SAND2019-10008PE

PV Performance and Reliability in Snowy Climates: Opportunities and Challenges

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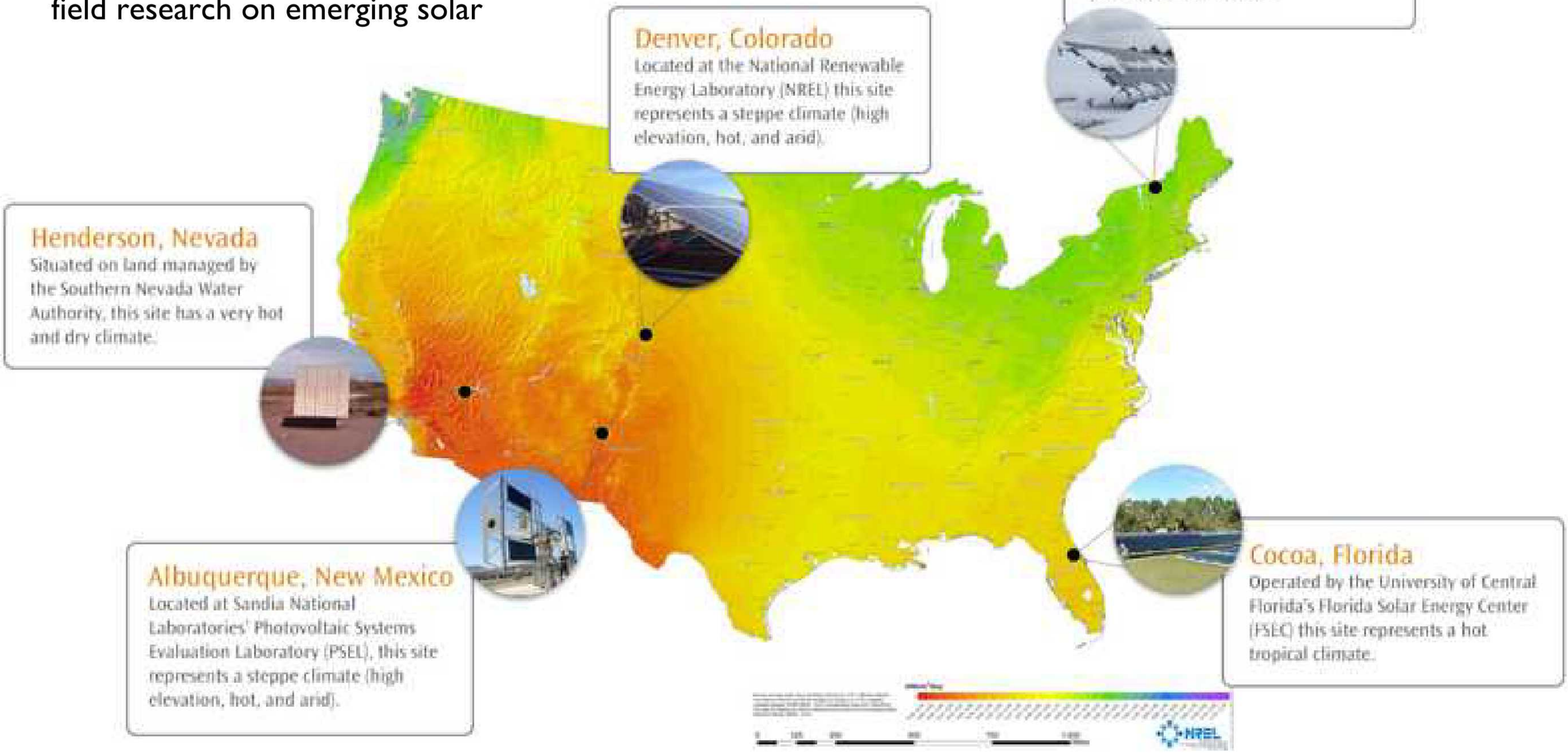
IAPG-RECWG 25 July 2019

The Regional Test Center Program

- Managed by Sandia, in partnership with NREL
- Represent five distinct climates
- Provide a technically equivalent platform for field research on emerging solar

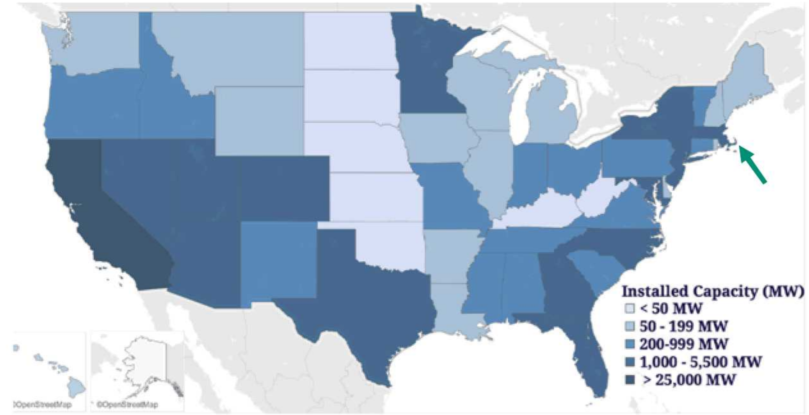


* Note: the Vermont Regional Test Center is no longer operational; some of Sandia's northern latitude solar research is now being conducted in partnership with Michigan Technical University.

Solar Capacity in the US

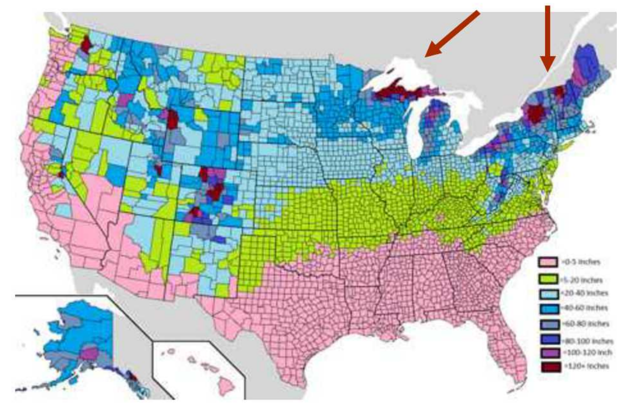
Trends:

- Continued growth: capacity increase of 25% from 2018 to 2019 (2nd biggest year on record)
- More geographically distributed
- New markets opening up as costs drop
- Impact of climate on performance and reliability increasingly important



Snow affects 100% of the US; some of the fastest growth is in regions with heavy snow

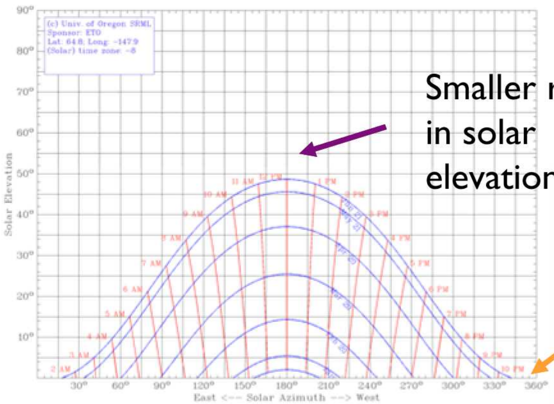
Research Opportunity:
Minimal data on long-term performance of PV systems at northern latitudes despite rapid growth; almost no data on design optimization



Alaska has 2MW of solar
563kWdc installation –GVEA in Fairbanks

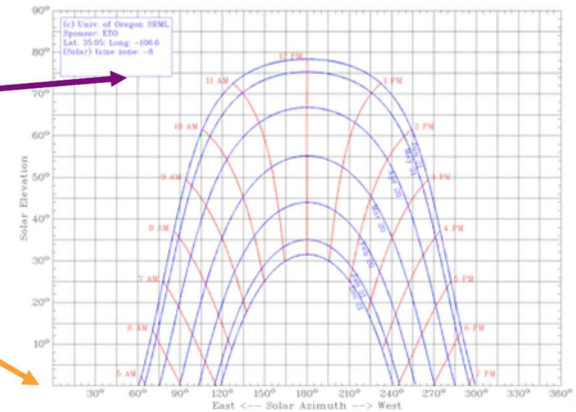
PV has Performance Challenges at High Latitudes

- Year-round insolation very non-uniform:
  --Long days in summer (21.5hrs in Fairbanks; 14.5 in Albuquerque, NM)
  --Short days in winter (4hrs/10hrs)



Smaller range in solar elevation

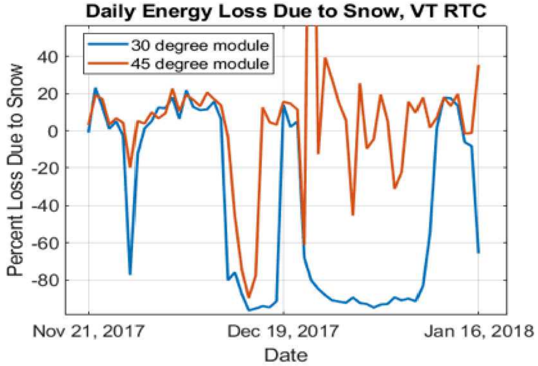
Larger range in azimuth



Fairbanks, AK (64° N)

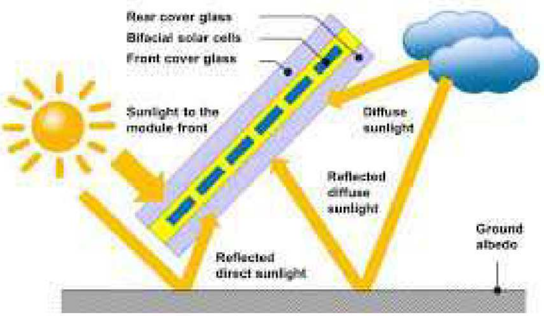
Albuquerque, NM (35° N)

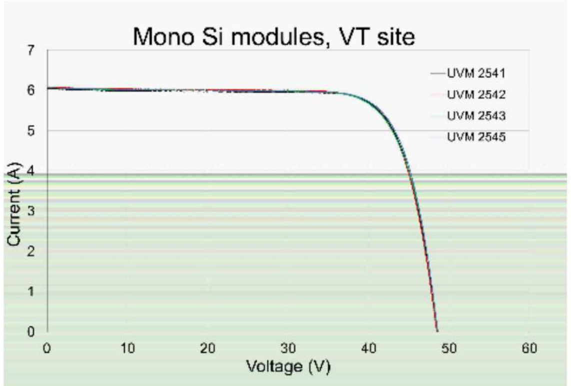
- Snow losses can be significant (>90% in a month, depending on conditions; 2-5%/yr) = economic losses
- Snow and ice build-up can introduce reliability issues
- Snow removal adds cost and risk



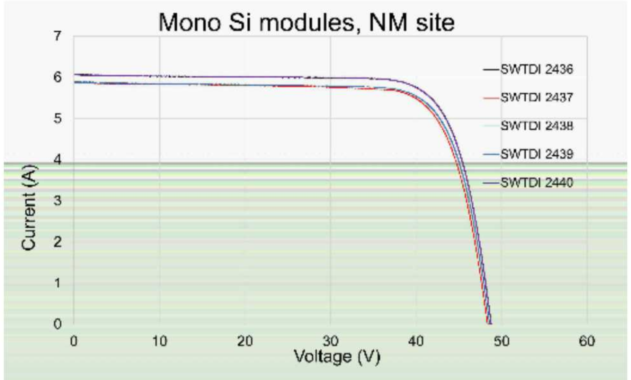
But Also Performance Advantages

- Solar cells perform best at lower temperatures
- Evidence that PV degradation rates are lower in cold climates than hot ones
- Snow is highly reflective (albedo >.8)
- The combination of snow and cold ideal for high-efficiency bifacial PV systems





Which module was kept indoors and which three were in the PV system?



Which two modules were kept indoors and which three were in the PV system?

Source: Dan Riley, Sandia

- Opportunities to improve PV efficiencies in snowy regions: design and technological choices matter

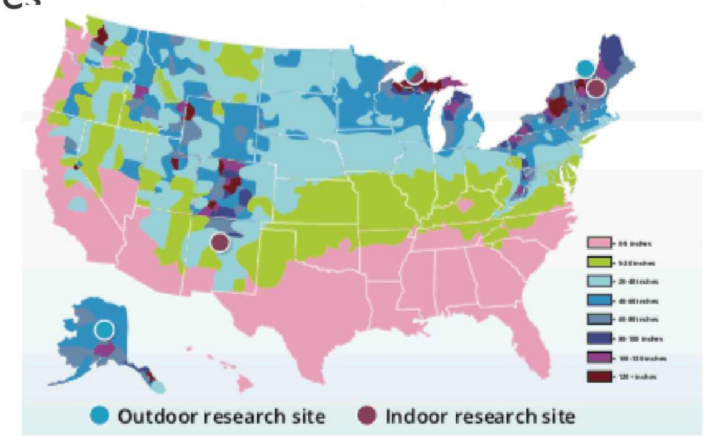
Sandia's Snow Project

Mission

To increase the performance and reliability of PV systems deployed in regions of the US that regularly see below-freezing precipitation…in order to further the deployment and optimal operation at northern latitudes

Technical Objectives

- Quantify snow losses across multiple locations, module technologies and system configurations
- Identify topological and other component features that either impede or accelerate snow-shedding
- Develop advanced snow models for more accurate estimates of snow shedding
- Identify and mitigate reliability issues specific to snow and ice adhesion



Team

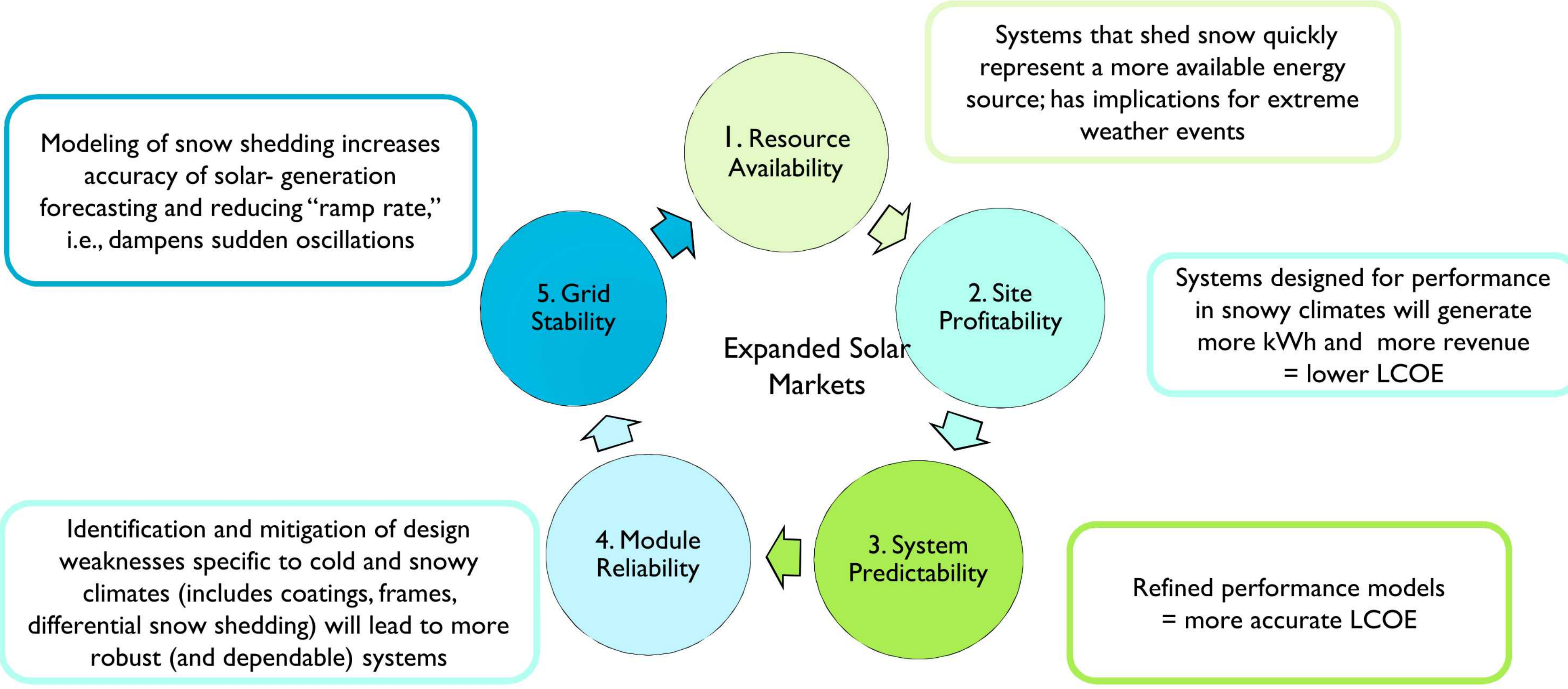
Sandia National Laboratories

Michigan Technological University 1885

ACEP Alaska Center for Energy and Power

CRREL

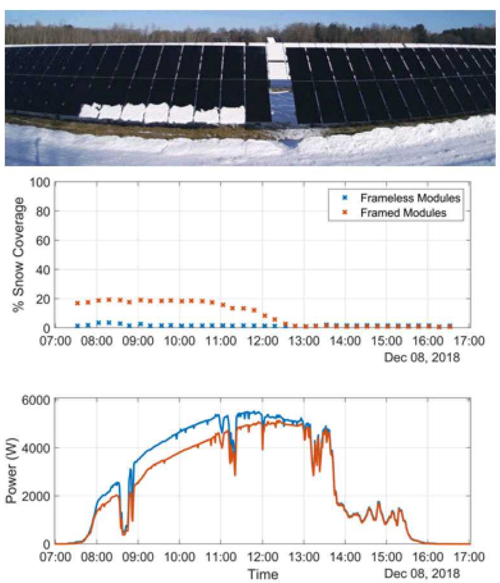
Multi-Pronged Value Proposition



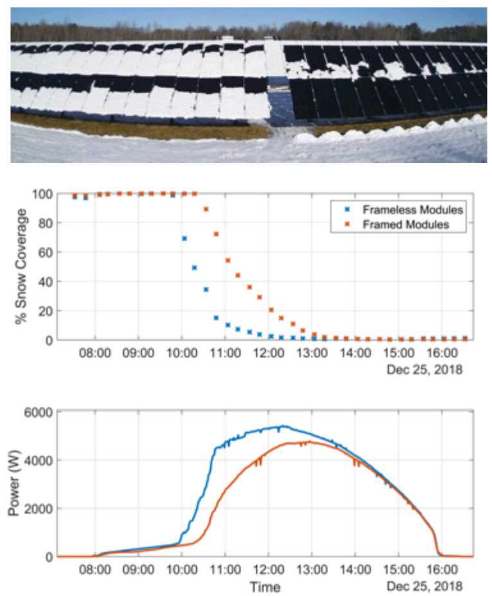
1. Performance of Framed vs Frameless Modules

Identical Stion CIGS modules; two 6kW arrays

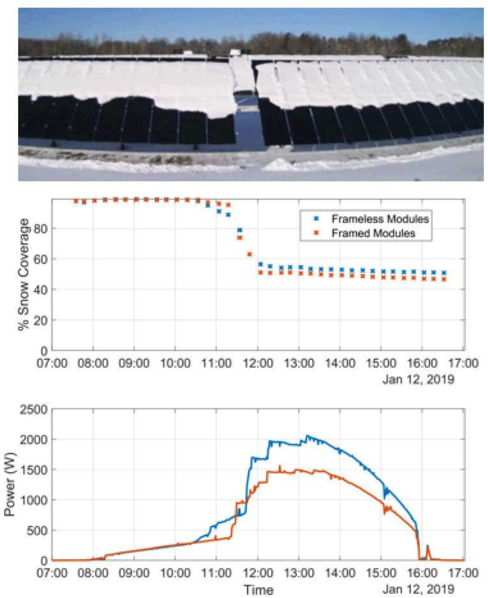
Results:



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 -10°C.



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

To Frame or Not to Frame?

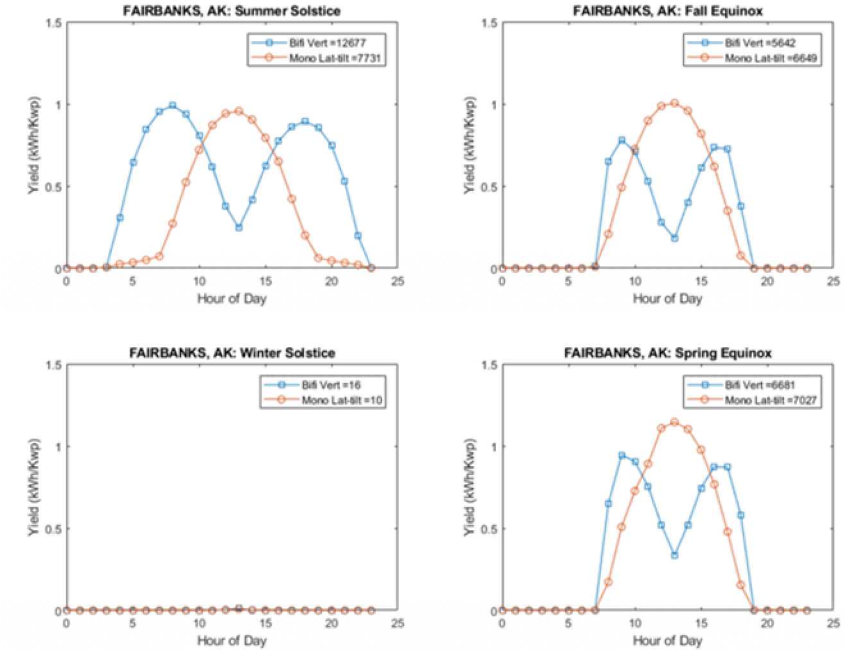
- Snow sliding is primary mechanism by which snow is removed but module frame can impede sliding.
- Rates of sliding are temperature dependent; data is needed to improve snow models.
- Height of the array important to minimize ground build-up.
- Energy gains by going frameless can be significant: during the month of December 2018, <u>frameless modules produced 13% more energy</u> than framed modules.
- But installation costs and handling risks of frameless need to be considered.
- Module clips can also impede snow shedding.

Above array has vertical clips

2. Performance of Bifacial Systems: Vertical Arrays in Alaska

Why Bifacial?
- Fixed-tilt bifacial PV systems produce 5-30% more energy than comparable monofacial systems
- Snow (high reflectivity) and cold maximize bifacial performance
- Increase in cost is negligible
- Data from high-latitudes is limited
- May have resilience value in Alaska

Rethinking fixed-tilt: Vertical bifacial
- Sandia study of bifacial performance in Fairbanks, AK, suggests E-W vertical arrays have performance advantages:
  - 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 (but shading could be an issue.



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

Weather

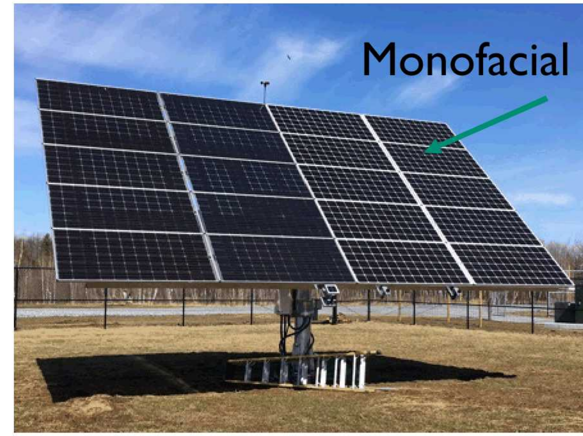
Rare thunderstorm in Anchorage causes first lightning-related power outages in years

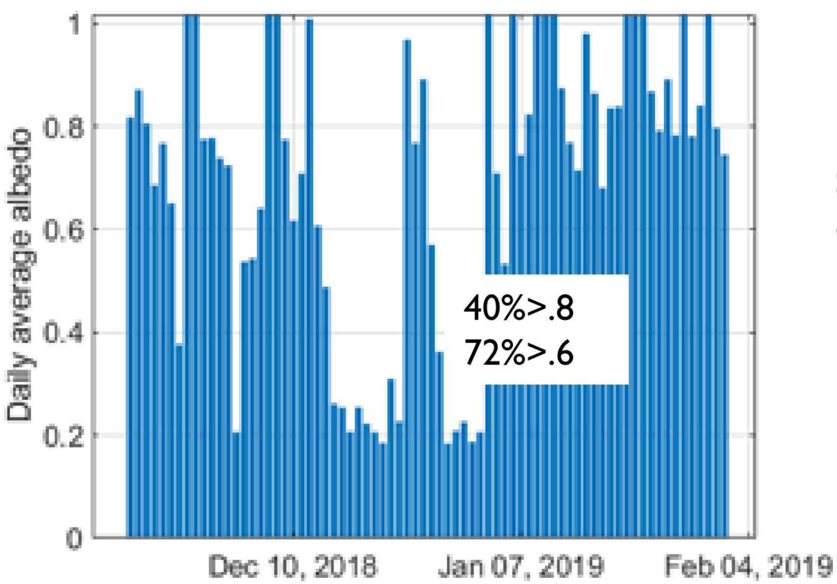
Author: Madeline McGee Updated: May 20 Published May 17

2. Performance of Bifacial Systems: Dual- Axis Trackers in VT

Tracker	Strings	Modules	Module/Cell Technology	Max Power
Tracker One	2	10	Monofacial mono c-Si, 60-cell framed	290W
		10	Bifacial N-type mono c-Si, 60-cell; glass/glass; frameless	290W
Tracker Two	2	10	72-cell mono c-Si monofacial, framed	325W
		10	72-cell mono PERC c-Si bifacial, glass/backsheet framed	325W

Bifacial





Albedometer readings

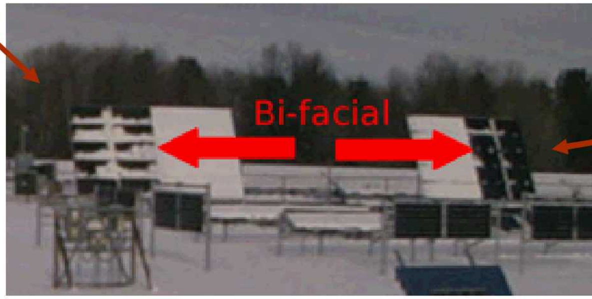
Shading of back-of-array was < 1.2%

Albedometer

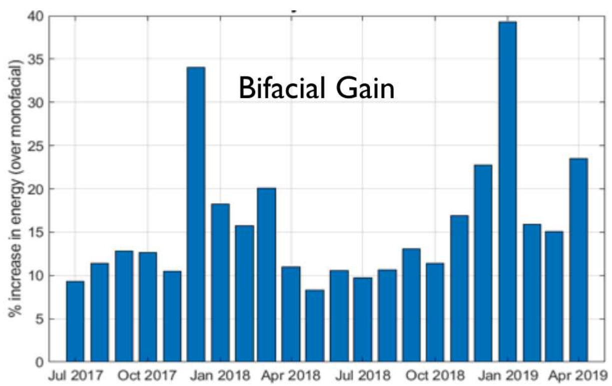
Back-to-back POA reference cells

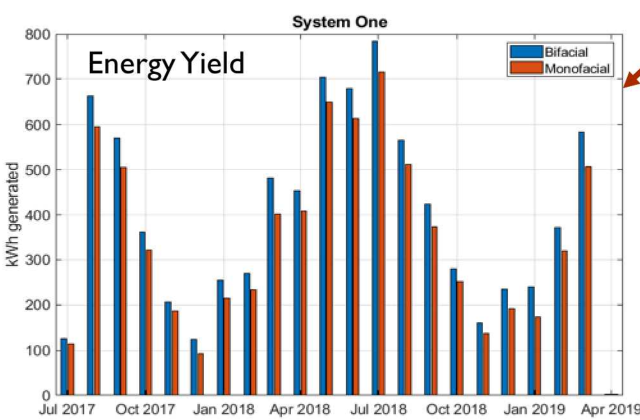
Results for Bifacial Dual-Axis Trackers

Mono-PERC
P-type



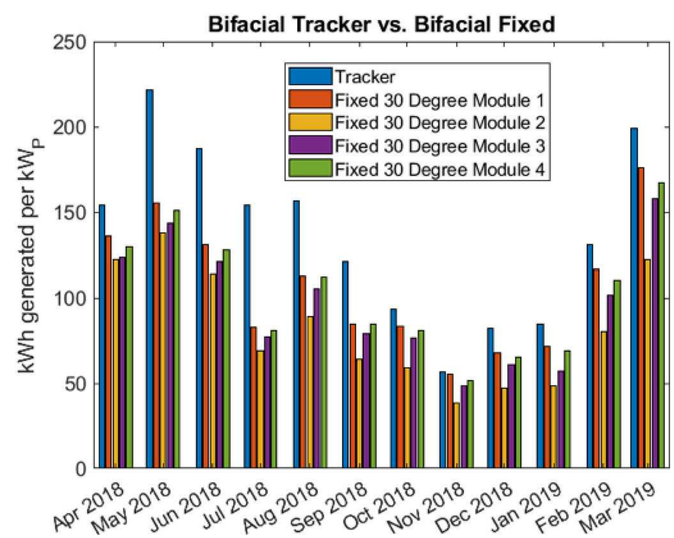
N-type
glass/glass
bifacials





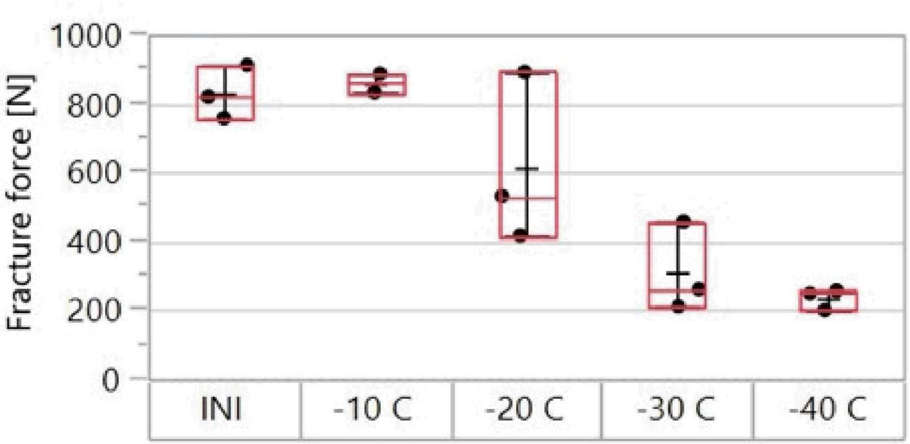
Tracker bifacials outperform tracker monofacials by 14%

- Two-axis tracking maximizes the amount of irradiance normal to the array
- High-albedo of snow favors bifaciaility
- Height of the modules and five-row module platform creates provides large optical capture area
- High-tilt angle and backside irradiance can accelerate snow shedding
- No data on long-term O&M costs
- Mechanical stress on module needs to be considered



Tracker bifacials outperform fixed-tilt bifacials by 41%

3. Solar Cell Integrity in Cold Climates with ice/snow load



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

Our Study Objectives:

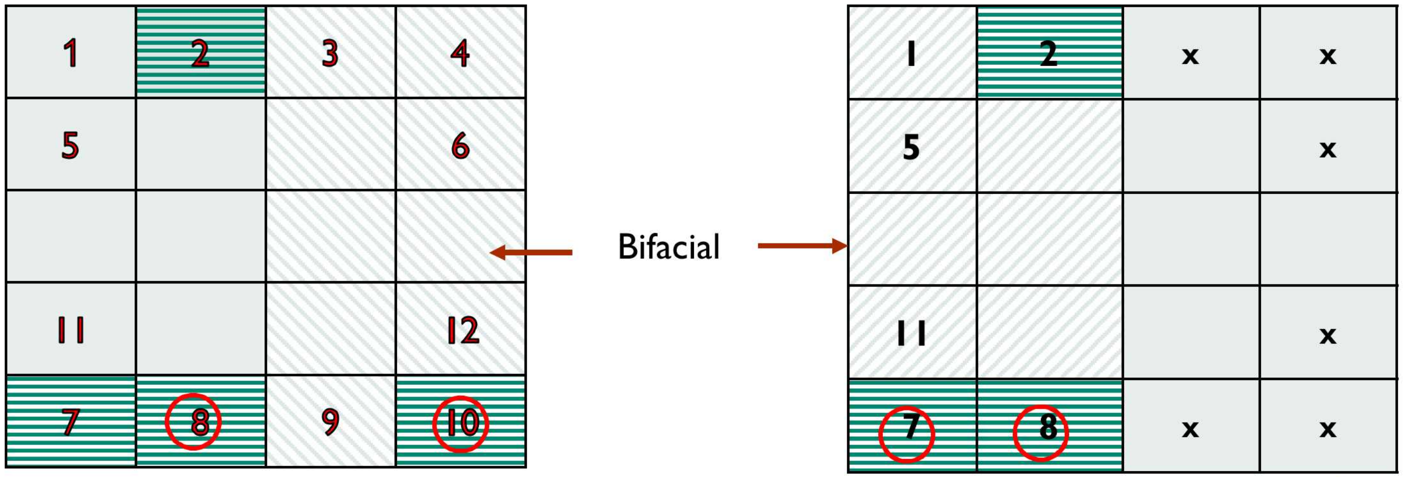
- To Identify cell damage in fielded modules likely caused by snow, ice and cold
- Correlate patterns of cell cracking with specific module technologies/architectures

Technical Approach:

- Subject a sampling of module technologies at the VT RTC (e.g., mono, poly, CIGS, bifacial, shingled) to electroluminescent (EL) imaging. Of greatest interest: bifacials on the dual-axis trackers and monolithic CIGS.

* E. Schneller, R. Frota, A. Gabor J. Lincoln, H. Seigneur and K. Davis, "Electroluminescence Based Metrics to Assess the Impact of Cracks on Photovoltaic Module Performance," WCPEC-4, June, 2018

3a. EL Imaging of Bifacial Modules on Dual-Axis Trackers

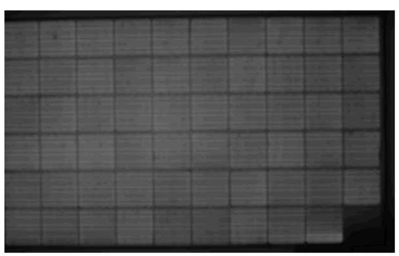


Tracker 1: 60-cell 6.7kW system

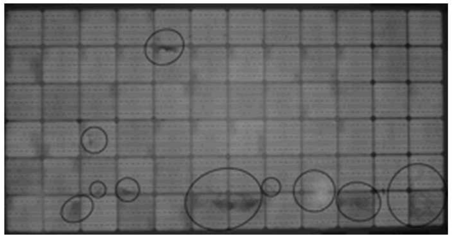
Tracker 2: 72-cell 7.2 kW System

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.

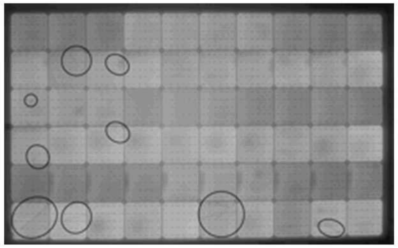
Tracker 1: #10



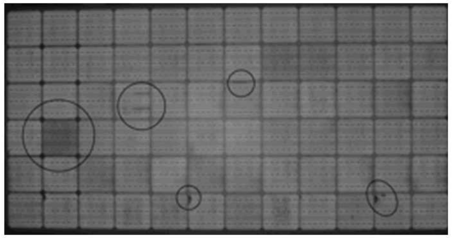
Tracker 2: #8



Tracker 1: #8

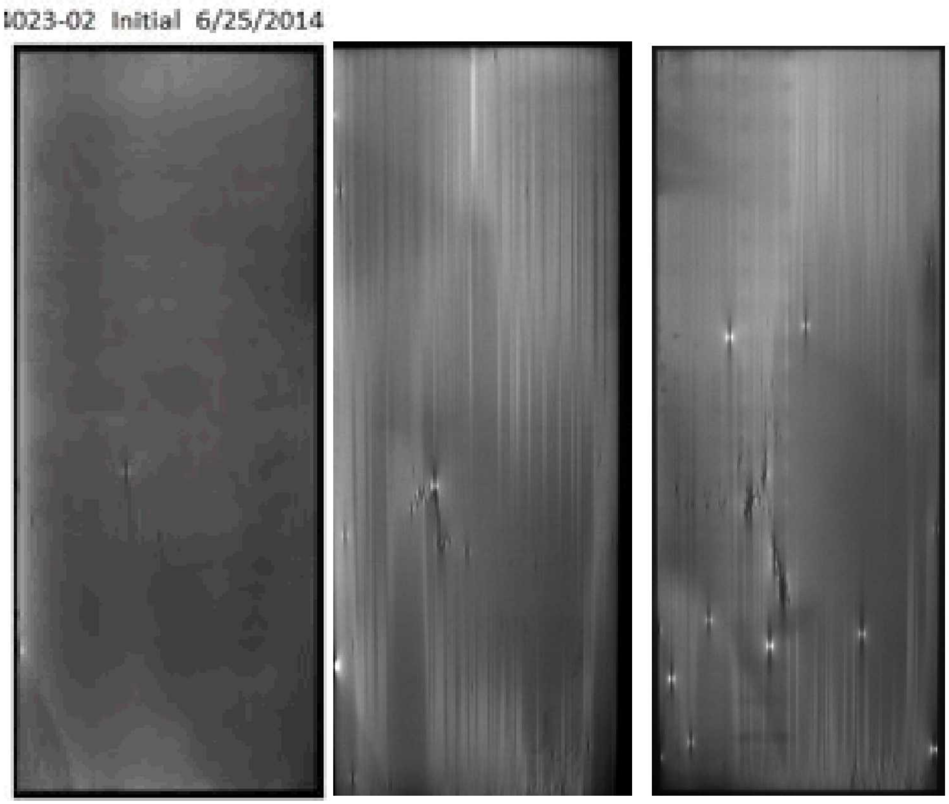


Tracker 2: #7



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.

3b. 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 include:
  - Frame architectures
  - Module and cell technologies
  - Racking and mounting designs
  - Module and frame coatings
- Our research on all of the above is continuing
- Please partner with us!

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Thank you!

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