



Thermal-mechanical-electrical model for PV module-level mechanical failure mechanisms

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Energy Efficiency &
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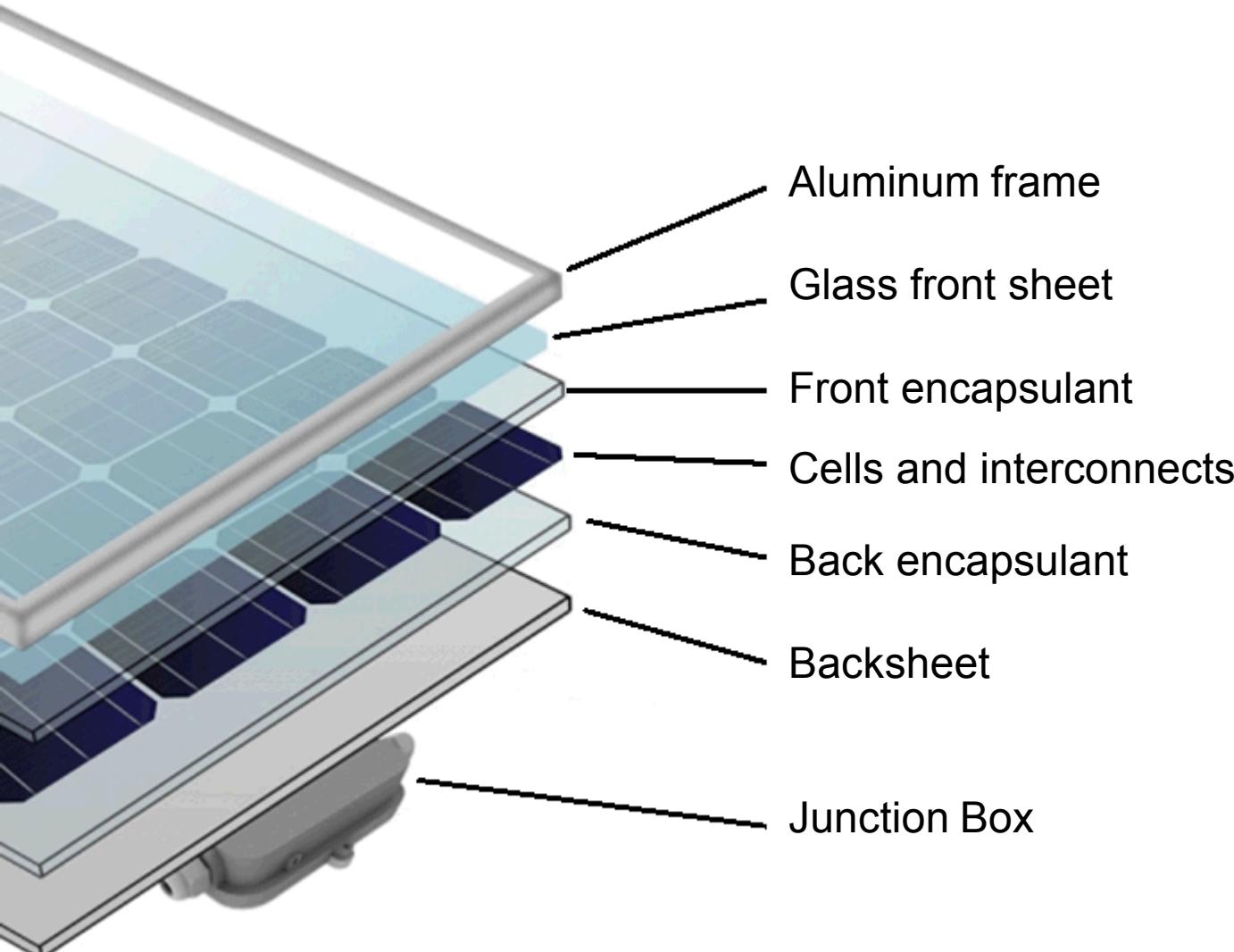
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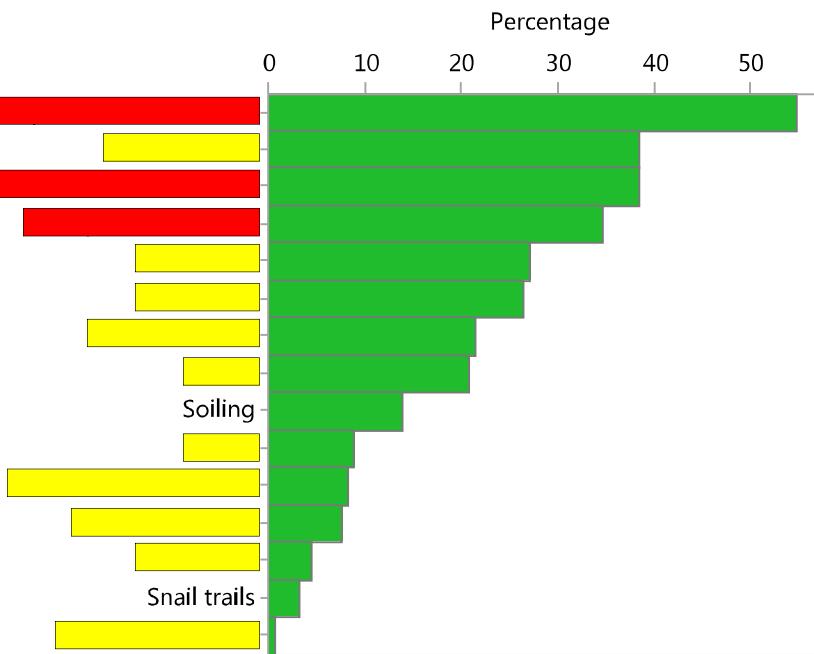
- PV modules and degradation mechanisms
- Design questions to be answered with modeling
 - Benefits of a module-level model; existing capabilities; previous efforts
- Model validation capabilities
- Capability development plan

DuraMAT Capability Area 2: Predictive Simulation

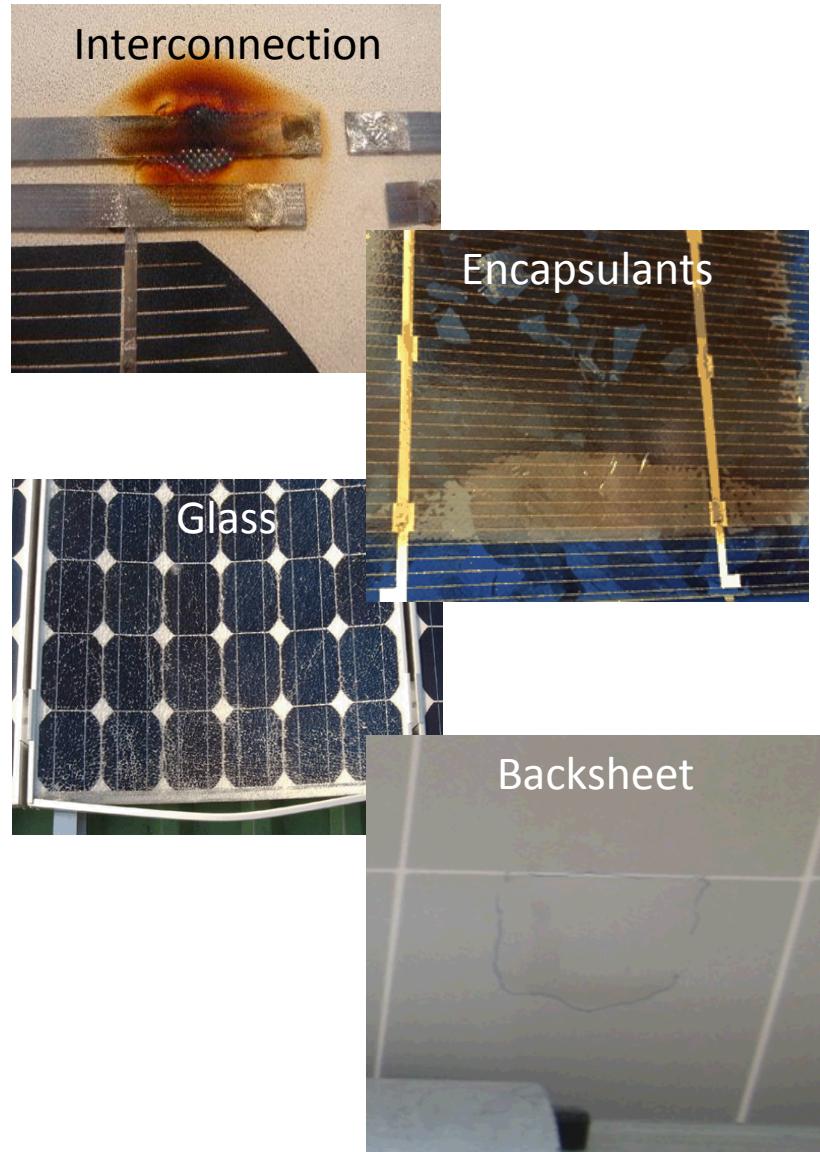
“This capability will be a suite of modeling and simulation tools, model workflows, and a community of experts who work in concert with experiments and data analytics... to help interpret and enrich existing test/experimental data, design durability-testing experiments, and help create design rules for Materials Discovery”



Thermo-mechanical-electrical failure mechanisms



PV failures and degradation modes reported in literature

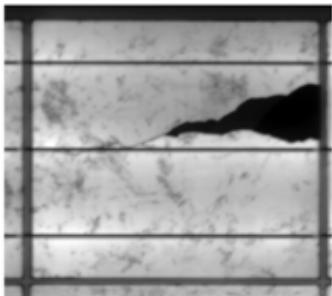


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Module design questions to be answered by modeling

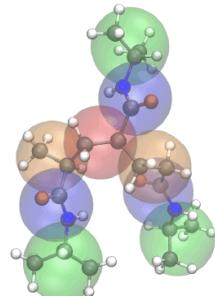


What is the driving force for delamination between layers?



What environments are most damaging?

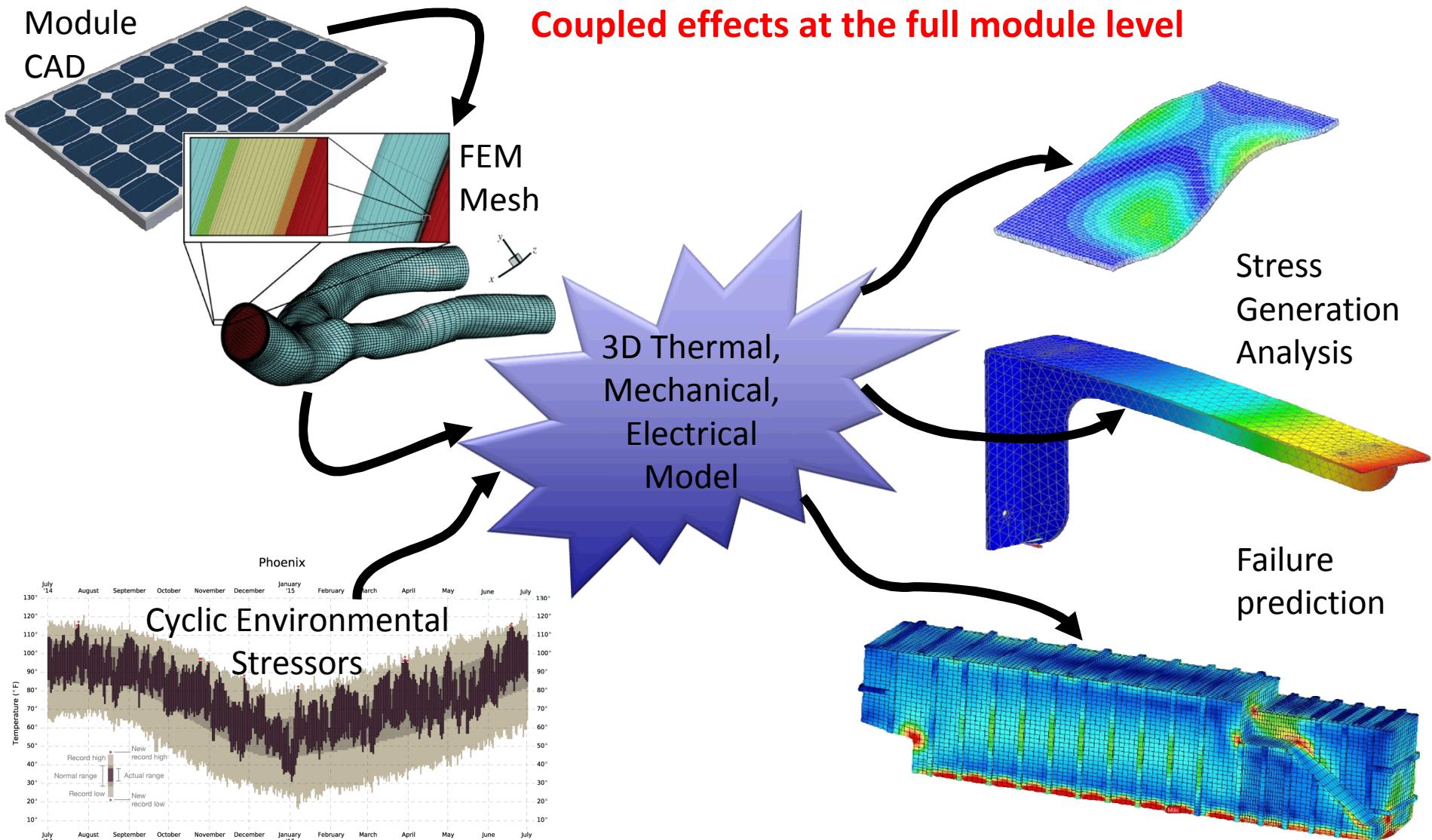
What would the ideal material properties of an encapsulant be to avoid cell cracking and delamination?



Are we *really* capturing a lifetime of exposure in accelerated tests?

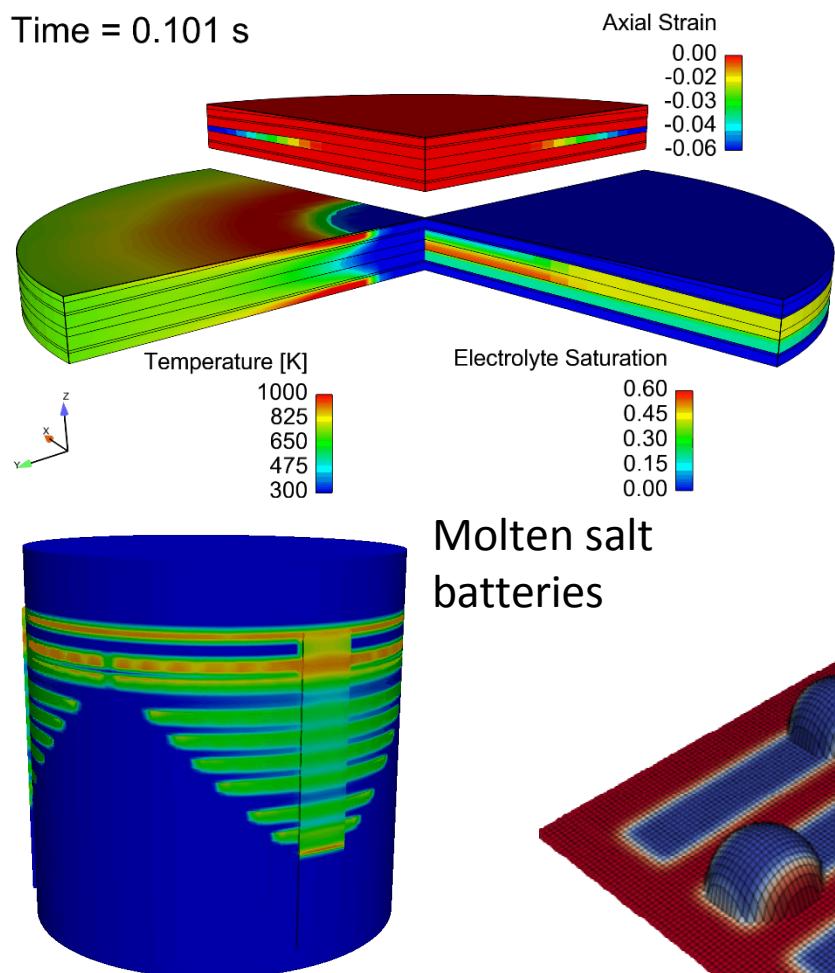


Thermal-mechanical-electrical module-level model capability

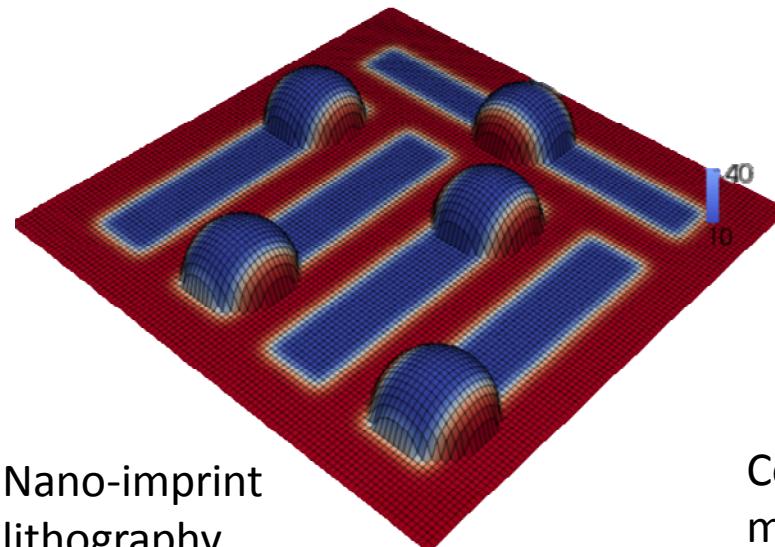


3D thermal-mechanical-electrical modeling capabilities

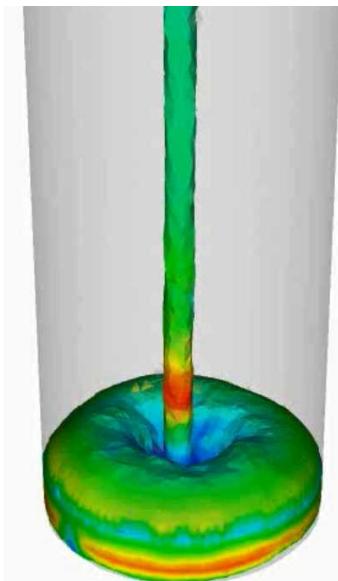
Time = 0.101 s



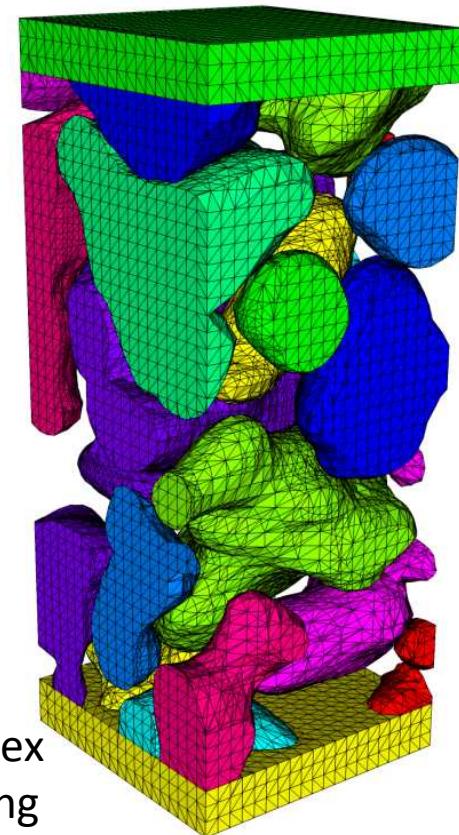
Molten salt
batteries



Nano-imprint
lithography



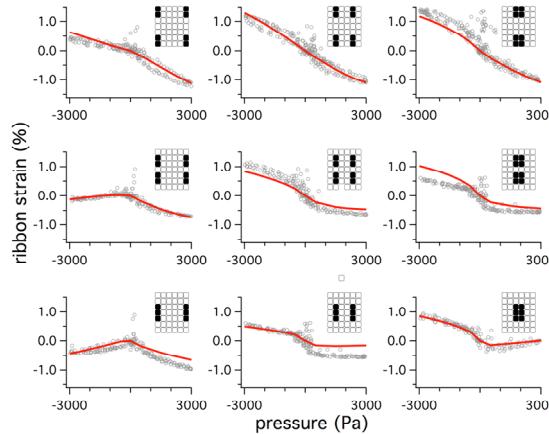
Constitutive
modeling:
non-Newtonian,
visco-plastic,
elasto-plastic



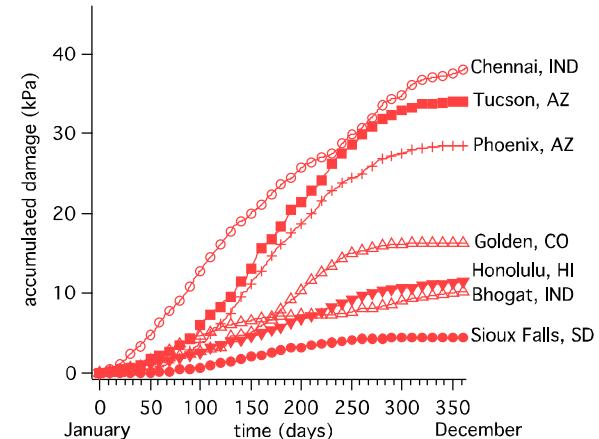
Complex
meshing

Previous modeling efforts at NREL

- 3D model of a flat plate PV module to simulate interconnect ribbon strain for module level loading
- 2D model of a flat plate PV module to simulate accumulation of solder thermal fatigue damage through outdoor deployment



Cell-to-cell ribbon strain vs. position in module



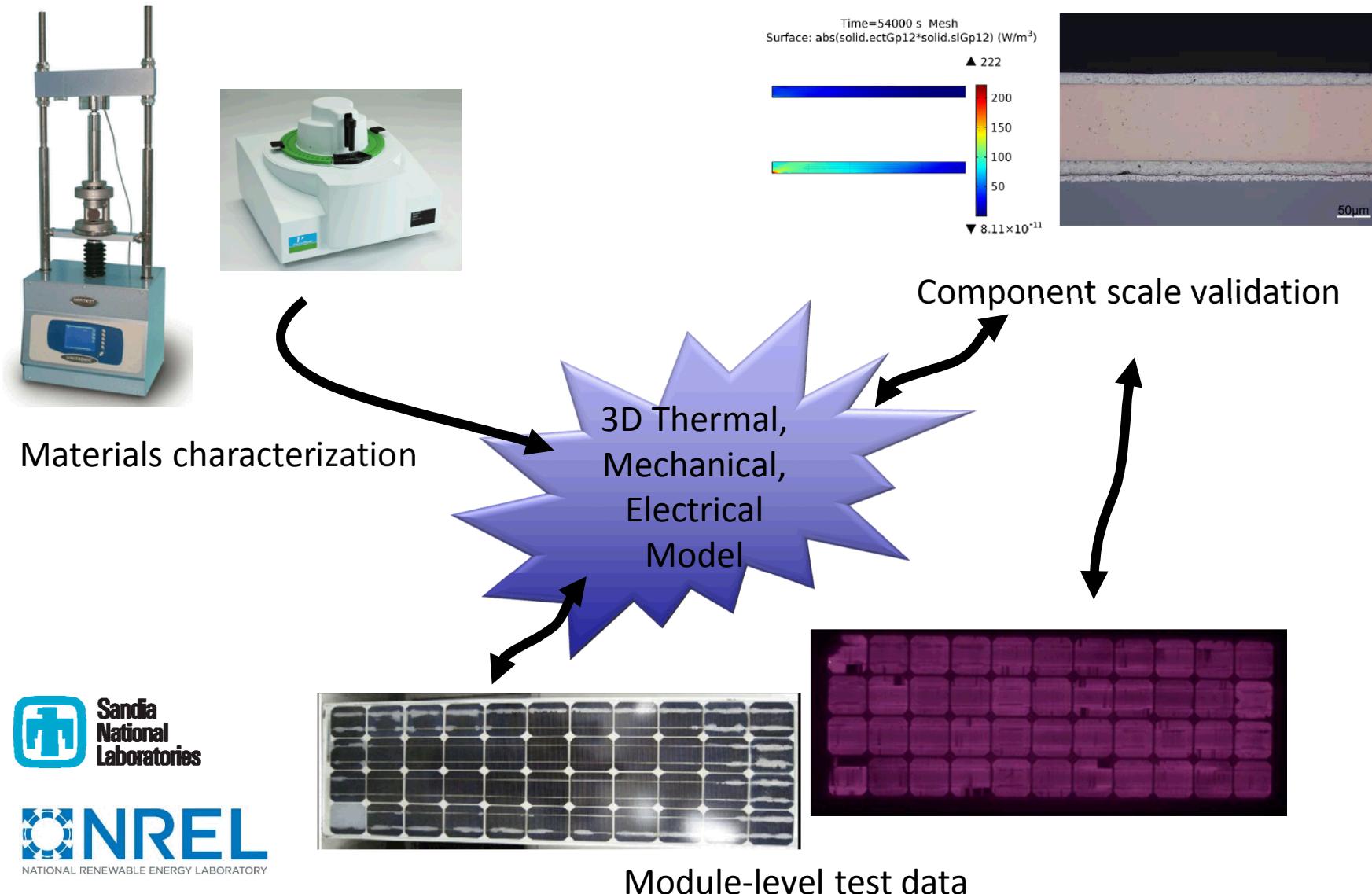
Damage rate vs. Geographical Location

- Results have elucidated:
 - Equivalency between mechanical test conditions and a 30 year exposure
 - What climate conditions drive fatigue damage rate

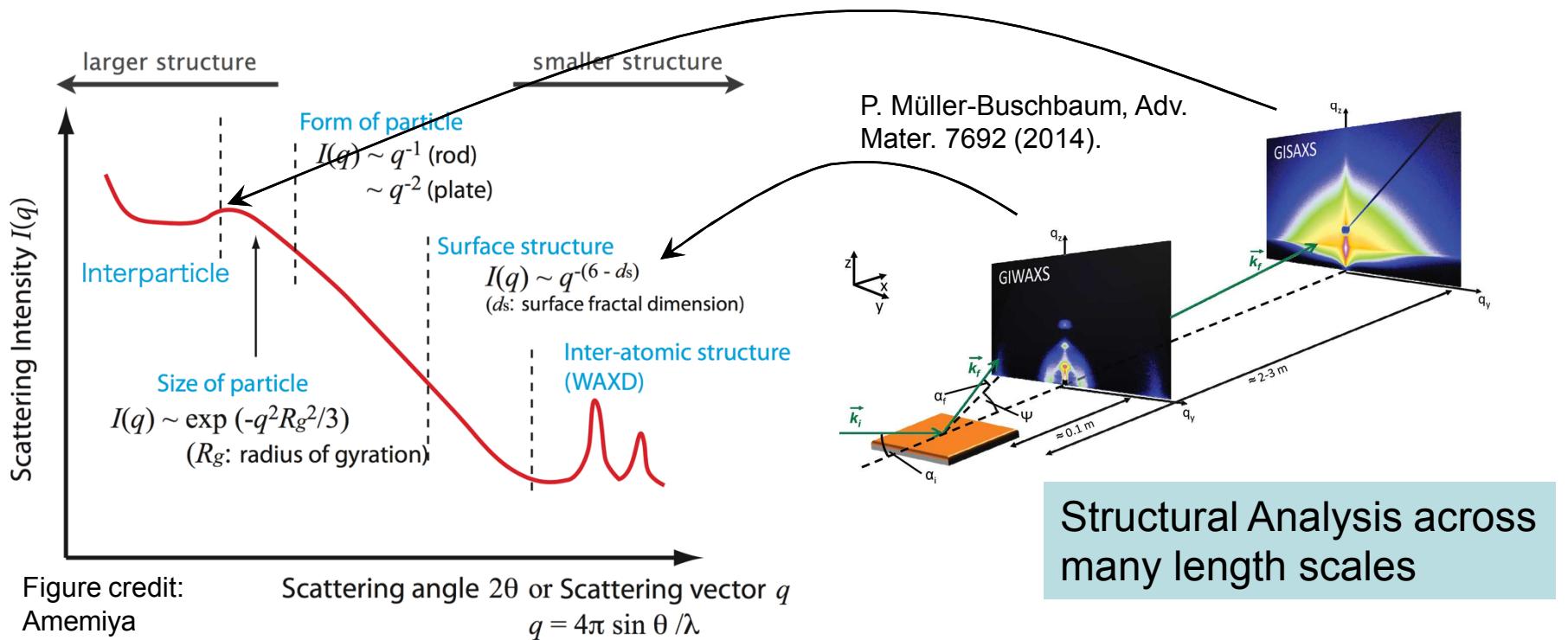
With existing modeling capabilities, much more is possible!

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- **Model validation capabilities**
- Capability development plan

Thermal-Mechanical validation capabilities



Thermal-mechanical validation capabilities



Operando Structural & Microstructural analysis

- Understand the effects of aging & thermal cycling
- Applied stressors:
 - Atmosphere
 - Humidity
 - Temperature
 - Light
 - Electric field bias
 - Mechanical loading

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Capability development plan

- Scope problem
 - Define the problem (nominal geometry and materials, types of stressors to include)
 - Scope the simulation (single model or coupled workflow? What are key degradation mechanisms to target?)
 - Identify property needs
- Build constitutive models
- Component-level modeling
 - Build model capability for critical components
 - Validate component-level models
- Module-level modeling
 - Combine component concepts into module-scale model workflow
 - Validate against real-world module data

Working with Sandia and DuraMAT

- Capability Area goal is “[a suite of modeling and simulation tools and a community of experts, available to DuraMAT partners and industry/academia teams]”
 - Sandia will stand up and maintain the simulation code and capability
 - Intermediate results to be published and disseminated to the community of practice
 - Intent is for all Sandia modeling expertise to be available to the DuraMAT network
- Collaboration opportunities exist:
 - DuraMAT Solicitation of Letters of Interest
 - Sandia-specific avenues
 - Cooperative Research and Development Agreement (CRADA)
 - Strategic Partnership Programs (SPP); Work For Others (WFO)

Questions?



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