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Optimization of Photovoltaic Systems for Northern Latitudes

Laurie Burnham
Sandia National Laboratories

SOLAR POWER INTERNATIONAL

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SAND2020-

The Changing Solar Landscape: Drivers of Growth and Their Impact

- Decreasing costs
- Increasing efficiencies
- Aggressive decarbonization policies

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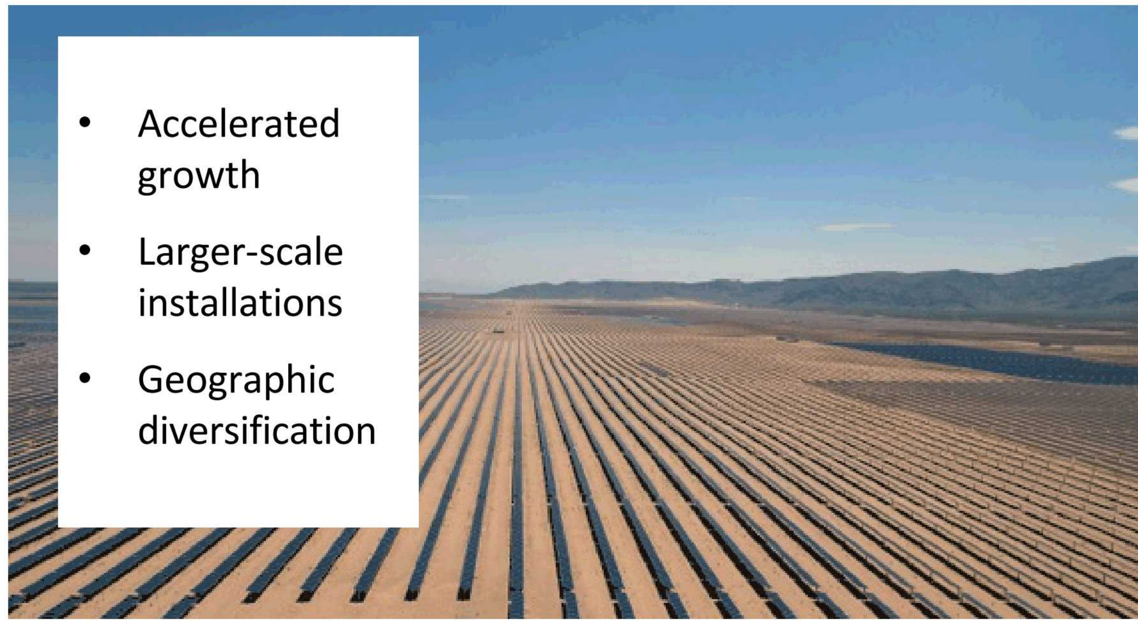


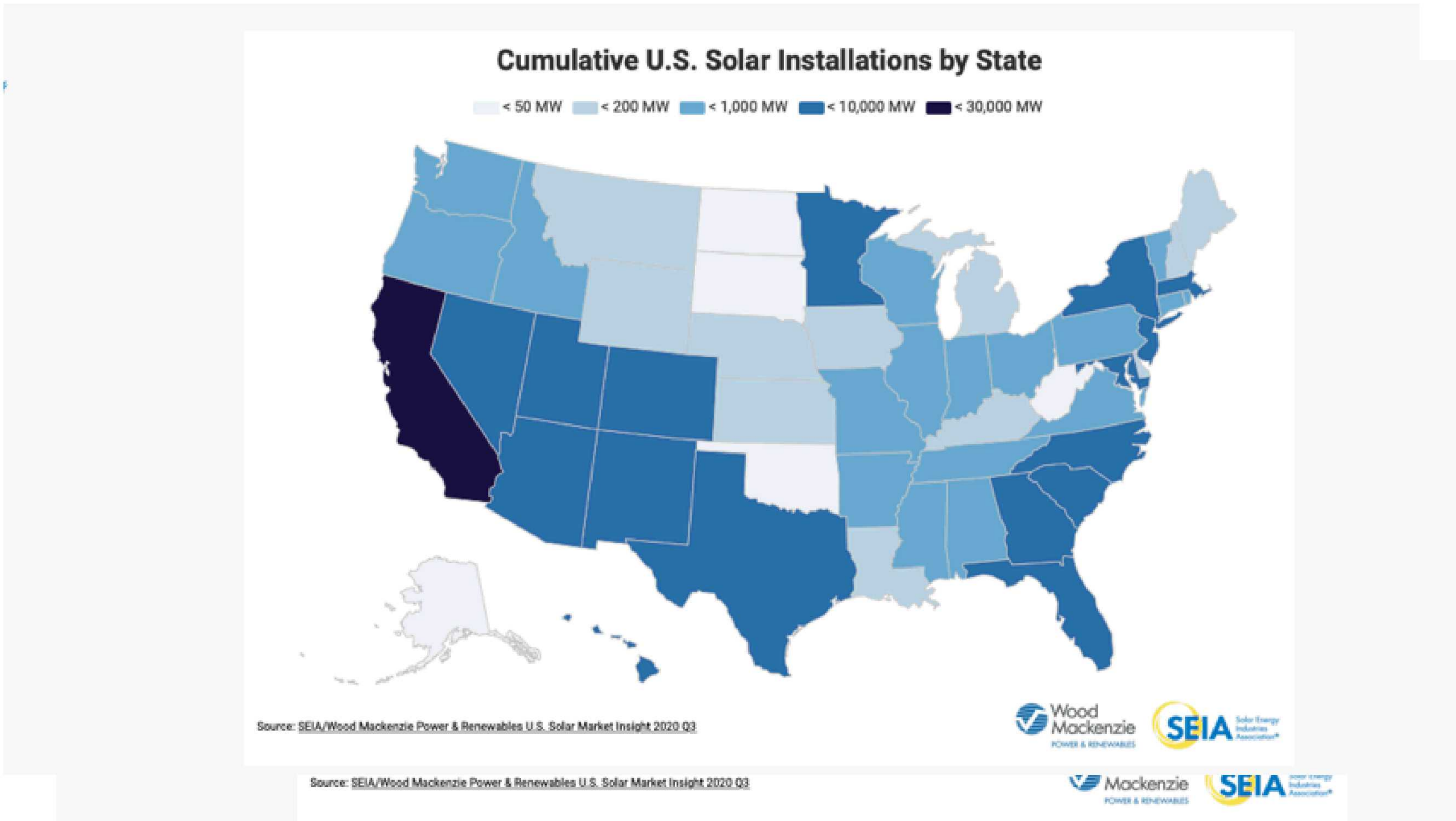
- Accelerated growth
- Larger-scale installations
- Geographic diversification

Growth in Latin America

Africa: Gambia plans 150 MW solar project with 20 MWh storage option

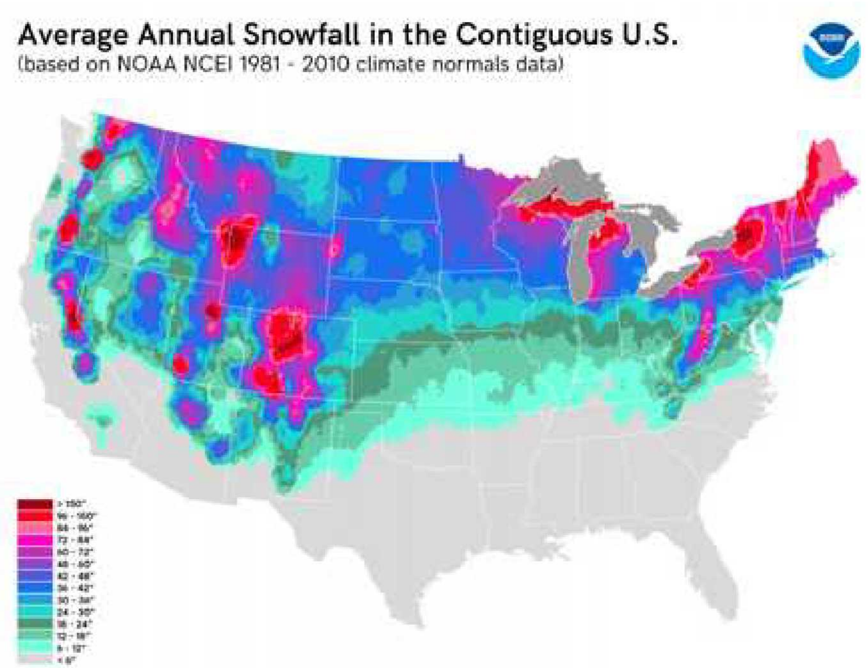
Singapore: Floating PV

Growth in Northern Regions: the US as a Case Study



Snow as a Factor in PV Performance the Northern US

- Snow occurs in all 50 states.
- More than 30% of the US sees significant snow.
- Extreme snow and hail events common: Nov 2019 storm dumped snow across the US: CA 49” (124cm); CO 15” (38cm); MN 25” (63cm).



2019

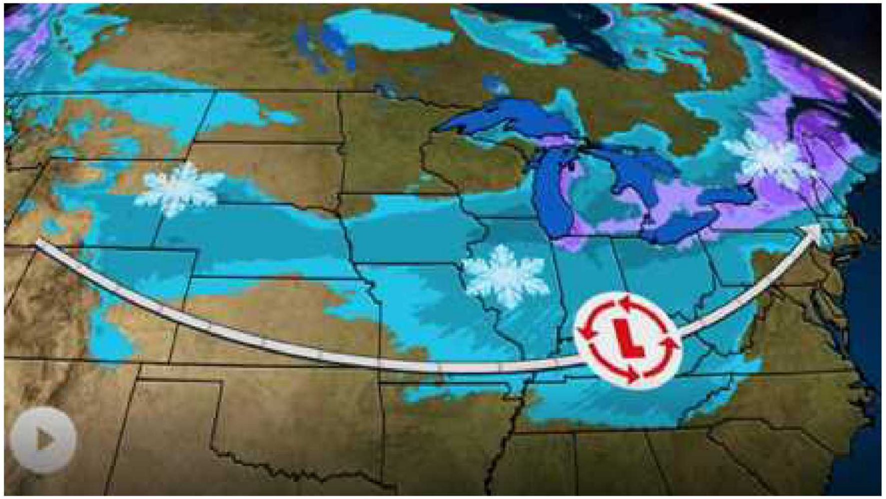
Winter Storm Brings Snow to at Least 30 States

SMARTNEWS *Keeping you current*

Record-Breaking Storm Dumps Four Feet of Snow on Parts of Montana

The September storm broke snowfall and temperature records across several states

Record-breaking hailstone in Colorado: 'Big hail like this can easily kill people'



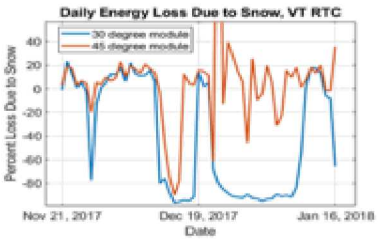
Why Snow Has the Solar Industry's Attention

Deployment in Northern Regions is Increasing:

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

Snow Losses Are Significant:

- Snow losses can be large (>90%/month; 2-5%/yr)
- Average irradiance levels are low



Reliability is Poorly Understood:

- Long-term impact of snow loading not known
- Global climate change = extreme weather: record-breaking snow and hail storms

Bottom Line: LCOE calculations hard to calculate!

State	Rank 2016	Rank 2017	Rank 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

Some of some fastest solar growth is in regions with heavy snow

Alaska has 2MW of solar
563kW in Fairbanks

Why Snow is Challenging

- Properties of ice are well-known; **far less is known about snow.**
- Also nothing about snow is constant: depth and density, reflect atmospheric variables and change as snow accumulates and compacts over time.
- Snow can melt and partially reform; distinct layers can be identified.
- Crystalline structure is highly variable, impacting reflectivity and transmissivity.
- Albedo is also not constant.
- Snow predictions have large margin of error.

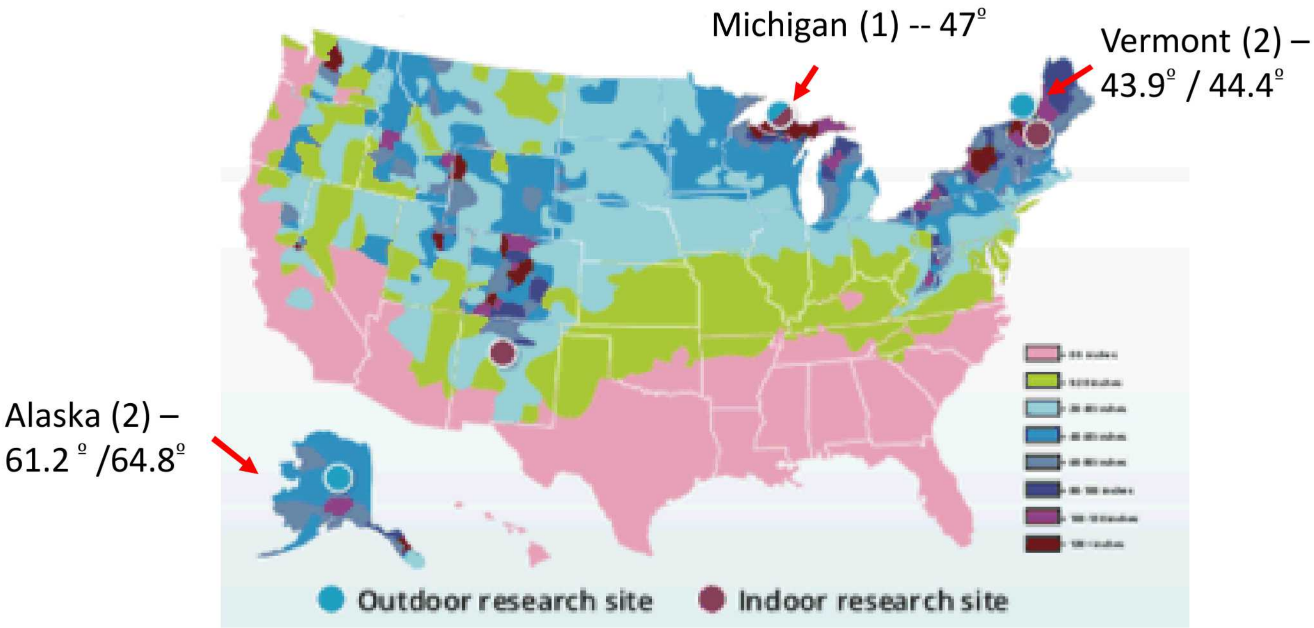
Alexey Kljatov; NOAA

Sandia's Snow Research Portfolio

Started as a 3-year, DOE-funded, Sandia-led research project: "Snow as a Factor in PV Performance and Reliability." For more info, see energy.sandia.gov/snow

Objective:
To further the deployment and optimal operation of PV systems in northern regions by measuring snow losses and demonstrating effective mitigation strategies

Five Field Sites:



Average annual snowfall in the US

Four-member project team:

Sandia National Laboratories

Michigan Technological University

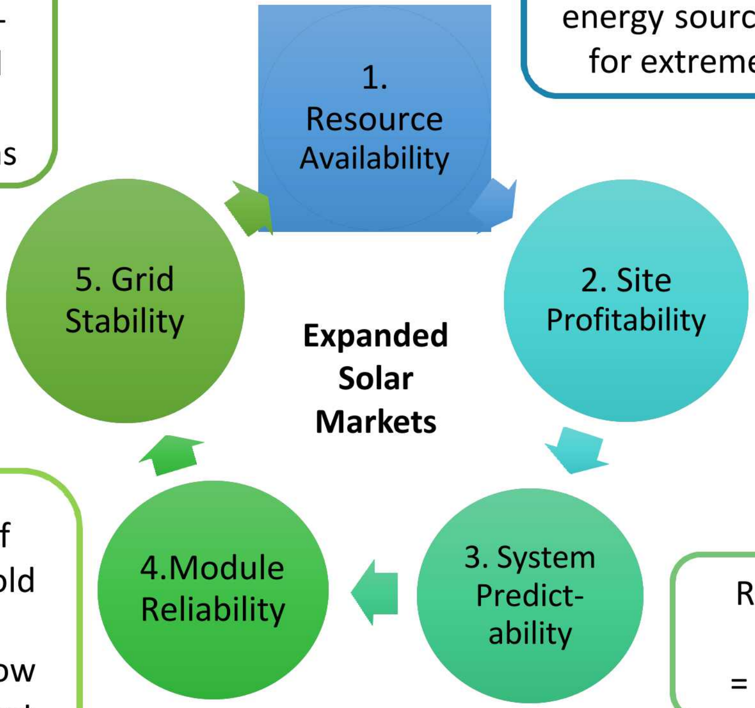
University of Alaska Fairbanks

University of Michigan

Project Has a Multi-Pronged Value Proposition

Modeling of snow shedding increases accuracy of solar-generation forecasting and reducing "ramp rate," i.e., dampens sudden oscillations

Systems that shed snow quickly represent a more available energy source; has implications for extreme weather events

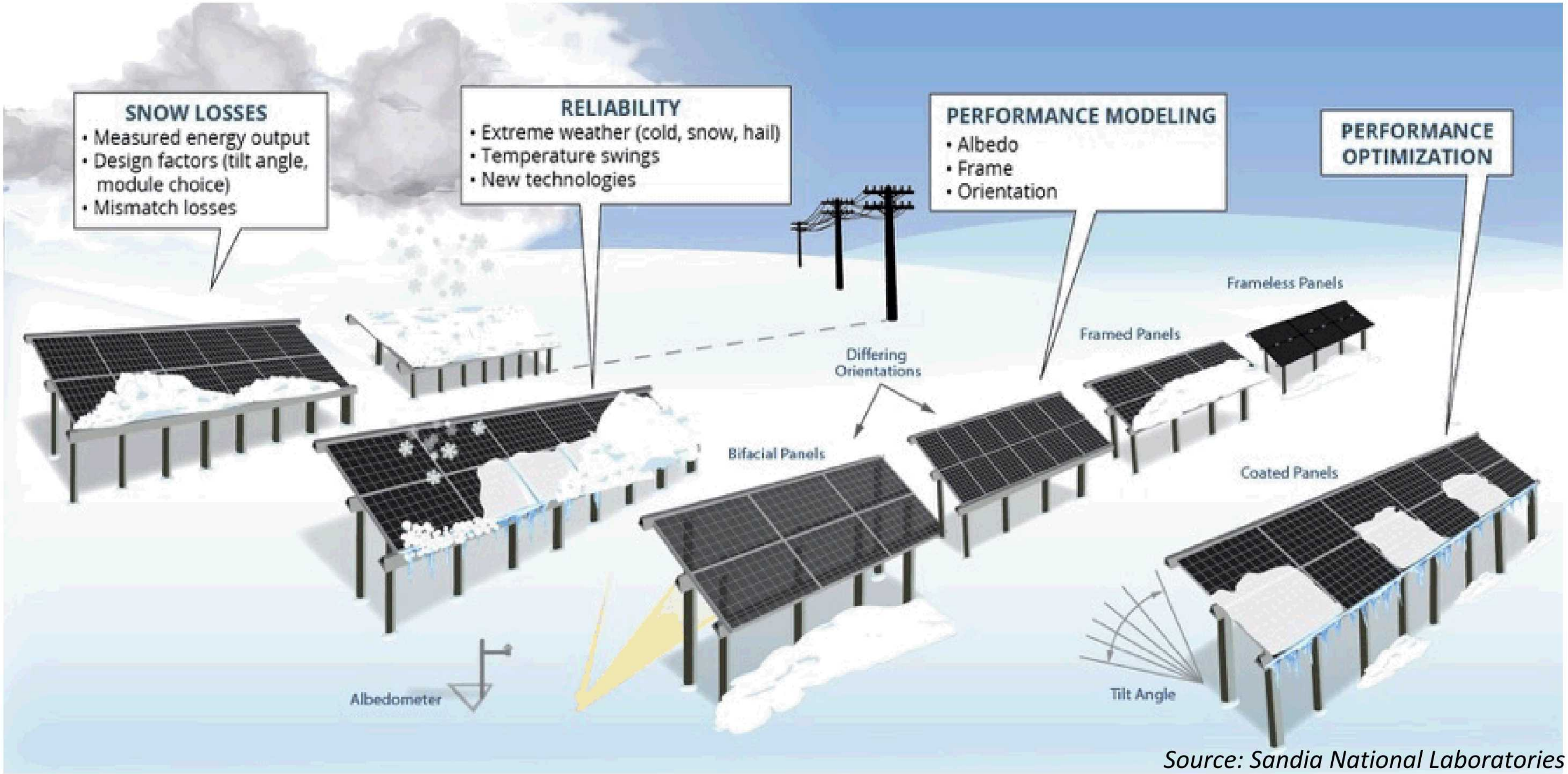


Systems designed for performance in snowy climates will generate more kWh and more revenue = lower LCOE

Refined performance models = more accurate LCOE

Identification and mitigation of design weaknesses specific to cold and snowy climates (includes coatings, frames, differential snow shedding) will lead to more robust (and dependable) systems

Four-Part Technical Approach



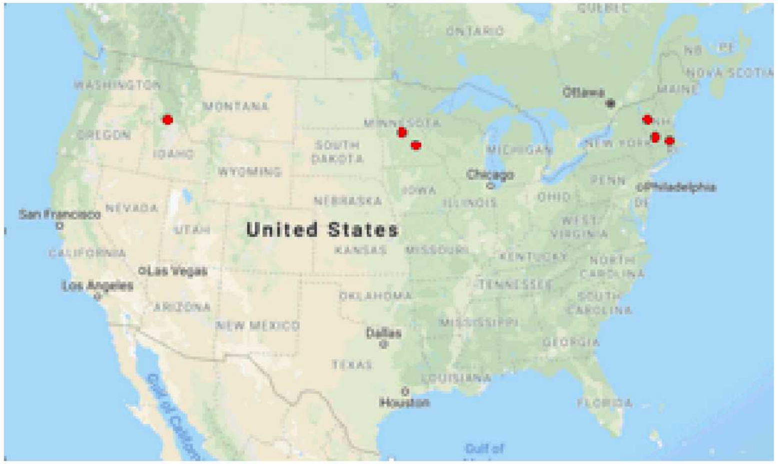
Source: Sandia National Laboratories

1. Snow Losses:

Utility-scale data analysis

Objective: to measure actual snow losses across the northern US and identify contributing factors

- Data we are collecting:
  - -Inverter power data
  - -Plane of array (POA) irradiance
  - -Ambient air temperature, wind speed and relative humidity; BOM temperature
  - -Images at 15’ intervals to provide data on:
    - --Percentage of snow cover
    - --Percentage of energy loss attributable to snow cover
  - -System metadata



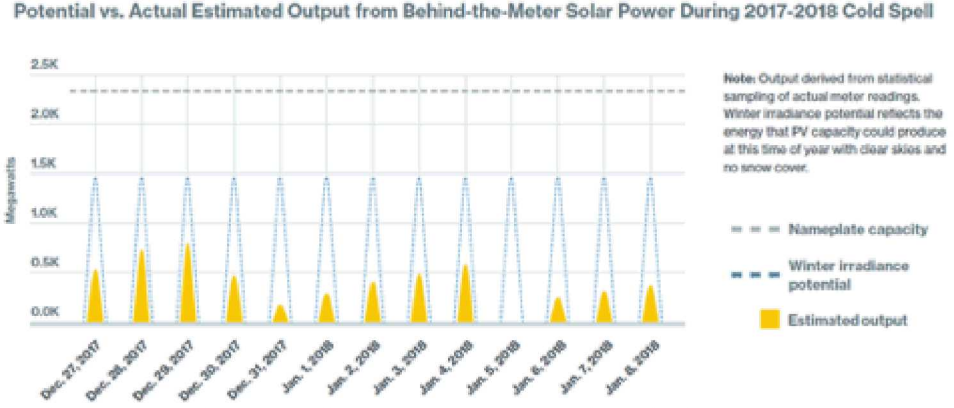
Partnerships with developers and asset owners

- Participation criteria:
  - -Onsite monitoring, including heated pyranometer and meteorological instrumentation
  - -O&M support
  - -Automated access to time-stamped data, including energy data
  - -Site metadata
  - -Willingness to forgo snow-clearing, if routinely done
- Concept is expandable; opportunities for machine learning

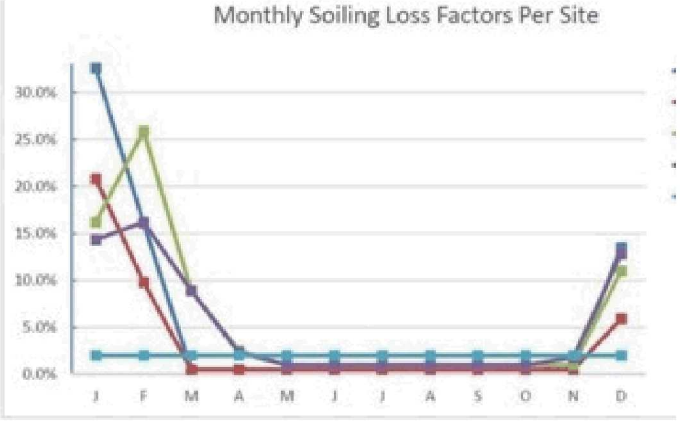
Example: Data from Massachusetts

Challenge: large variability in weather statewide.

Objective: improve predictive models to include snow coverage losses; track actual snow losses.



Representative snow losses over two-week period



Inconsistent loss factors

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
32.6%	16.1%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	13.5%

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
20.8%	9.8%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	5.9%

Array soiling losses, two consecutive years

Snow losses significant and hard to predict

2. Reliability Challenges:

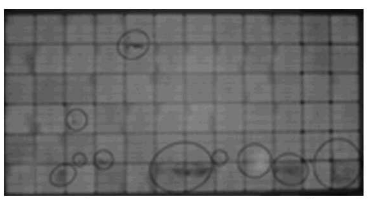
Short and Long-Term Stressors

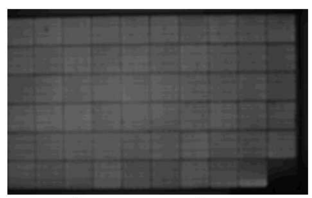
Thermo-mechanical Loading

Objective: measure mechanical loads (module displacement) under different meteorological conditions.

Long-Term Cold Exposure (need for longitudinal studies)

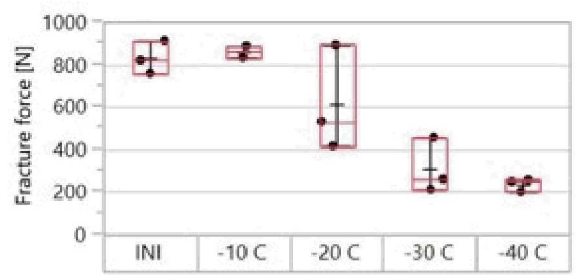
Framed bifacial





Frameless bifacial

Objective: correlate patterns of cell cracking with snow load, module and ***cell technologies*** *over time*



Schneller *et al* show less force is needed to induce cell cracking as temperatures drop

Extreme Weather

Objective: Track in situ crack formation; mitigation strategies

Funded by:

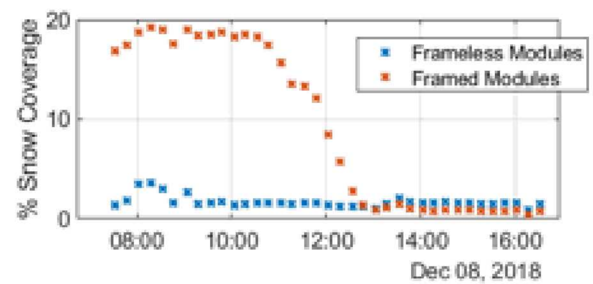
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

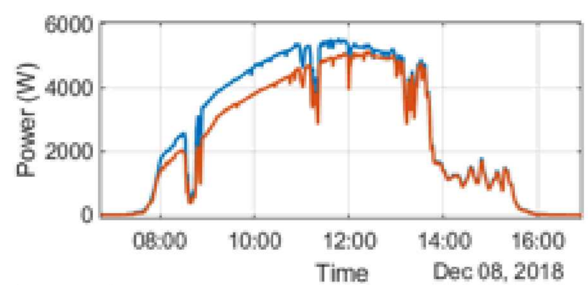
3. Performance Modeling:

Impact of frame on snow-shedding

Framed modules on the left; frameless on the right.

- Images taken at 15’ intervals from adjacent CIGS arrays, one framed, one frameless
- Image analysis showed frameless modules *generally* shed snow 50% more quickly than framed modules
- Energy gains from frameless—relative to framed—were ~ 13% in December, 2018.
- Height of the array needs to be considered to prevent build-up of snow on the ground.





D. Riley, L. Burnham, B. Walker and J. Pearce, “Differences in Snow Shedding in Photovoltaic Systems with Framed and Frameless Modules,” *Proc.IEEE PVSC-46*, 2020, 4pp.

3. Performance Modeling:

Albedo

Objectives:

1) Rethink modeling assumptions: does snow really have an albedo of ~.8?

2) Quantify seasonal and diurnal variation, as a function of:
   - Irradiance
   - Angle-of-incidence
   - Spectral variation
   - Age of snow
   - Depth of snow

3) Refine bifacial performance model to include albedo of snow

4. Performance Optimization:
Strategies to accelerate snow-shedding

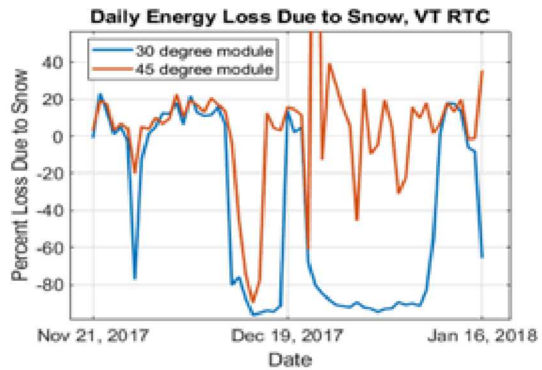
Passive strategies:

- Tilt angle
- Presence of frame
- Module orientation (sliding distance relative to frame)
- Module surface (friction coefficient)
- Edge gap
- Module clips
- Module technology (bifacial)

Active strategies:

- Snow removal (rake, blower)
- Adjustable tilt angle
- Reverse-current injection

Tilt Angle

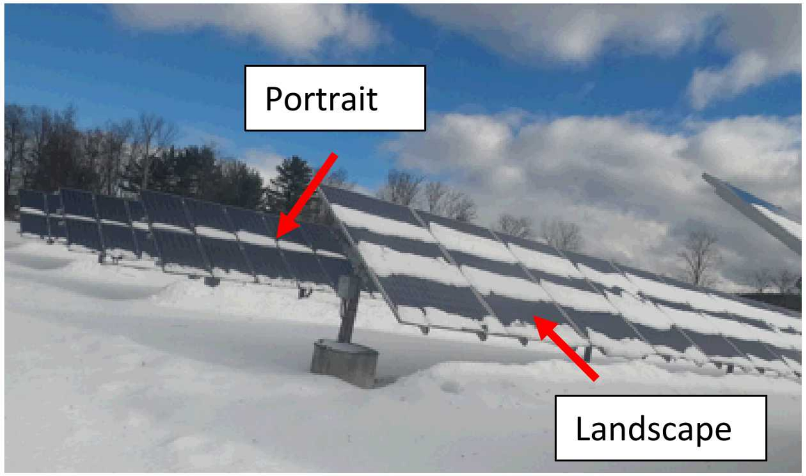


Edge Effect

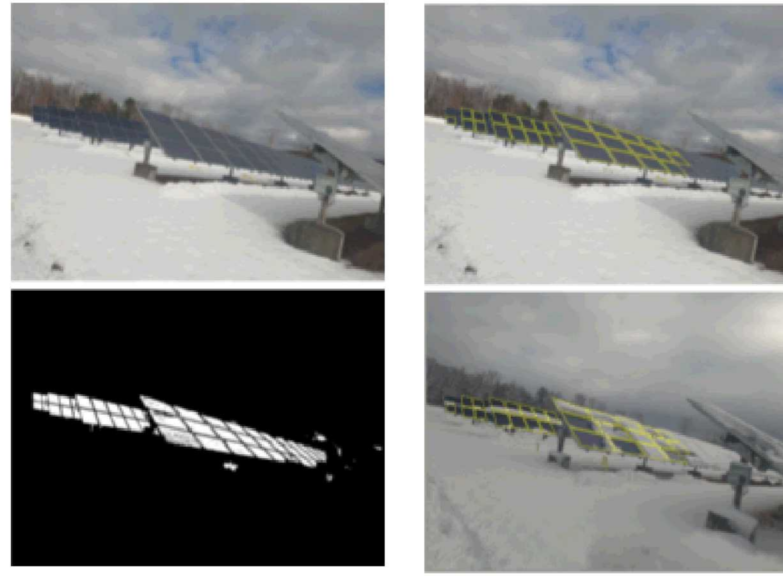
Clip Effect

L. Burnham, D. Riley, J. Braid, “Design considerations for photovoltaic systems deployed in snowy climates,” *Proc. EU PVSEC*, 2020, 5pp.

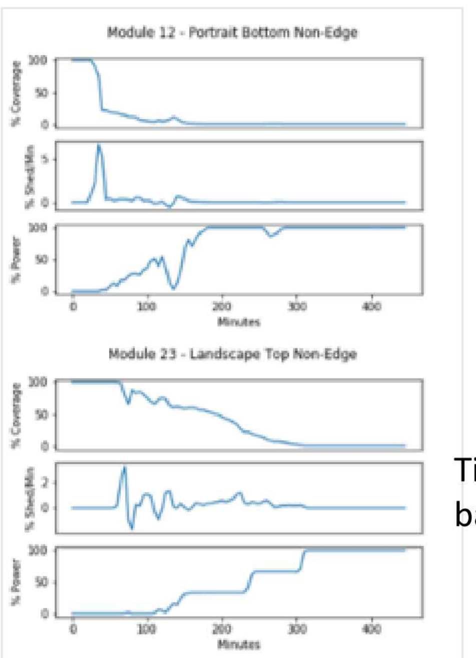
Design Optimization: Module Orientation



Adjacent arrays in Bradford, VT



Methodology for image extraction



Time-series metrics based on image analysis

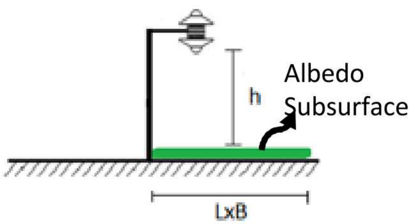
Orientation	Energy yield (%)	Time to start shed (min)	Time to produce power (min)	Time to 90% power (min)	Time to finish shed (min)
Landscape	59.3	47.5	65	310	310
Portrait	73.5	30	55	185	212.5

Energy-yield metrics

J. Braid, D. Riley, J. Pearce and L. Burnham, "Image analysis method for quantifying snow losses on PV systems," *Proc.* IEEE PVSC-47, 2020, 7pp.

II. Bifacial Performance

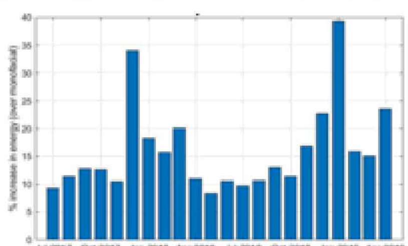
Albedo measurements



Seasonal and diurnal variation:

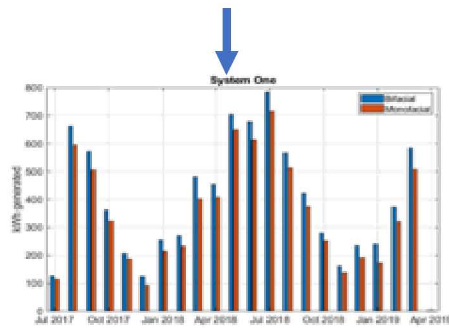
- Irradiance
- Angle-of-incidence
- Spectral variation
- Age of snow
- Depth of snow

Bifacial Dual-Axis Tracker Systems

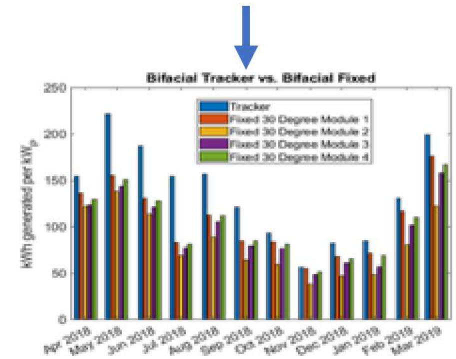


Bifacial Gain

Tracker bifacials outperform tracker monofacials by 14%



Tracker bifacials outperform fixed-tilt bifacials by 41%

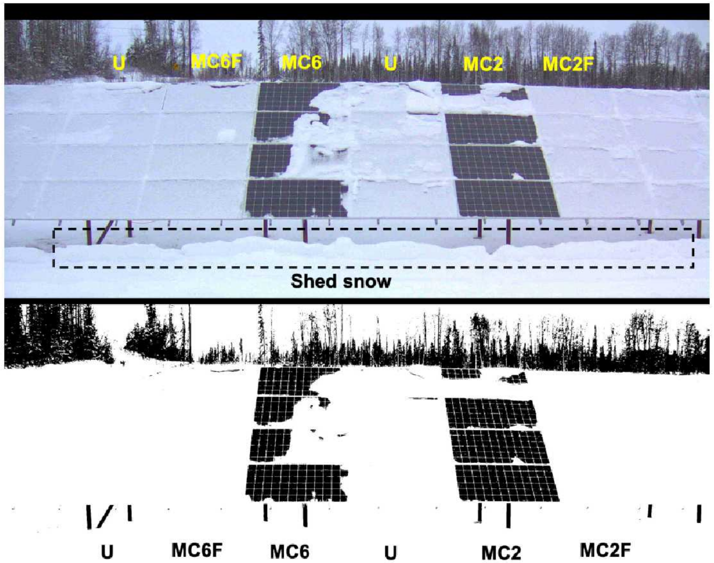


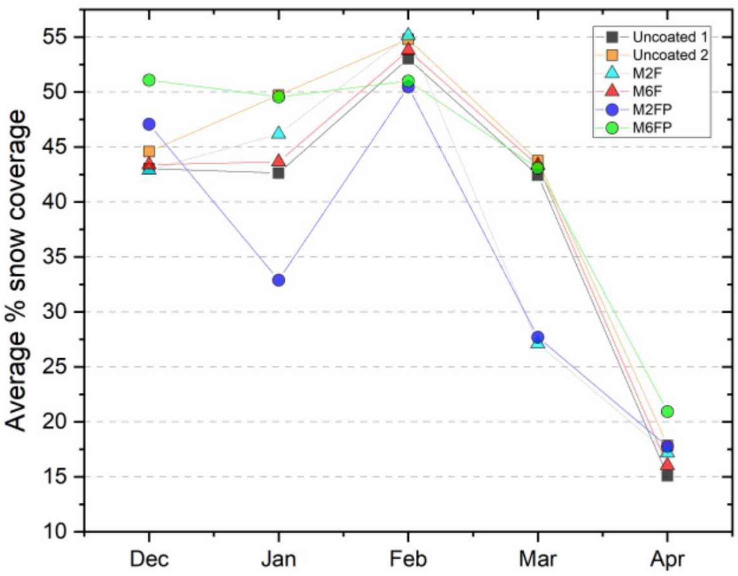
Energy Yield

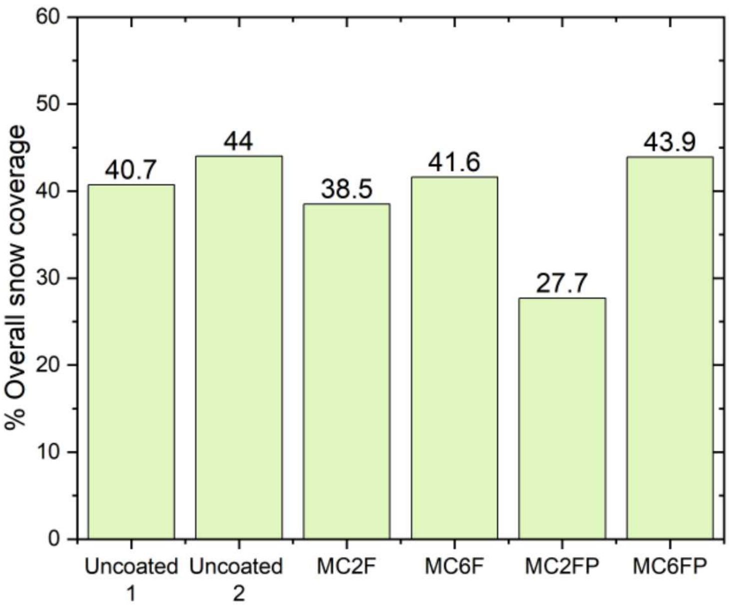
L. Burnham, D. Riley, B. Walker, and J. Pearce,. "Performance of Bifacial Photovoltaic Modules on a Dual-Axis Tracker in a High-Latitude, High-Albedo Environment," *Proc. IEEE PVSC-46, Chicago*, IL, 8pp, (2019)

Design Optimization: Snow-phobic Coatings

- Two proof-of-concept coatings selected based on transmissivity and functional characteristics
- Applied to fielded modules in MI, VT and AK
- Time-series data collected on percent of column covered in snow
- Results are promising; will be repeated in winter of 2021







Data presented is from Willow, AK

Summary

- Solar is expanding rapidly across northern regions
- Deployment is outpacing our knowledge of snow losses and reliability issues
- Project hypothesis: significant increases in system efficiency are possible through design optimization
- Specific opportunities for 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!

Laurie Burnham

lburnha@sandia.gov

505-845-7354