



Modeling the Performance of PV Systems in Northern Latitudes

PVPMC Workshop – 7 May 2024

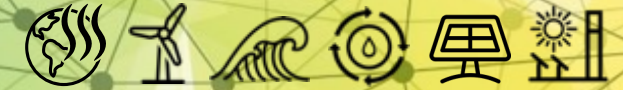
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Why Modeling Matters: PV Growth in Wintry Climates

1. High growth rates

- The north is the new solar frontier
- As of 2021, 31% of all operable US PV capacity was located above 40°N.*

2. Favorable operating climate for solar

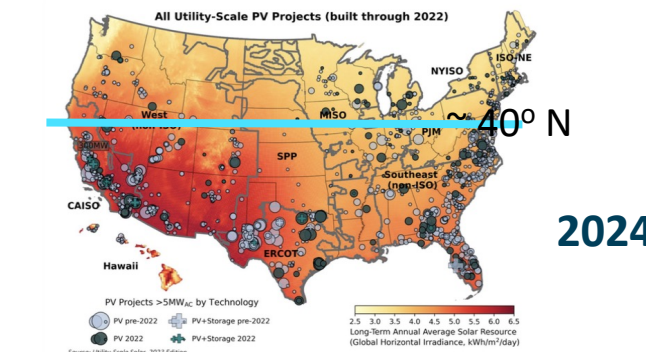
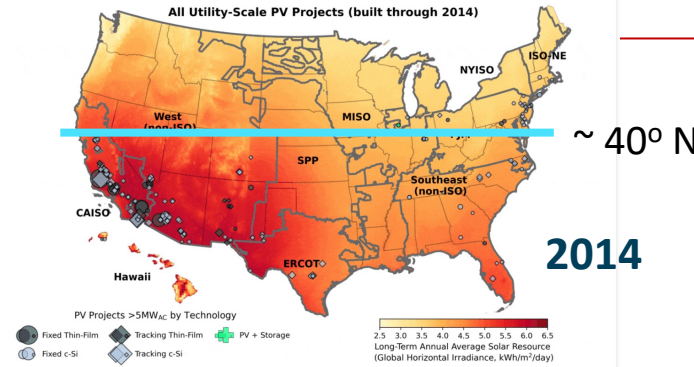
- Cooler temperatures = higher solar-cell efficiencies
- Lower cell-degradation rates
- Fewer component failures (?)

3. Especially favorable operating climate for bifacial modules

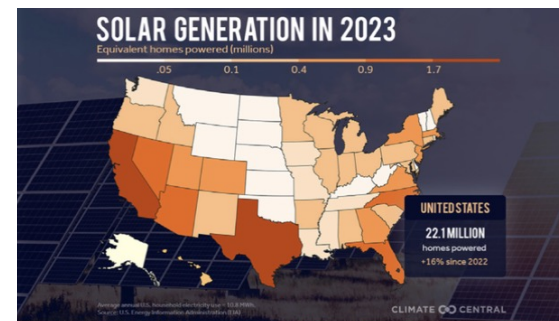
- Snow has a high surface albedo in winter = significant bifacial gain
- High albedo is restored with every snowfall



* From the U.S. EIA,, Annual Generator Report, EIA-860A/860B



LBNL, Utility-Scale Solar, 2023 Edition



July 26, 2022

State Approves New York's Largest Solar Farm

500-megawatt Cider Solar Farm Takes Big Step Toward Achieving the Empire State's Clean Energy Goals

NEWS HIGHLIGHTS

New York's Office of Renewable Energy Siting (ORES) has approved Hecate Energy's permit for the 500-m (MW) Cider Solar Farm, the largest solar energy project in New York State history.

Minnesota will soon be home to 5th largest solar facility in the nation

By Eric Rosenzweig
April 25, 2024 / 10:30 PM CDT / CBS Minnesota

Wisconsin's Largest Solar Project is Now Fully Operational

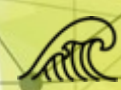
More than 800,000 solar panels powering customers with renewable energy.

Madison, Wis., Jan. 4, 2024—Madison Gas and Electric (MGE) and We Energies are setting another milestone in delivering affordable, reliable and clean energy to their customers. The final panels at the Badger Hollow Solar Farm are now in service, completing the largest solar project in Wisconsin history.



Comparative analysis of cross-climate degradation rates

Percent change in P _{MP} after 8 years			
	Florida	New Mex.	Vermont
Mono-Si fielded	-2.02	-2.36	-0.67
Multi-Si fielded	-16.57	-7.97	-5.97
CdTe fielded	-16.62	-15.49	-10.05
Mono-Si unfielded		-0.26	
CdTe unfielded			0.22



Why Modeling Matters: Snow Losses Matter

Snow Impacts Performance

1. Power losses are significant

Snow shading of modules causes significant power losses throughout winter months

2. Snow is ubiquitous

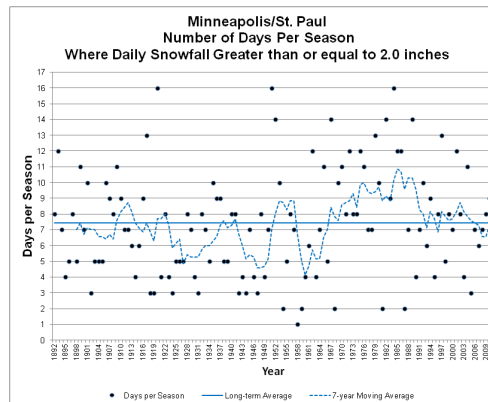
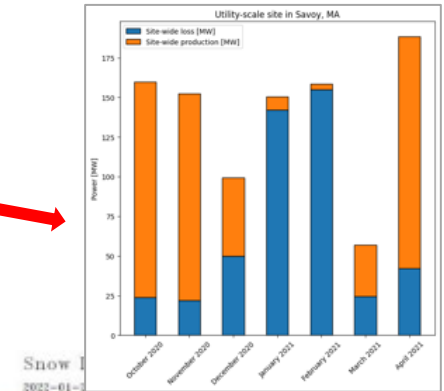
Snow occurs in every state; a single storm can impact > 50% of US

3. Snow takes PV offline (resource challenges)

Blizzards can sweep across the US, resulting in zero solar generation.

5. Design optimization is a big unknown

- Module configuration
- Leading Edge Height
- Module physical characteristics



January 29, 2022

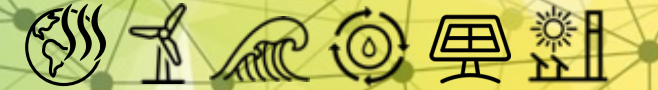
Area Covered By Snow: 39.1%
Area Covered Last Month: 39.4%

Snow Impacts Reliability

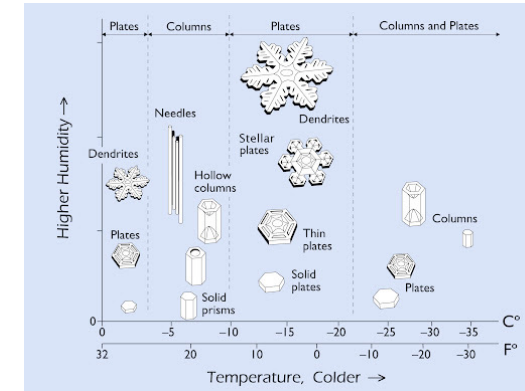
1. Wintry climates have unique stressors

Snow is repetitive and always accompanied by cold temperatures

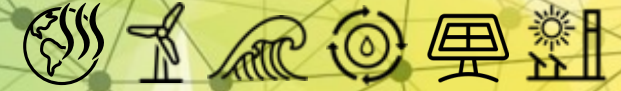
But Snow-Loss Modeling Has Its Challenges



1. Snow is constantly changing
 - Morphology (including porosity and reflectivity) of snow depends on temperature and humidity
 - Over time, snow compacts, erodes; can undergo multiple melt-freeze cycles
 - How to measure: water equivalent vs snow depth?
2. Snow adhesion to a solar panel depends on
 - Climatic conditions (snow depth; ambient temp; humidity; wind)
 - System design (tilt angle; module orientation; height above ground; fixed-tilt vs tracker)
 - Module architecture (frame, location of module clips, surface roughness)
3. Snow distribution on panels is often non-uniform; patterns of partial shedding not well understood
4. Design of solar panels is constantly changing
 - Larger format modules = more surface area
 - Diversity of module clips and frame profiles; little data on how they compare
 - Electrical designs are evolving
 - Different solar cells may have different spectral responses
5. Snow losses can be impacted by uniformity and density of snow; irradiance; ambient air temperature; back-of-module temperature (bi-faciality)



Majority of Sandia's Research Takes Place at MI Tech

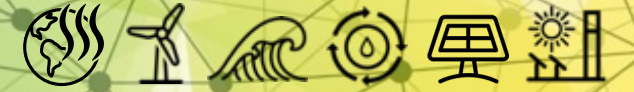


- MI Regional Test Center commissioned in 2021
- 14 experimental systems (some repurposed from VT)
- 7 industry partners (Array Tech, Unirac, Maxeon, GAF, Heliene, Morgan Solar, Origami Solar, Snow-Free Solar)

Time-series data includes:

- Irradiance (GHI, DNI, DHI, POA)
 - String-level DC current and voltage
 - Tbom
- Digital images of system





Questions?

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