Perovskite PV Accelerator for Commercializing Technology (PACT)

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https://pvpact.sandia.gov

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Acknowledgements

- This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office Award Number 38050.
- The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

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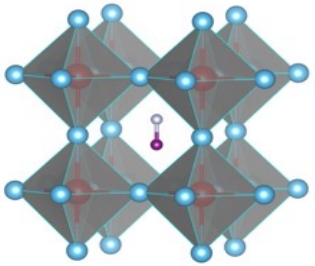
What are Perovskite Photovoltaics?

- "Perovskite" refers to a crystal structure.
- Metal Halide Perovskite PV has a range of chemical compositions:

ABX_3



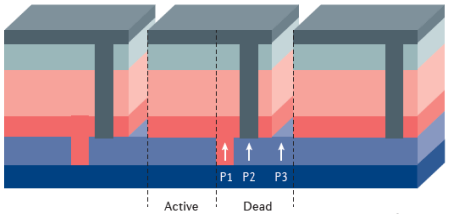
A= Pb, Sn, Ge, Bi, Sb, …
X=halides (Cl, Br, I)
B= Organics or metal (Cs)

- To make things even more complex, alloys are possible.

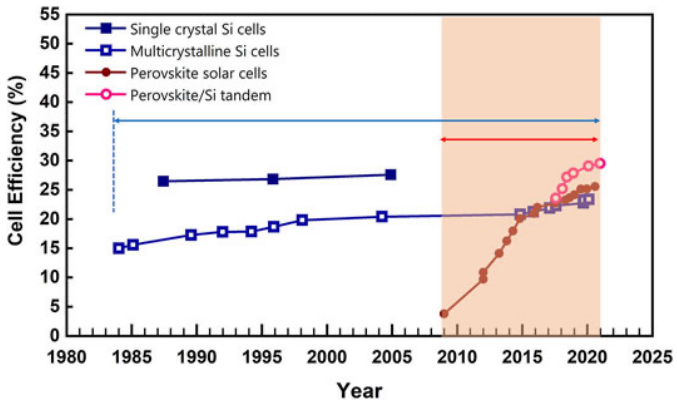
History

- First perovskite PV cell made in 2009
  - <3% PCE (power conversion efficiency)
- PCE has risen fast
  - >= 25.6% today at the cell level (limit – 33%)
  - It took 40 years to achieve this PCE for c-Si.
- Promise of low cost manufacturing
  - Low temperature
  - Solution processing
  - High speed manufacturing
- New result from NREL led team (Jiang et al. 2022):
  - Perovskite solar cell with PCE>25%
  - Reactive surface engineering breakthrough – electric field helps to stabilize and boost efficiency.
  - Retained 87% of initial PCE after over 2,400 h (1000 W/m^2 and 55°C in air (encapsulated))

Monolithic module integration



Source: (Li et al., 2018)



Zhang et al., 2022

Perovskite PV Performance Targets in the US

- DOE SETO has set performance targets for perovskite modules
  - Higher efficiency
  - Larger areas
  - Durability
  - Manufacturing scale

Revised Performance Target Matrix:

Configuration	Aperture Area PCE[1]	Total Module Area[2]	Durability	Sample Population Requirements
Single Junction	18% PCE	>=500 cm^2 with at least 4 interconnected cells	Pass IEC 61215 Module Quality Test (MQT) 10, 11, 13 and 21 and ISOS-L-2 at specified durations with <10% relative performance loss per test[3] 6 months continuous outdoor testing with <3% relative degradation overall and <1% degradation in the final 3-month span[4]	>1 kW total, at least 20 modules for outdoor testing[5]
PVSK-only Tandems	24% PCE			
Hybrid Tandems	27% PCE			

Source: SETO

How to Support the Commercialization?

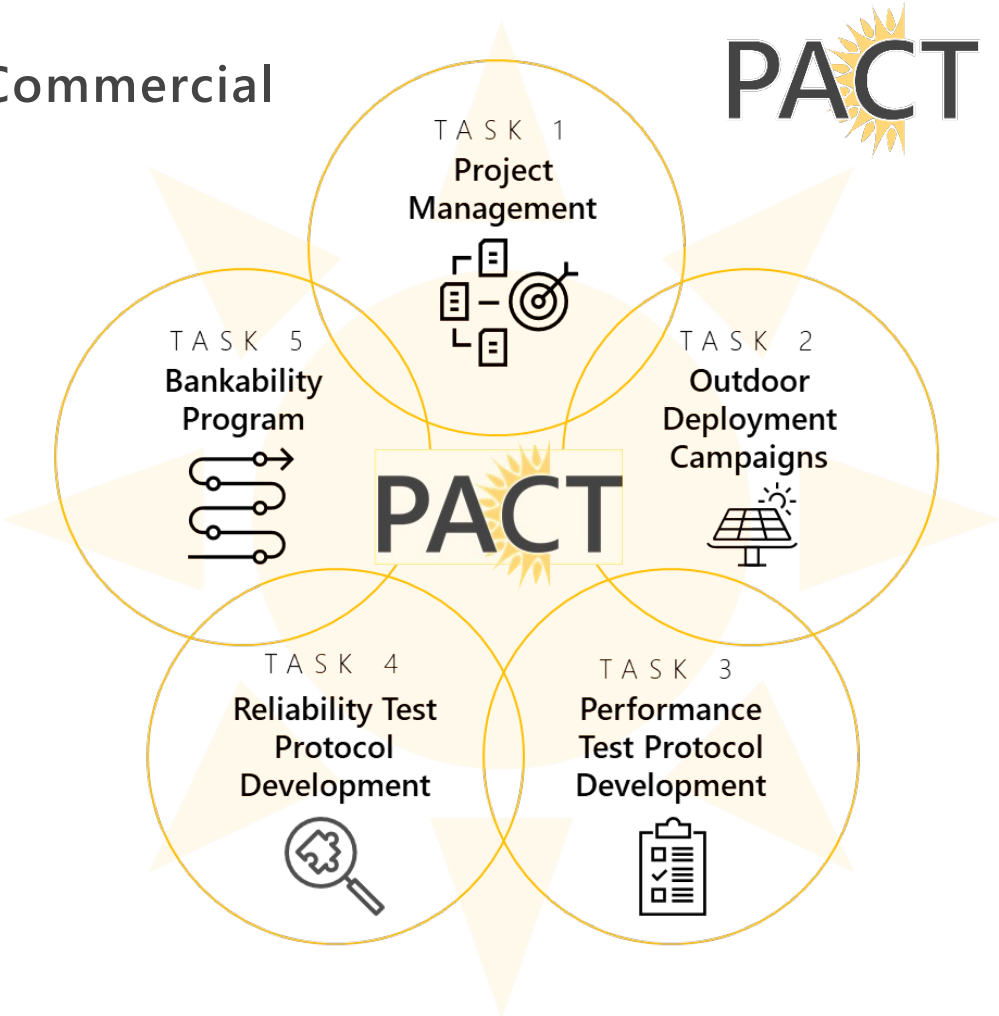
PACT

- We need a common set of testing protocols (performance, reliability)
  - Tests should represent/reproduce **relevant** conditions/failures seen in the field.
  - For example: Light and elevated temperature testing appears to be important. Extended STC testing gives a false impression of reliability.
- Industry needs to demonstrate that high efficiency, reliable perovskites can be scaled to larger sizes, be made using commercial manufacturing equipment, and produced at a rapid rate.
- Support new companies with testing, manufacturing, and bankability services.
- More research on sustainability potential of perovskite PV.

PACT: Perovskite PV Accelerator for Commercial Technologies

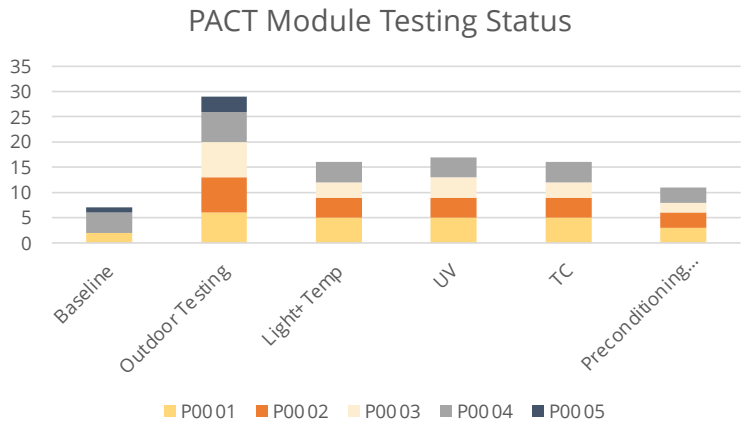
- Sandia is leading a multilab validation center (Team includes NREL, LANL, EPRI, Black & Veatch, and CFV Labs). https://pvpact.sandia.gov

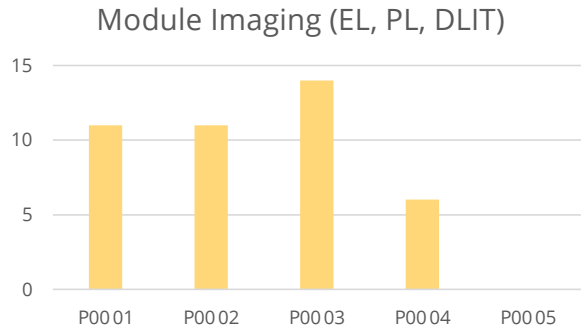
- We are partnering with four universities to supply perovskite mini-modules for testing.
  - University of North Carolina
  - University of Toledo
  - University of Washington
  - SLAC/Stanford University



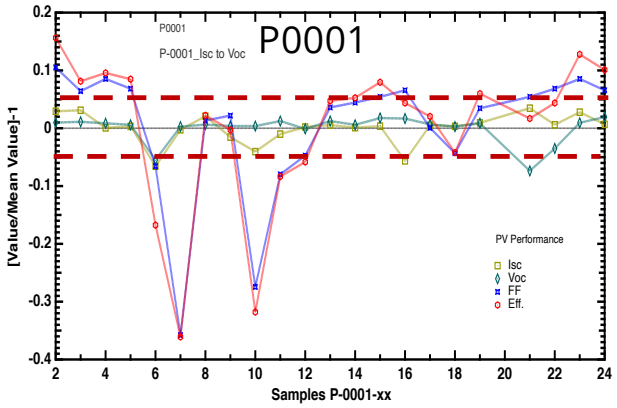
PACT Module Testing Status

- We have received >100 modules from our university partners.
- Distributed to
  - Baseline and controls (7)
  - Outdoor testing (29)
  - Light and elevation temperature (16)
  - UV (17)
  - Thermal cycling (16)
  - Preconditioning development (11)
- Module imaging (42)

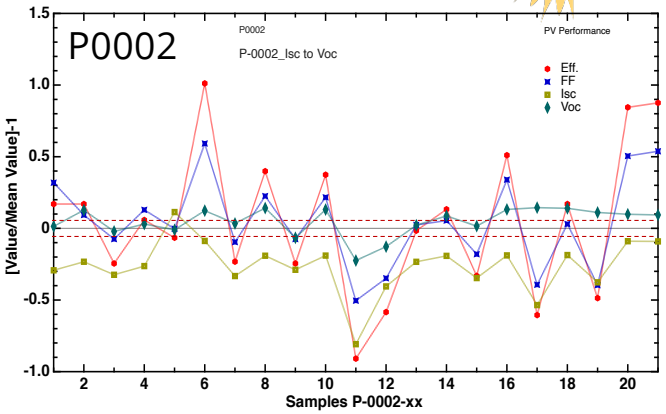


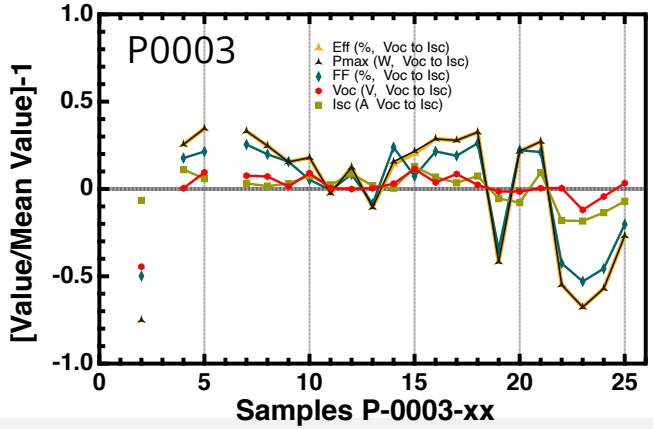


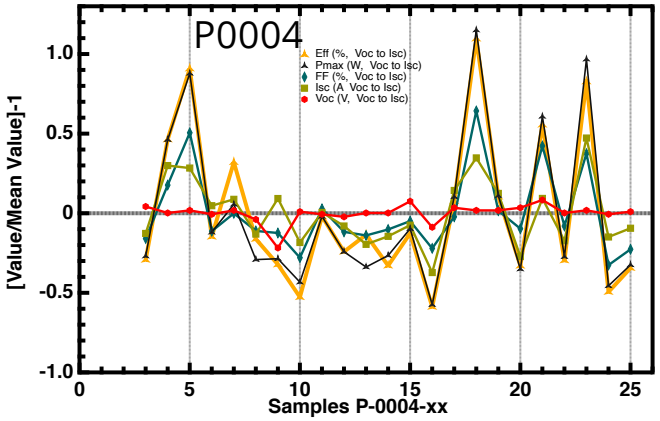
Initial Characterization of PACT Modules



Variations between modules in a batch is a major issue.







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PACT: Outdoor Testing

- Early field tests have had mixed results.
  - Some modules fail in days
  - One module has lasted for months!
  - Failures appear to be related to manufacturing issues and not failure of the perovskite absorber layer.
- PACT is actively reaching out to perovskite startup manufacturers to begin helping them develop their products for the market.

2-axis tracker at Sandia

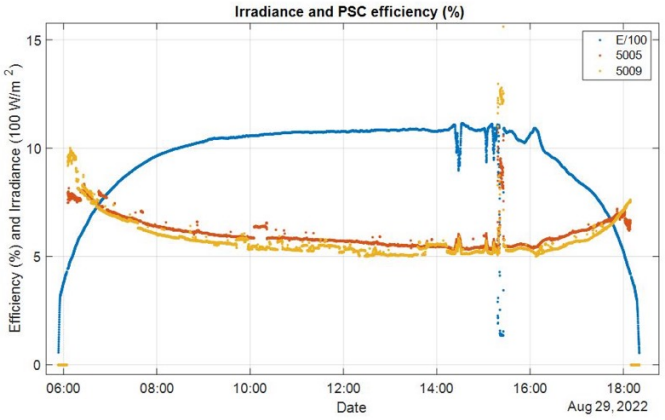
16-channel load/measurement box from CFV labs.

Outdoor Monitoring at CFV Labs

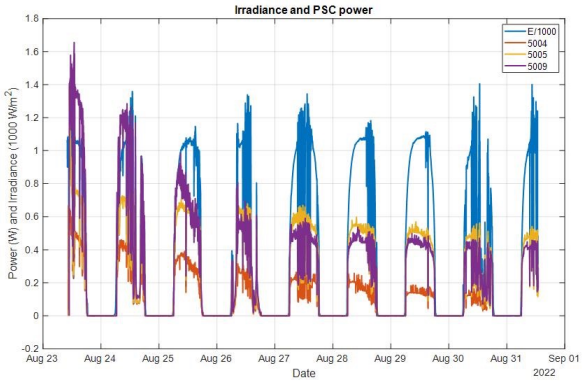
Fixed-tilt test rack at NREL

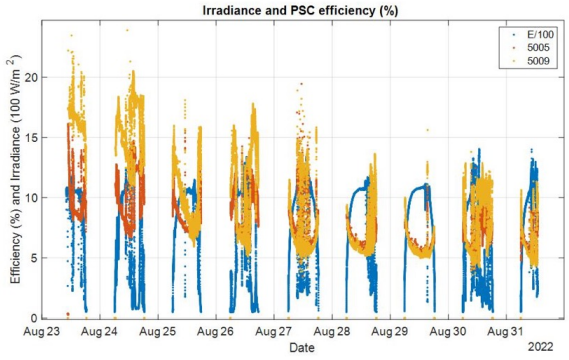
P0003 Outdoor Testing

- All modules saw rapid degradation and then somewhat stabilized after three days.
- Efficiency over the day shows some interesting patterns
  - Declines from ~17% to ~6% over time.
  - Highest in morning and evening
  - Lowest in midday (likely caused by high Rs)



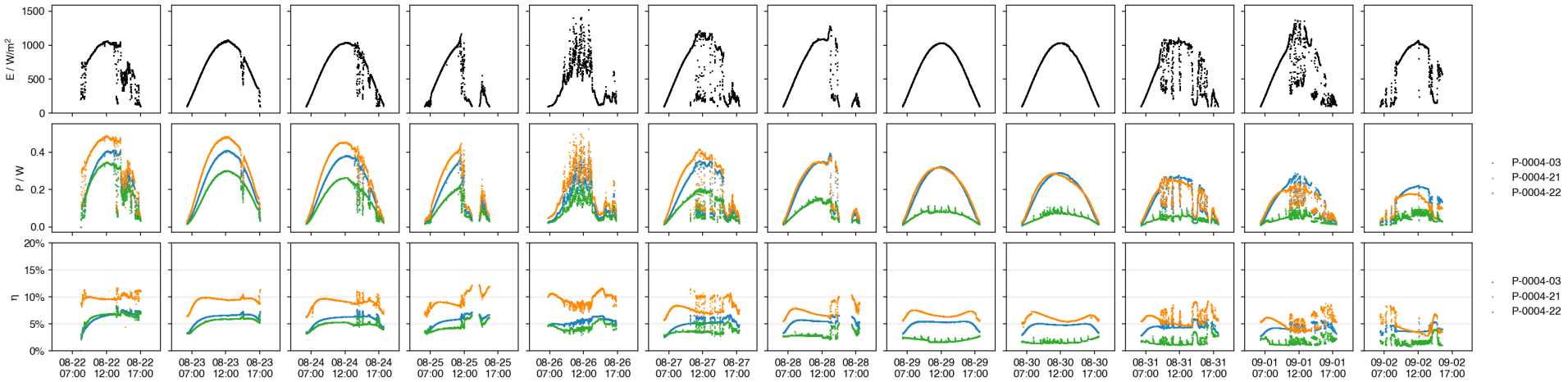
P0003 Module in Field in NM





Rapidly declining performance precludes performance model characterization.

P-0004 Outdoor Testing



- Champion module performing at about 10%
- Modules fairly stable over the first week though low starting efficiency
- Losing ~50% power over 12 days.
- Not showing the same Rs issues we see with P-0001/P-0003

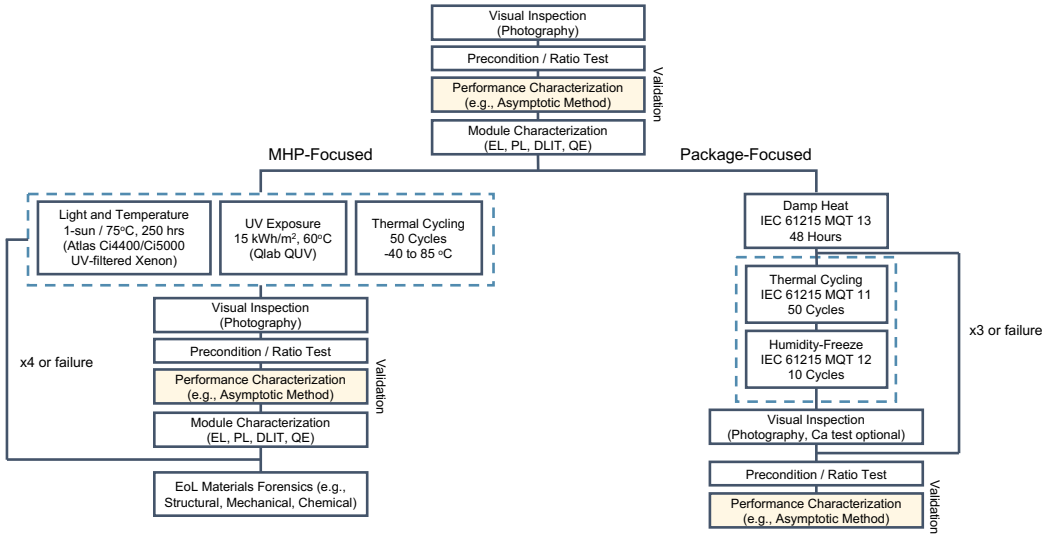
Accelerated Tests Need to be Adapted to Perovskites

- Qualification tests (e.g., IEC 61215) help to provide confidence that modules will initially survive outdoor deployment – they do not test long-term reliability.
- These tests are modified for different PV technologies (e.g., c-Si, a-Si, CdTe, CIGS, etc.)
- Tests should demonstrate realistic observed field failures.

Parallel Event – Wed 17:00 – 18:30:
- "Pathways and Challenges of reliability testing for perovskite based photovoltaic devices"

PACT Poster – Fri 8:30 – 10:00
- 3EO.1.2 Towards Standardization of Accelerated Stress Testing Protocols for Metal-Halide Perovskite Photovoltaic Modules

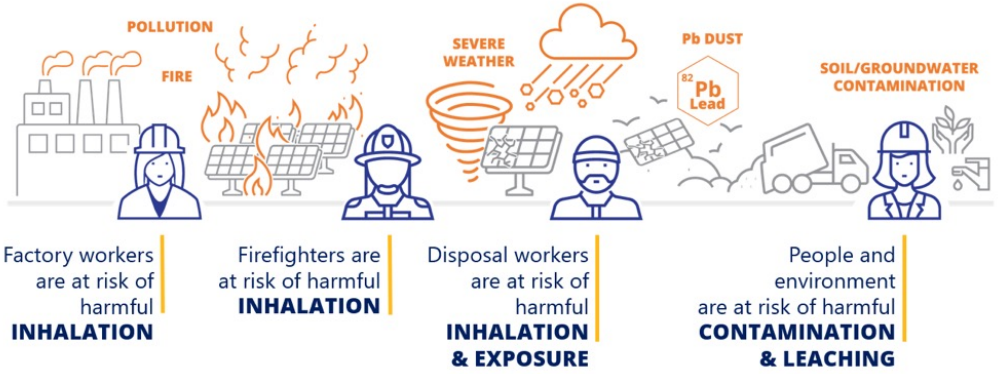
Initial PACT Accelerated Reliability Protocol

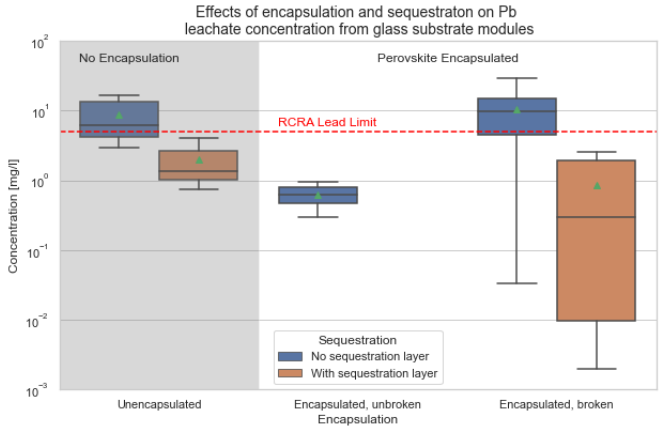


Bankability of Perovskites – Lead Risks

- Most promising perovskite formulations contain **lead in a highly soluble form**.
- Risks of lead toxicity present challenges for bankability of this technology
  - Leaching, fire, disposal, etc.

- How much lead will leach out if module breaks and exposed to water?
- Researchers are investigating materials to sequester lead inside the module.
  - We reviewed 35 leaching experiments comparing the effects of encapsulation and sequestration materials.
  - All samples with sequestration materials added passed the RCRA Lead Limit (5 mg/l)





Torrence, Libby, and Stein (2022) In Review

PACT Poster: Mon 13:30 - 15:00
- 2AV.1 .38 Environmental and Health Safety Risk Assessment for Perovskite Solar Cells and Modules

More Information

Many documents are available on the PACT website (https://pvpact.sandia.gov)

- Legal agreements
- Data management plan
- Module packaging guidelines
- Module stress test protocol
- Preconditioning protocol

Thank you!

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Publications and Protocols

PACT is working on the first versions of performance and reliability test protocols for perovskite PV technologies. Once they are complete they will be available on this page.

- PACT Module Preconditioning Protocol Version 0.1 (219 downloads) (3/30/2022)
- PACT Recommended Packaging Procedure – version 4 (149 downloads) (3/29/2022)
- PACT Module Design Acceptance Criteria (Research) V. 1.0 (128 downloads) (3/14/2022)
- PACT Module Design Acceptance Criteria (Industry) V 1.0 (181 downloads) (2/24/2022)
- PACT Nondisclosure Agreement (99 downloads) (2/24/2022)
- PACT Materials Transfer Agreement (89 downloads) (2/24/2022)
- PACT Perovskite PV Module Stress Testing Protocol Version 0.1 (180 downloads) (3/14/2022)
- PACT Center Factsheet (145 downloads) (11/3/2021)
- PACT Data Management Plan (142 downloads) (10/20/2021)