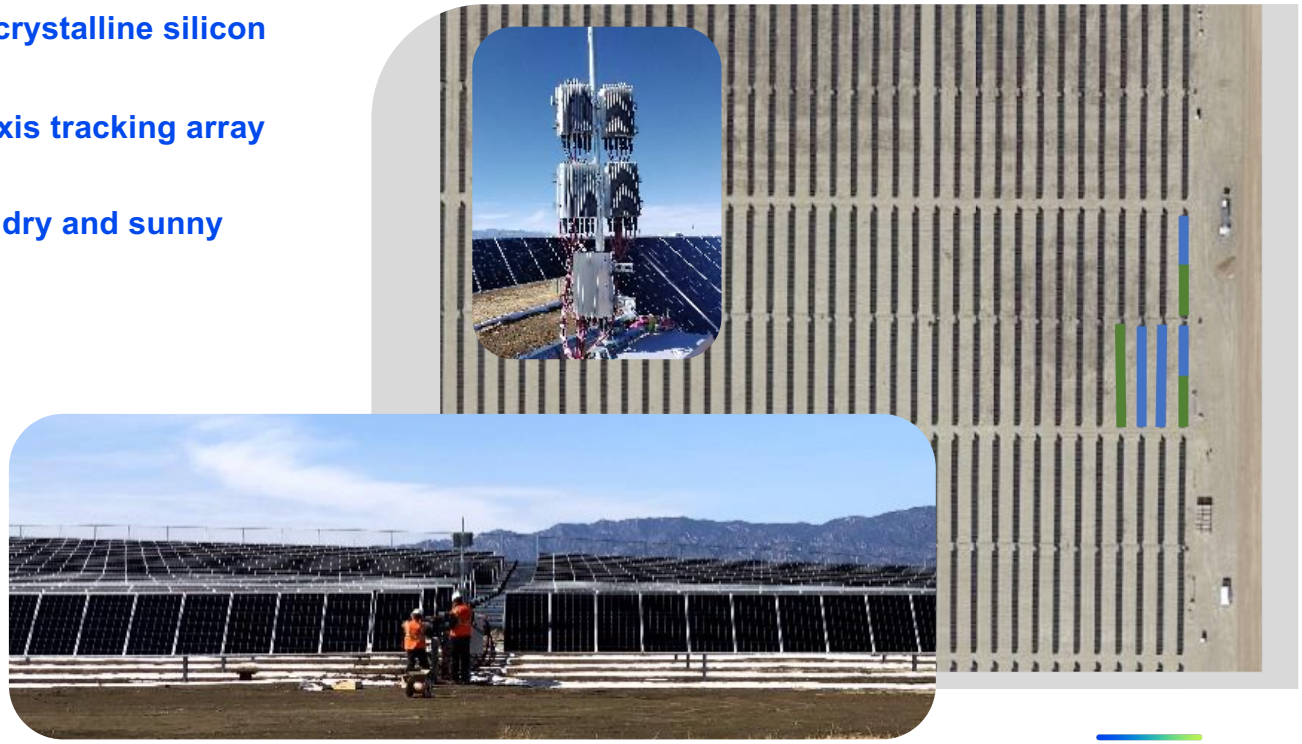
Overview

- **Bifacial Test Bed**
  Motivation and Description
- **Albedo**
  Measured vs. satellite data and model impact
- **Rear Side Irradiance**
  Variability and model impact
- **Bifacial Snow Gains**
  Snow shed and increased energy production

Bifacial Test Bed

Description

- **375W monofacial and bifacial crystalline silicon modules**
- **Embedded in existing single axis tracking array in 2020**
- **Colorado location – snow, but dry and sunny**
- **Exterior and interior strings**
  - Monofacial (blue)
  - Bifacial (green)
- **AMPT DC-DC converters interface to plant inverters**



Bifacial Test Bed

Instrumentation

- **>2 years of 1 minute sensor data**
  - Hukseflux albedometer
  - Calibrated silicon reference cells for front and rear side plane of array irradiance
  - Thermocouple (small) temperature sensors
  - Site weather station provides wind speed and humidity measurements
- **2021 year data create hourly PVSyst model**
  - 1.23 DC:AC ratio

Albedo

Monthly Averages

Month	Data Average	Satellite Albedo Source 1	Source 2	Source 3
Jan	0.39	0.27	0.31	0.53
Feb	0.52	0.27	0.34	0.39
Mar	0.27	0.21	0.26	0.26
Apr	0.25	0.21	0.23	0.23
May	0.25	0.2	0.2	0.21
Jun	0.23	0.2	0.2	0.16
Jul	0.22	0.19	0.2	0.18
Aug	0.23	0.19	0.18	0.17
Sep	0.23	0.2	0.2	0.17
Oct	0.29	0.2	0.21	0.20
Nov	0.30	0.2	0.24	0.21
Dec	0.34	0.27	0.31	0.38

Albedo

PVSyst Model Results

Difference in Predicted Annual Energy Production Relative to Model Using Measured Average Monthly Albedo

Source 1	Source 2	Source 3
-0.85%	-0.61%	-0.45%

	Data	Satellite Albedo		
Month	Average	Source 1	Source 2	Source 3
Jan	0.39	0.27	0.31	0.53
Feb	0.52	0.27	0.34	0.39
Mar	0.27	0.21	0.26	0.26
Apr	0.25	0.21	0.23	0.23
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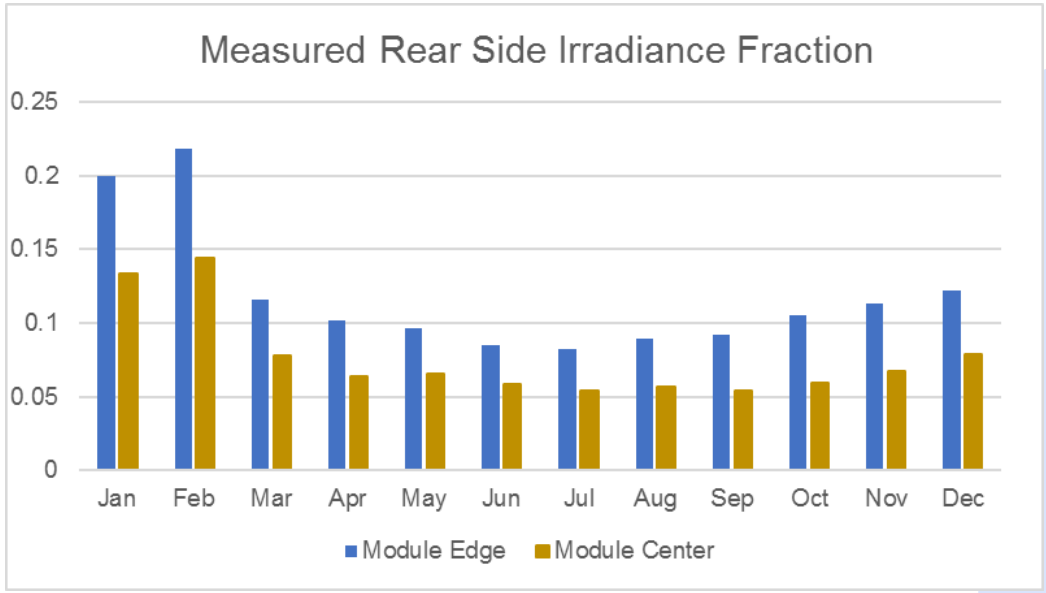
Rear Plane of Array Irradiance

Field Measurements



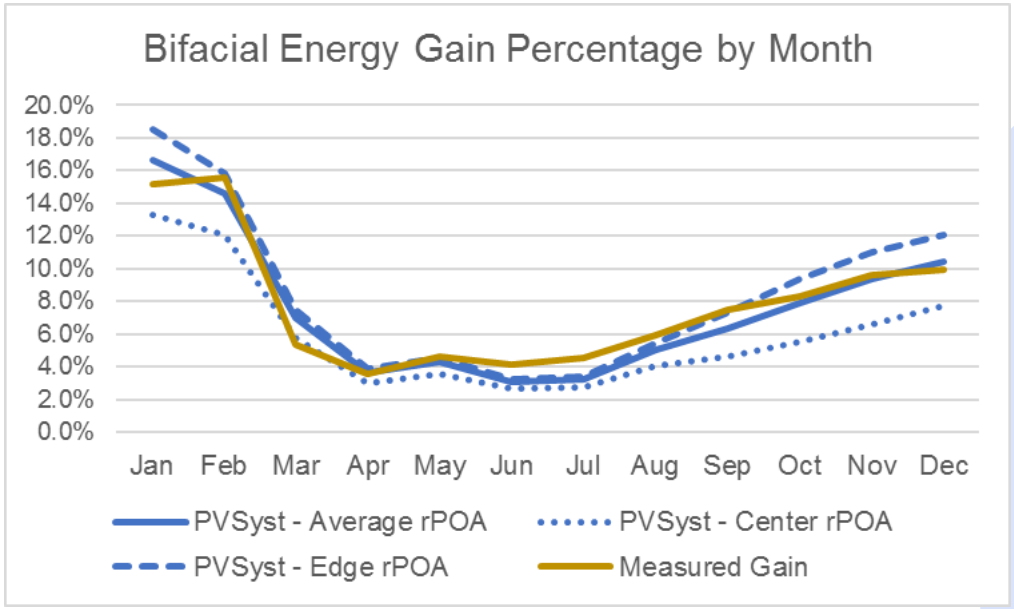
Total average annual rear side irradiance fractions:

Edge Sensors: 10.9%

Center Sensors: 7.0%

Rear Plane of Array Irradiance

Energy Model Impact



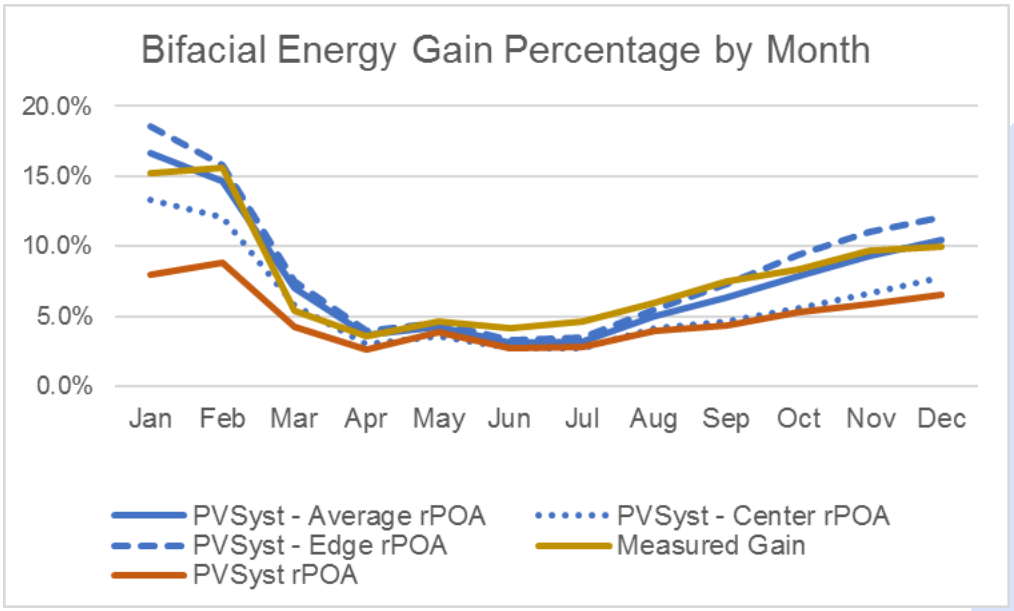
Total Annual Measured Bifacial Energy Gain: 6.6%

Modeled Annual Bifacial Energy Gain, Avg. rPOA: 6.7%

(edge +1%, center -1%)

Rear Plane of Array Irradiance

Energy Model Impact



PVSyst calculated rear side irradiance fraction: 9.1%

PVSyst annual bifacial gain with calculated rear side irradiance: 4.5%

Bifacial Snow Gains

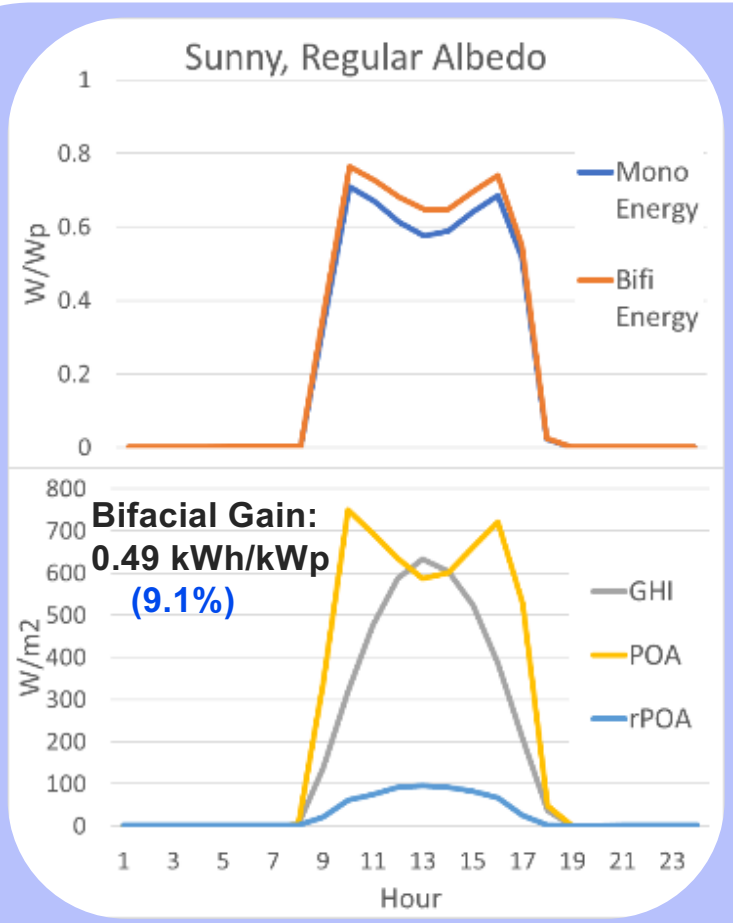
In 2021, the project site experienced

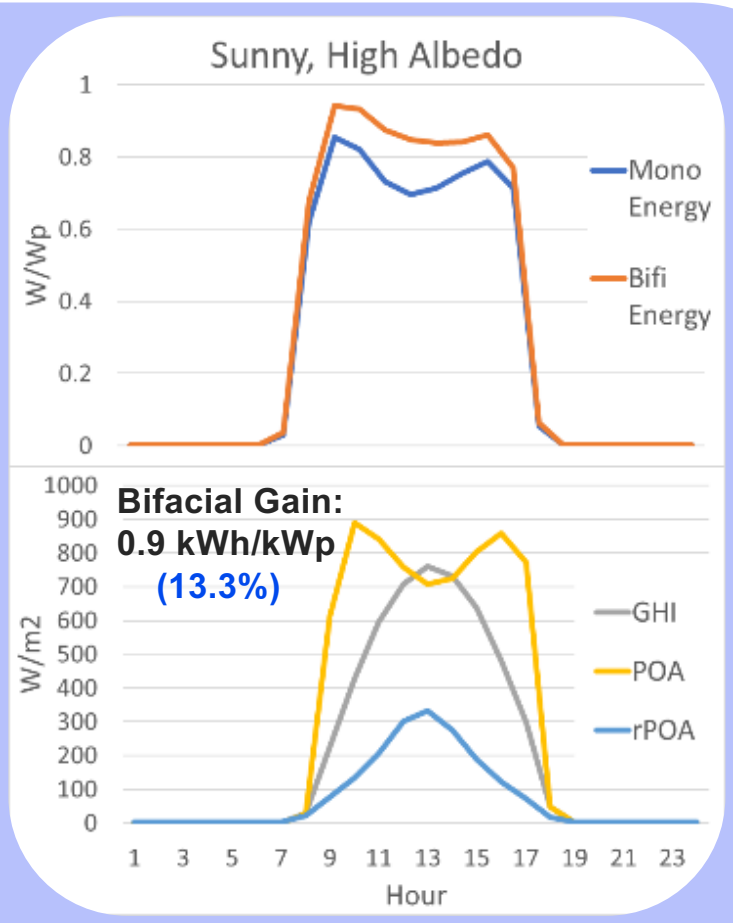
- **26 recorded snow events, some spanning multiple days**
- **54 full or partial days with high ground albedo indicative of snow cover**
- **20 full or partial days with module performance affected by array snow cover**

Note that project site has typically sunny and dry climate characteristic of Colorado

Bifacial Snow Gains

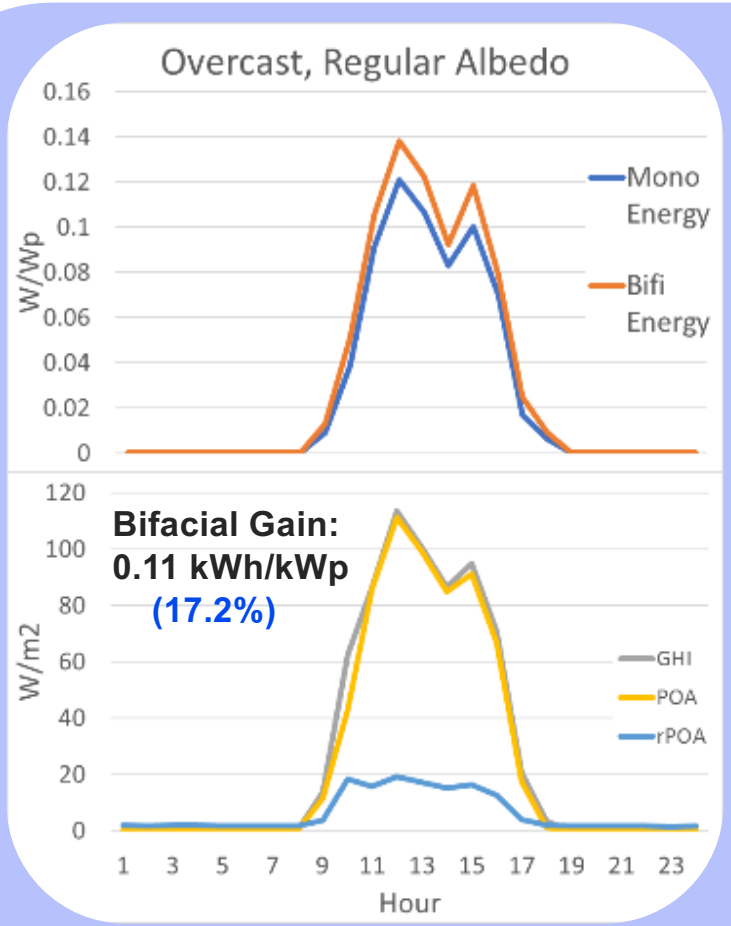
Sunny Day Examples

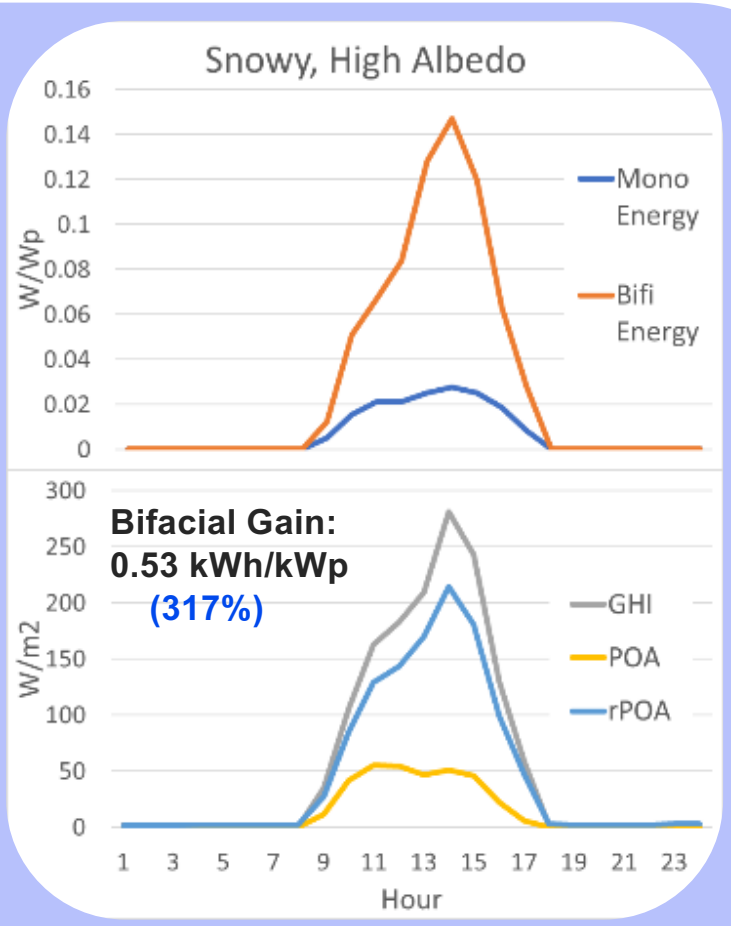




Bifacial Snow Gains

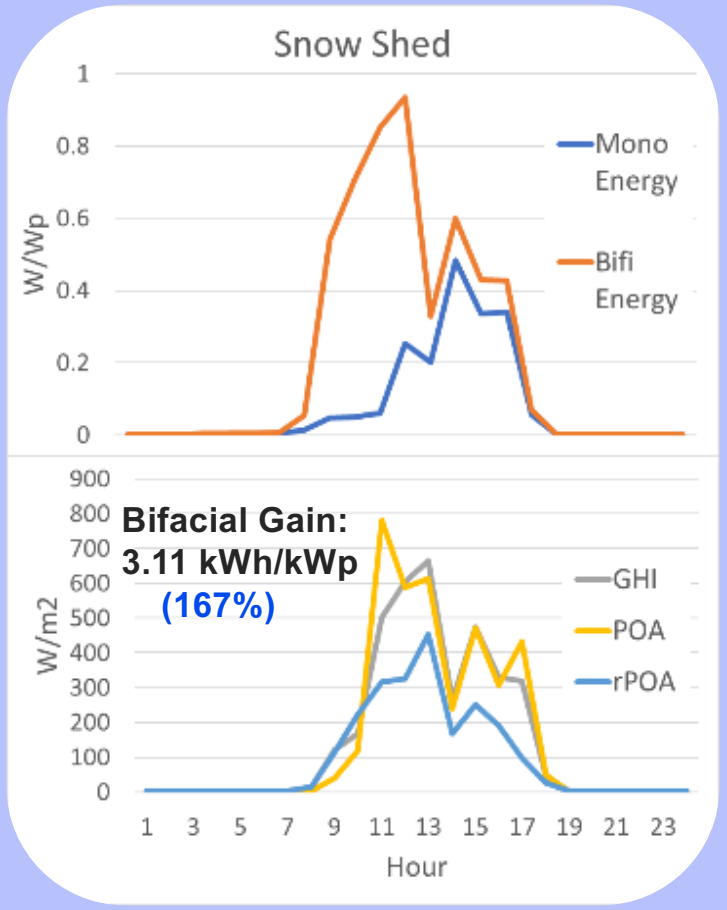
Overcast Day Examples

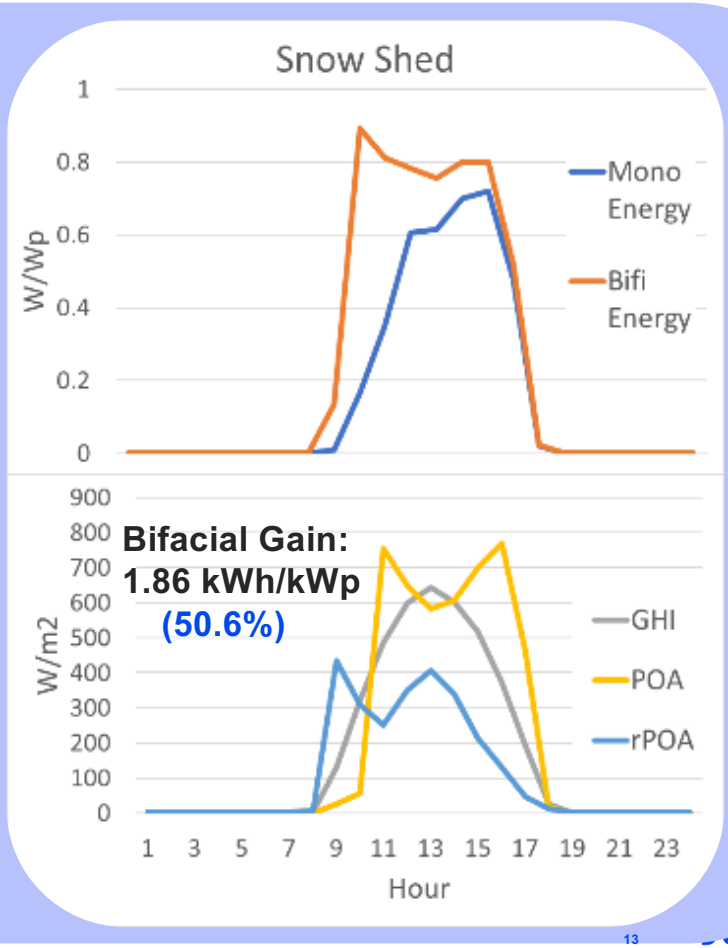




Bifacial Snow Gains

Snow Shed Examples

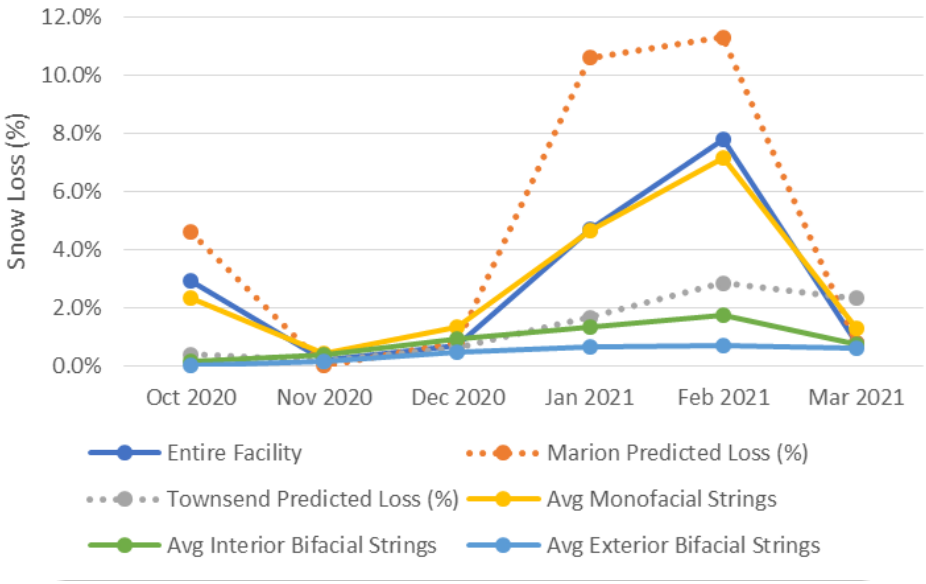




Bifacial Snow Gains

Snow Loss Modeling Implications

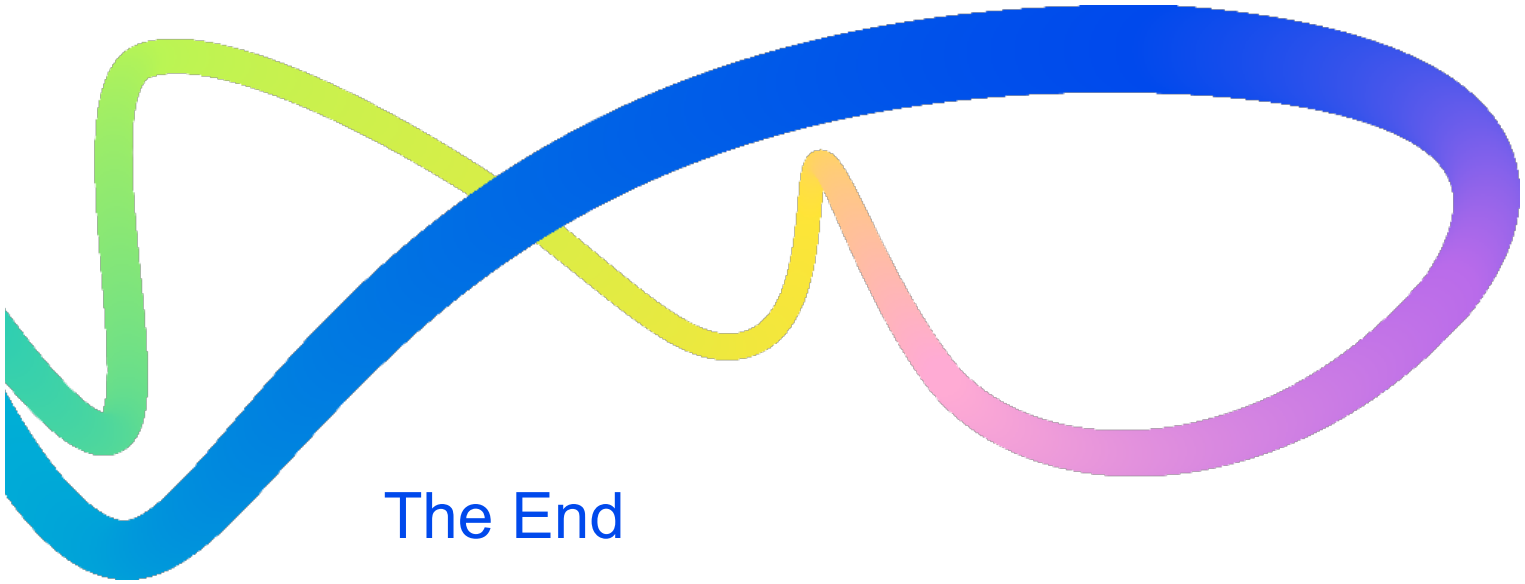
- **20 days with module performance affected by snow cover account for 20% of the system‘s overall annual bifacial gains**
- **Current models overpredict snow losses for bifacial modules on single axis trackers (limited dataset)**
- **Useful snow loss model enhancements could include accounting for enhanced gains from snow albedo and snow shedding for bifacial modules**



Credit: O. Westbrook, “Comparison of Measured and Modeled Snow Losses for Photovoltaic Systems in Colorado,” PVSC 2022

Summary

- A bifacial test bed provides useful ways to understand differences in bifacial module behavior and improve confidence in PV models
- Albedo is a non-trivial source of uncertainty in bifacial PV modeling which can be reduced by site measurements
- Irradiance can vary widely across the rear side of a module on a single axis tracker and an average value appears to reflect bifacial energy gains well
- Bifacial modules on a single axis tracker demonstrate faster snow shedding than their monofacial counterparts and receive a significant performance boost from ground snow-cover, which are not well reflected in current snow loss models



The End

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