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Solar Photovoltaic Systems for Northern Latitudes: Recent R&D

Amy R. Halloran, P.E.; Laurie Burnham; Daniel Riley; Joshua S. Stein.

Arctic Circle Assembly 2019

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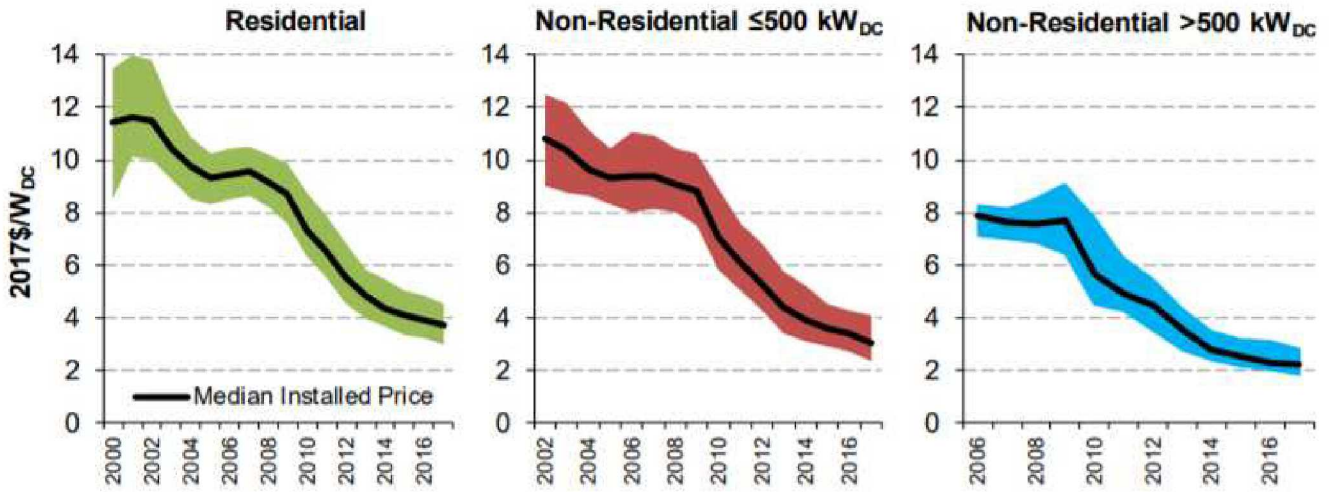


Notes: Solid lines are median prices, and shaded areas are 20th-to-80th percentile ranges. Statistics shown only if at least 20 observations are available for a given year and customer segment. See Table 1 for annual sample sizes.

Solar PV Costs have decreased dramatically, making solar systems more economically viable in less ideal locations

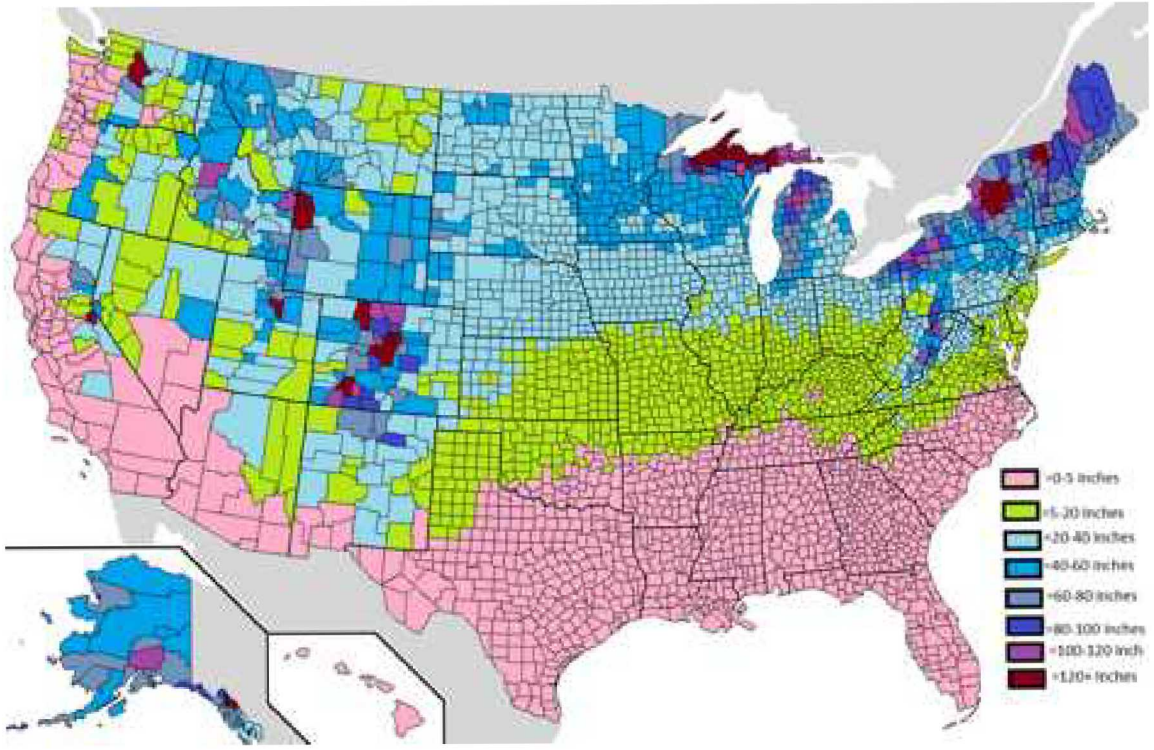
Barbose & Darghouth, *Tracking the Sun: Installed Price Trends for Distributed Photovoltaic Systems in the United States*, Lawrence Berkeley National Lab, SEPT 2018

This cost decrease is reflected in the distribution of PV in the US

- 4 of Top 10 US States for PV Growth are Above 40°
- Alaska has 2 MW of solar: 563 kW in Fairbanks (lat 64.83 °)

	Rank		
State	2016	2017	2018
California	1	1	1
Texas	6	4	2
North Carolina	4	2	3
Florida	9	3	4
Nevada	5	9	5
New York	12	12	6
New Jersey	10	11	7
Minnesota	14	6	8
Arizona	7	7	9
Massachusetts	8	5	10

State solar installation rankings 2018, SEIA



This cost decrease is also yielding growth of PV in the Arctic

132.5 kW AC fixed angle solar PV system with >200 kWh of battery storage capacity North of the Arctic Circle

Colville Lake, Northwest Territories

https://www.ntpc.com/smart-energy/how-to-save-energy/colville-lake-solar-project

PV Benefits and Challenges in High Latitudes

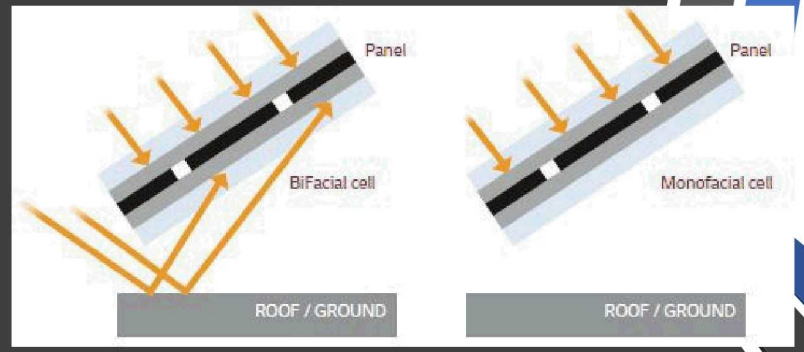
- Challenges:
  - Short winter days
  - Low Solar Elevation and large range in Solar Azimuth means the Sun spends a lot of time at high incidence angles to a fixed plane.
  - Snow can block sunlight from reaching solar panels
  - Unknown how impacts overall resilience
- Benefits:
  - Long summer days Cold = higher PV efficiency (0.5%/°C)
  - Snow has >>reflectivity (albedo >0.8) -enhances ground-reflected irradiance.
  - Evidence that PV degradation rates are lower in colder climates

Opportunities to Understand and Improve Performance

Two Sandia projects:

- Bifacial PV Performance
- PV Performance and Reliability in Northern Latitudes

Bifacial PV Modules



New high-efficiency PV cell technologies are made bifacial (e.g., PERC, HIT)

Power can be collected from the front and rear

Rear efficiency is 60-95% of front (*bifaciality factor*).

Produces more energy than monofacial modules: 5-20+%

PV Magazine: "Overall, bifacial panels now add only about 3% to the total cost of a tracker system"

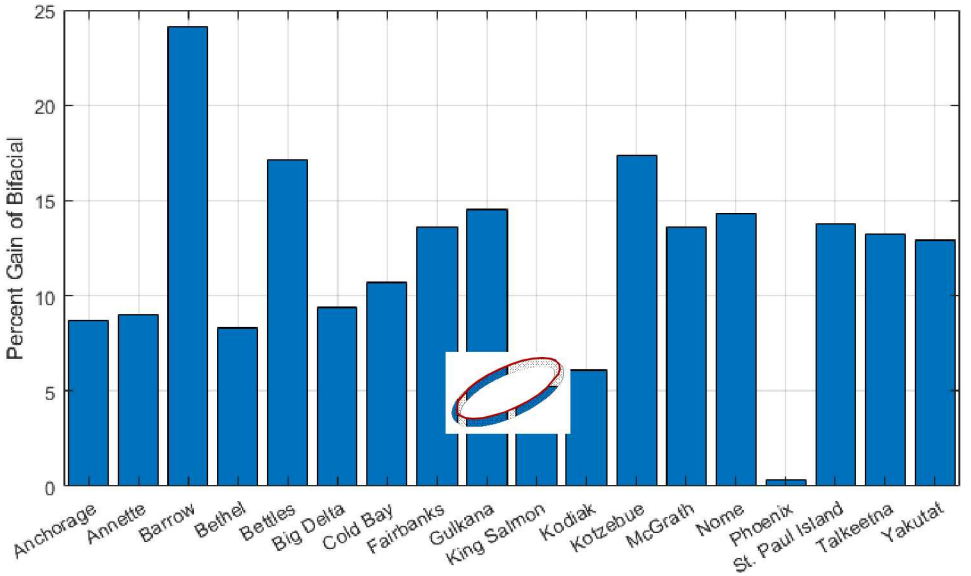
J.. Stein, Solar PV Performance and New Technologies in Northern Latitude Regions, PVPMC 12th Conference, Albuquerque, NM, SAND2018-3727C

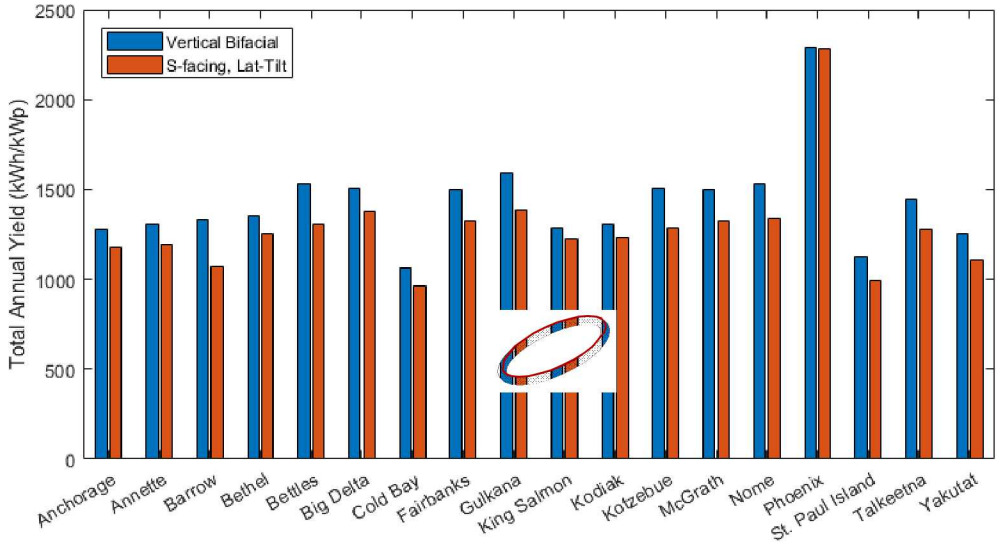
Bifacial PV Performance Study

Compared E/W-facing Vertical Bifacial and S-facing Latitude-Tilt monofacial systems in Alaska

Results

- E/W-facing Vertical Bifacial outperformed S-facing Latitude-Tilt monofacial systems
- Bifacial advantages increase with latitude and duration of snow on ground.
- Vertical bifacial takes advantage of large range in solar azimuths
- Vertical bifacial collects light from highly reflective snow-covered ground.





Case for Rethinking PV Design in the Far North?

- Bifacial PV modules are becoming more available
  - Costs will come down as production increases.
- E-W Vertical bifacial may have advantages
  - Capable of 5-20% more energy than traditional designs.
  - Power profile is wider and may better match loads.
  - Vertical modules may shed snow better & collect less dirt.
- E-W Vertical bifacial challenges (opportunities?)
  - Commercial racking solutions for vertical bifacial is not developed.
  - Field layout to minimize shading needs to be designed.
  - Testing standards for bifacial modules is still under development.
- Sandia and UAF are collaborating on collecting needed field data in Fairbanks.

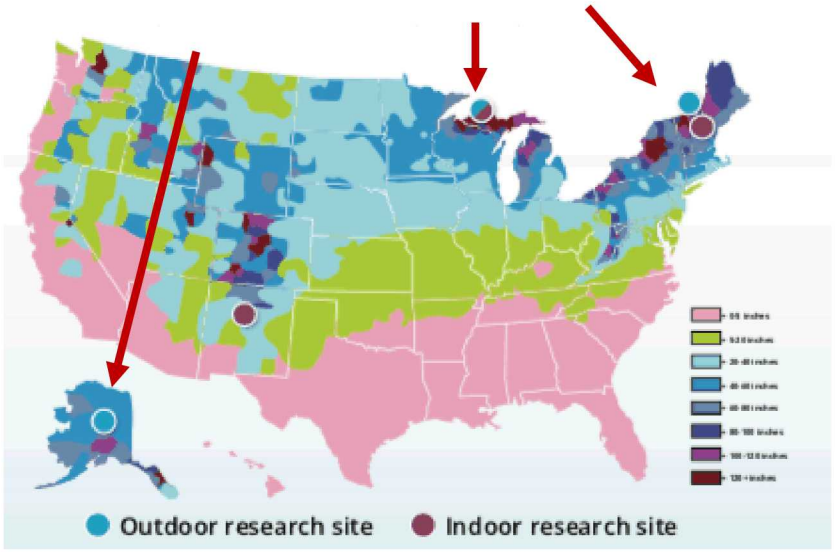
Other Opportunities to Improve Performance

Sandia's multi-institutional Snow Project, funded by the U.S. Department of Energy Solar Energy Technologies Office (SETO)Objective (year 1 of 3)
To further the deployment and optimal operation of PV systems in northern regions of the U.S.

Four Primary Areas of Interest:

1. US snow losses
2. Design optimization
3. Performance modeling
4. Reliability

Three Field Sites:



Reliability is Poorly Understood:
Long-term impact of snow and ice loading is unknown

Team:

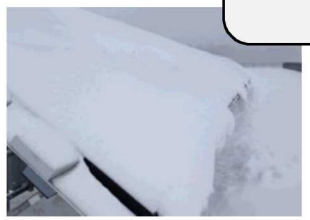
Sandia National Laboratories

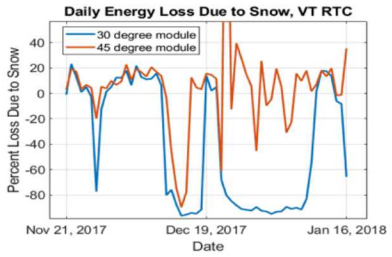
Michigan Technological University

ACEP Alaska Center for Energy and Power

Partners in AK include the **Golden Valley Energy Association** in Fairbanks and **Renewable Independent Power Producers of Anchorage**

Four Primary Areas of Investigation





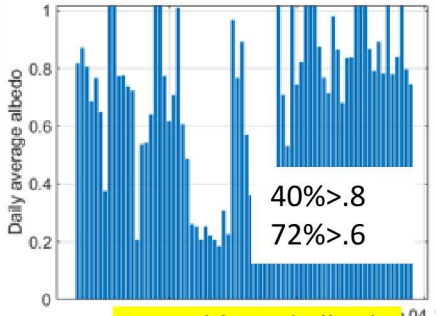
Tilt angle contributes to snow losses

- Frame
- Coating
- Color
- Clips

Snow Shedding (energy gains/losses)

Bifacial Performance

- Albedo and spectral variation
- Mounting
- Orientation
- Height



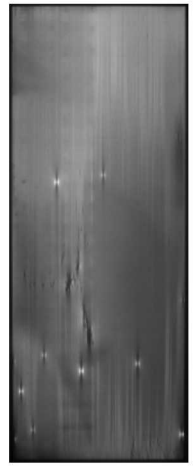
Ground-based albedo measurements Dec-Feb in VT

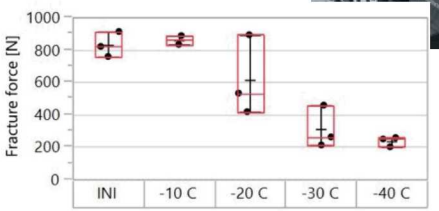
Module and cell reliability

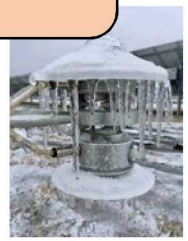
Snow shading and mismatch losses

- Snow and ice loading
- Extreme cold

- Shade-tolerant modules; mismatch losses

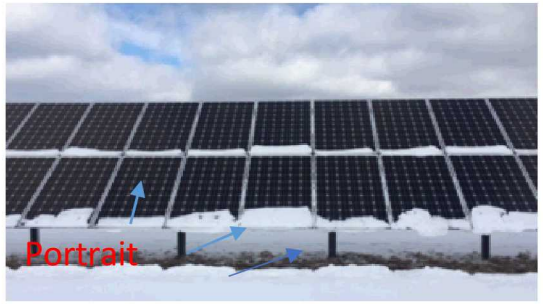






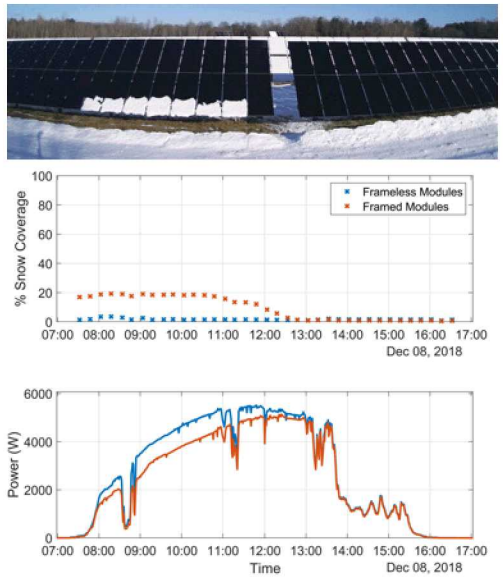
Study by Schneller et al shows less force is needed to induce cell cracking as temperatures drop*

Snow Shedding: Framed vs Frameless Modules

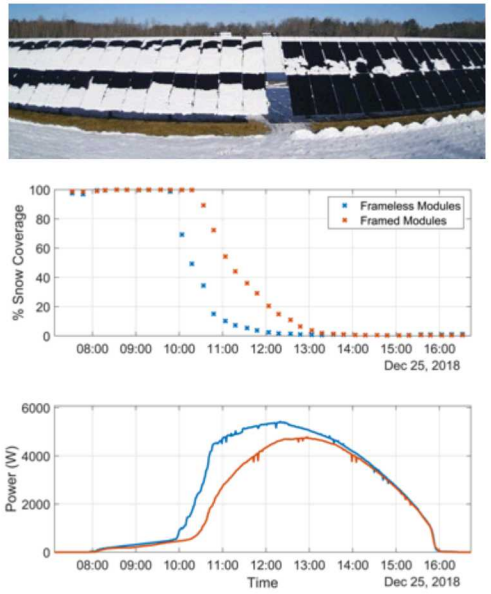


In December 2018, frameless modules produced 13% more energy than framed modules. (installation costs and handling risks of frameless need to be considered.)

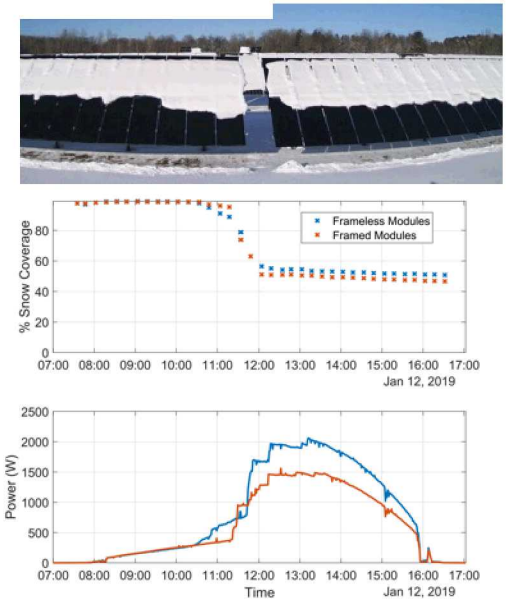
Identical Stion CIGS modules; two 6kW arrays



Snow shedding at different rates at 9:15 12/8/2018. Note that 20% snow coverage causes significant energy losses.



Snow shedding at different rates at 10:45 12/ 25,/2018. Ambient air temps were -10ºC.



Snow shedding at 14:15 on 1/12,/2019. Low ambient and module temperatures inhibited sliding and reduced the benefit of frameless modules.

Riley, D., Burnham, L., Pearce, J, Walker, B, "Snow Shedding Differences between Framed and Frameless Modules," IEEE PVSC-46 Conference; Chicago, IL, 2019

Bifacial Performance

Reliability of Bifacials on Dual-Axis Trackers

Bifacial →

1	2	x	x
5			x
11			x
7	8	x	x

Tracker 2: 72-cell 7.2 kW System

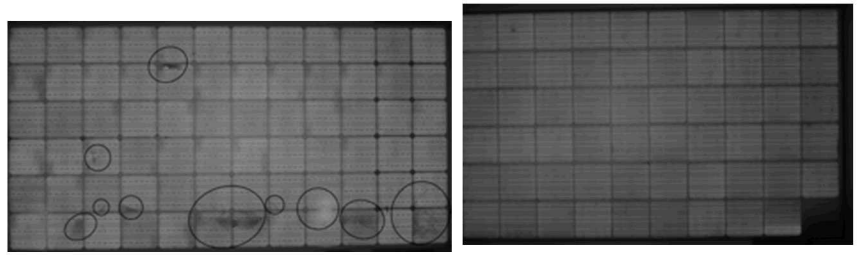
1	2	3	4
5			6
11			12
7	8	9	10

← Bifacial

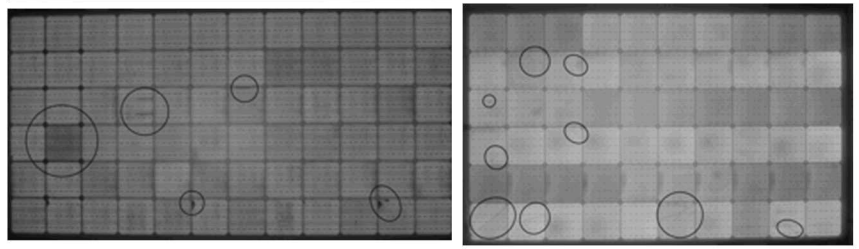
Tracker 1: 60-cell 6.7kW system

Bifacial modules are identified by diagonal stripes; modules removed for EL imaging are numbered; damaged modules are indicated by horizontal stripes; images shown here are identified by red circles.

Tracker 2: #8



Tracker 2: #7



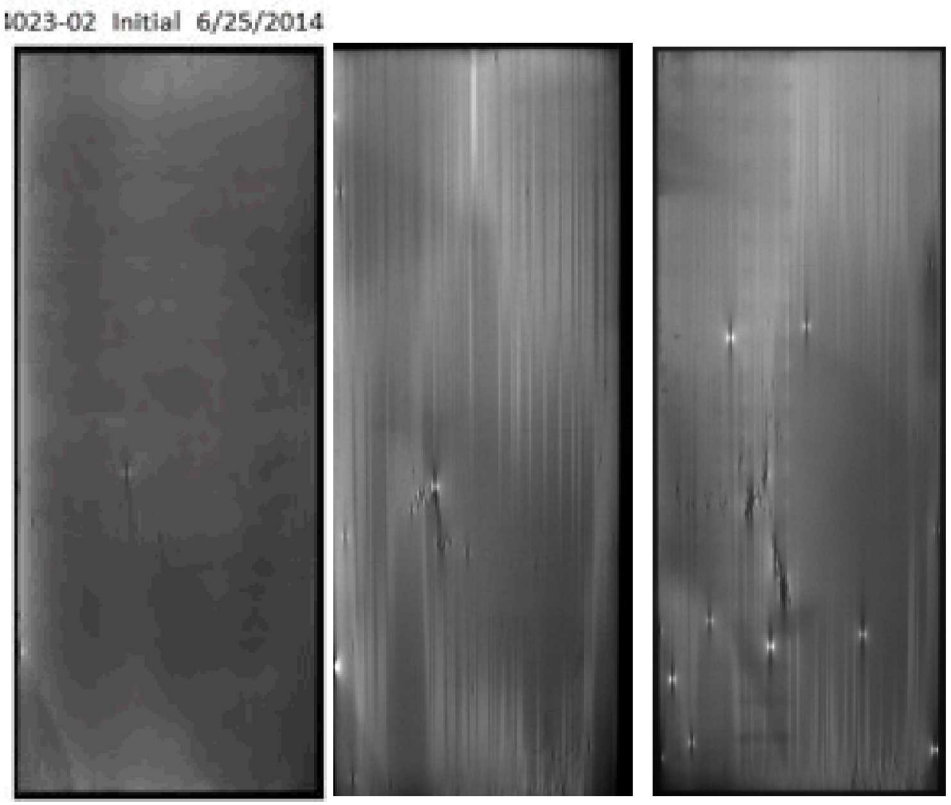
Tracker 1: #10

Tracker 1: #8

50% of the framed modules that were imaged show damage, which may be attributable to the different front and backsheets and uneven rates of expansion, susceptibility to stress.

Snow Shading and Mismatch Losses

EL Imaging of CIGS Modules



CIGS modules, with baseline image (*left*); fielded module four years later (*center*) and second fielded module (*right*.) Deterioration can be seen, with a worsening shunt in the module's center and new shunts on the left edge. The far right image, which lacks a baseline counterpart, is typical of most imaged modules.

Differential snow shedding and partial shading across monolithic CIGS modules creates electrical stress

Related work: T. Silverman, M. Deceglie, C. Deline and S. Kurtz, "Partial Shade Stress Test for Thin-Film Photovoltaic Modules," NREL CP-5J00-64456, Sept, 2015.

Conclusions

- Significant efficiency gains are possible by designing a PV system to its operating environment
- Specific opportunities for ~~a~~ cold-climate optimization include:
  - Frame architectures
  - Module and cell technologies
  - Racking and mounting designs
  - Module and frame coatings
- Our research on all of the above is continuing

Thank You!