normal variant method and run Principal Component Analysis (PCA).
- Train a Support Vector Machine (SVM) on the PCA results from the known materials
- Use SVM to classify the unknown materials Validate the classification graphically
- Interpret chemical signatures



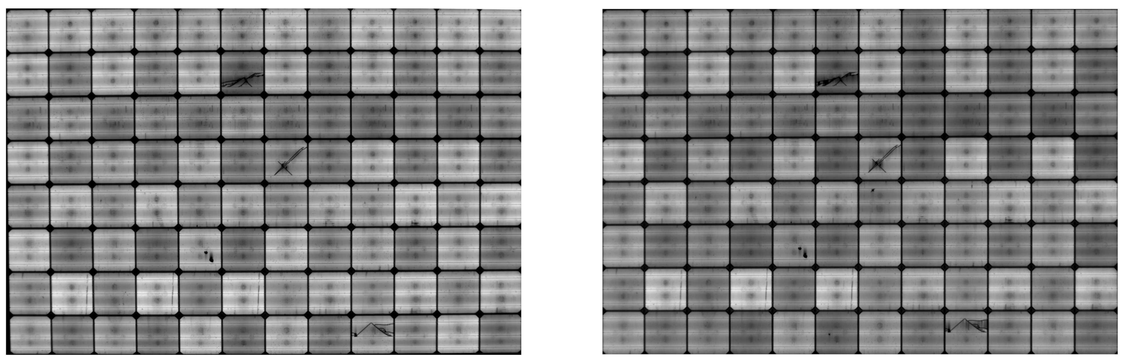
Classification accuracy is expected to improve as more data is added

Manufacturer	# mods	BS Outer Layer
Canadian Solar	10	PVDF/PMMA
Hanwa Q-Cells	10	PET
Jinko	10	PVF
LG	10	PET
Mission Solar	10	PET
Panasonic	10	PET



Non-Destructive Laboratory

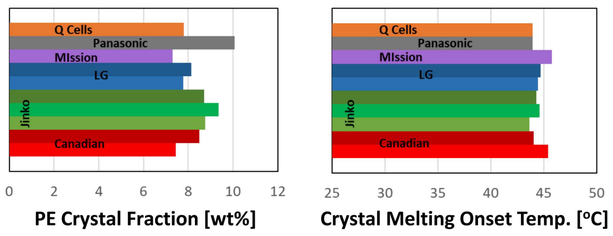
Manufacturer	Rating	Initial	Year 1	% change
Canadian Solar	300	300 ± 2	295 ± 1	-1.8
Hanwa Q-Cells	300	302 ± 1	295 ± 1	-2.2
Jinko	270	273 ± 1	268 ± 1	-1.9
LG	320	319 ± 1	316 ± 1	-0.9
Mission Solar	300	292 ± 1	289 ± 1	-1.0
Panasonic	330	330 ± 0	330 ± 1	+0.2



Initial — **Panasonic** — Year 1

Laboratory Destructive

- Preliminary Raman spectroscopy of BS outer layers was consistent with FT-IR material identification
- DSC characterization of front-side encapsulant layer showed similar crystal melting and glass transition behavior between all modules



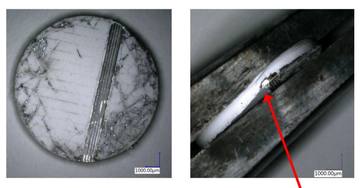
Sample Cores

- Two core samples from each module were extracted for laboratory destructive characterization. Additional cores available to DuraMAT partners
- Razor blade used to cut along cell surface on both sides, exposing front-side and back-side encapsulant surface
- Top and side view of back encapsulant + full backsheet:

Mission Solar

Black inner layer, BS layer or encapsulant?
Same seen on LG modules

Panasonic



Extremely thin encapsulant layer
Ribbon pressed deep into BS

Q-Cells

Representative of remaining modules
All white BS + distinct transparent encapsulant layer

- Small- and wide angle X-ray scattering (SAXS/WAXS) was conducted at SLAC on encapsulant + full BS peeled from back side of cell (*samples pictured lower left)*
- SAXS patterns show evidence of regularly spaced polycrystalline domains in all except LG and Panasonic samples
- Canadian Solar and Mission Solar samples have anisotropic scattering due to alignment of domains along an axis (likely along machine-direction of at least one BS layer)