# Field Performance of Bifacial PV Modules and Systems

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# 3-Yr Bifacial Research Project (FY16-18)

Sandia National Laboratories

Collaborative project between Sandia, NREL and University of Iowa
(https://pvpmc.sandia.gov/pv-research/bifacial-pv-project/)

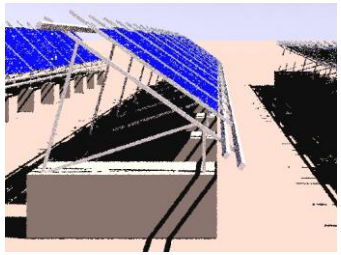
## Task 1: Measure Outdoor Bifacial Performance

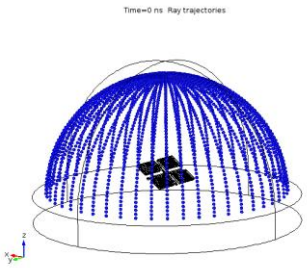
- Module, string and system scale
  - Adjustable rack with 4 modules
  - Fixed tilt racking with varying tilt and azimuth
  - Single axis and two-axis trackers
  - Arid sunny (NM and NV) and cold snowy climates (VT)
  - Irradiance measurements (rear-facing, spatial)
- Quantify
  - Performance of mono- and bifacial modules in similar deployments
  - Bifacial gain – see next slide
  - Spatial variability in backside irradiance
  - Effects of backside obstructions and shading

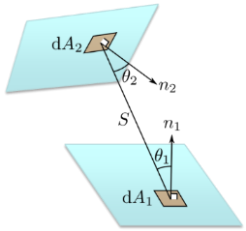
# 3-Yr Bifacial Research Project (FY16-18)

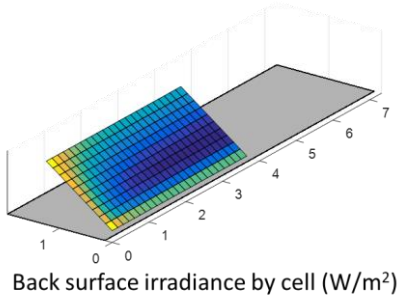
## Task 2: Develop Performance Models

- Irradiance modeling
  - Ray tracing methods – Sensitivity studies
  - View (Configuration) Factor methods : 2D for conventional arrays, 3D for cell-by-cell irradiance
- Module performance models



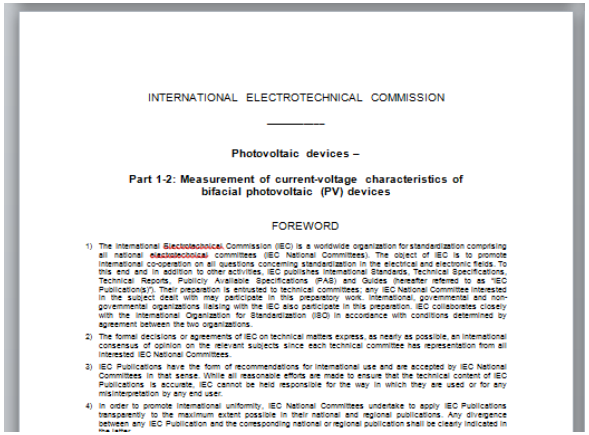



## Task 3: Support Rating Standards

- Support new bifacial rating standard (IEC 60904-1-2 - Draft)



INTERNATIONAL ELECTROTECHNICAL COMMISSION

Photovoltaic devices –

Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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https://pvpmc.sandia.gov/pv-research/bifacial-pv-project/

# Measuring Bifacial System Performance

- We compare bifacial modules to similar monofacial modules in the same mounting and orientation (e.g., fixed tilt, south-facing) using *bifacial gain BG*
  - $E_{bifacial}/E_{monofacial} = 1 + \mathrm{BG}$
- Normalize power by rated capacity to compare between systems
  - $BG = \dfrac{\sum \mathrm{P_{bifacial}(t)\ /\ P0_{bifacial}}}{\sum \mathrm{P_{monofacial}(t)/P0_{monofacial}}} - 1$
- BG varies with system, time of day and season due to:
  - Bifacial ratio (back/front module rating) : depends on cell technology and module design (>90%, >80%, >60%, ~35%)
  - Rear-surface irradiance (mostly ground reflected irradiance) is not proportional to front-side plane-of-array irradiance
    - Albedo – ground cover, can change with time of day and season
    - Shadows on the ground from nearby objects, moderated by elevating the bifacial array
    - Nearby obstructions (e.g., racking)
  - Power is not always proportional to total irradiance
    - Mismatch effects from spatially variable rear-surface irradiance

# Prism Solar Modules in NM, NV and VT

New Mexico


Measured Albedo
- Natural = 0.2 – 0.3
- White = 0.5 – 0.6

Nevada

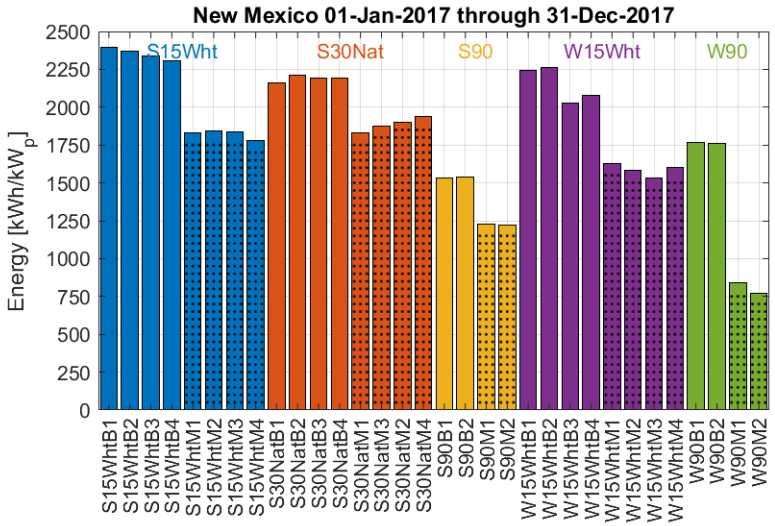
Measured Albedo
- Natural = 0.2
- White = 0.3

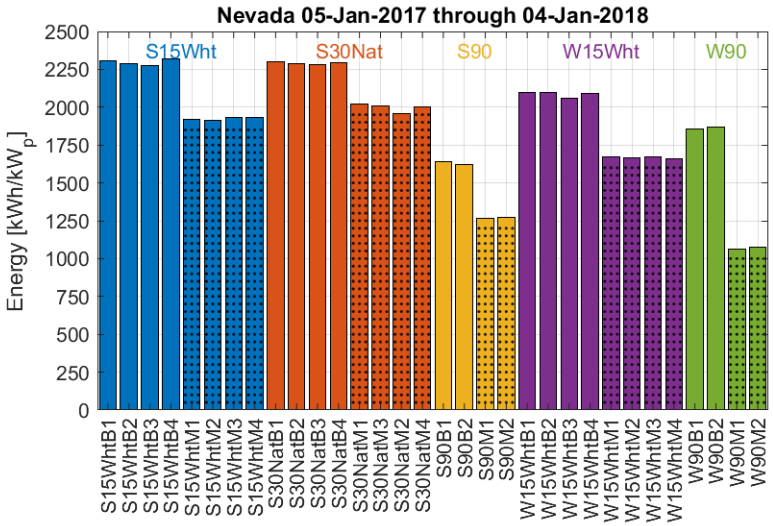
Vermont – summer

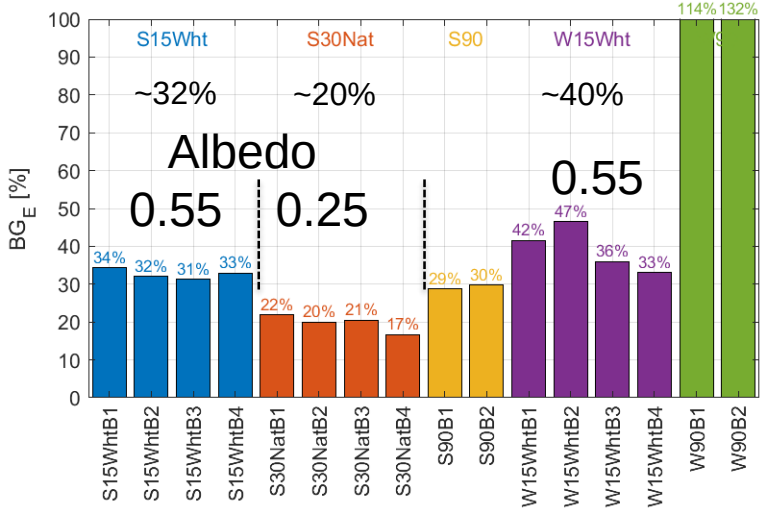
Measured Albedo
- Natural = 0.1 (Summer)
- White = 0.2 (Summer)
- Winter = ??

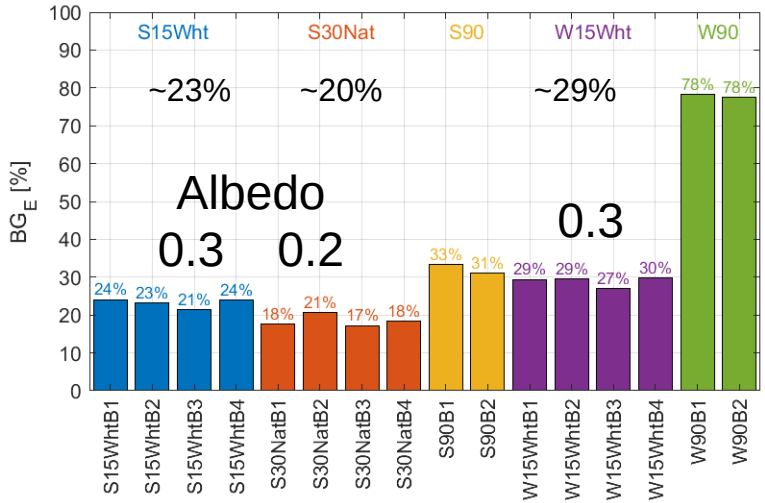
Vermont – winter (awaiting data)

# Comparison of annual energy (NM, NV)



# BG varies significantly by time of day

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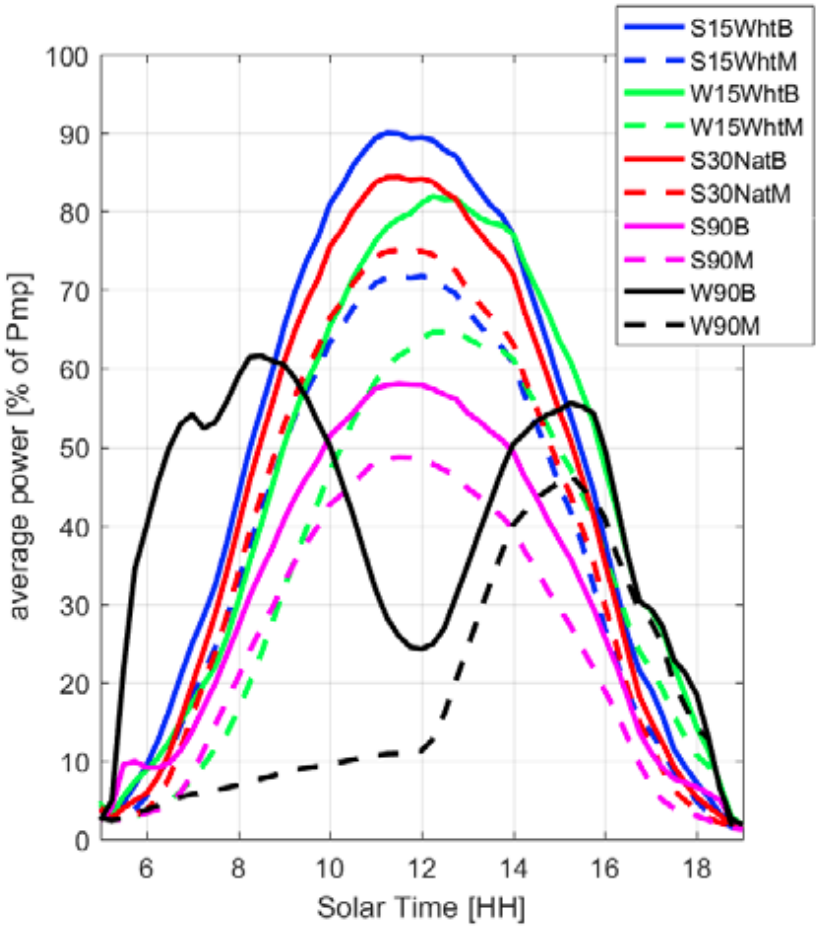
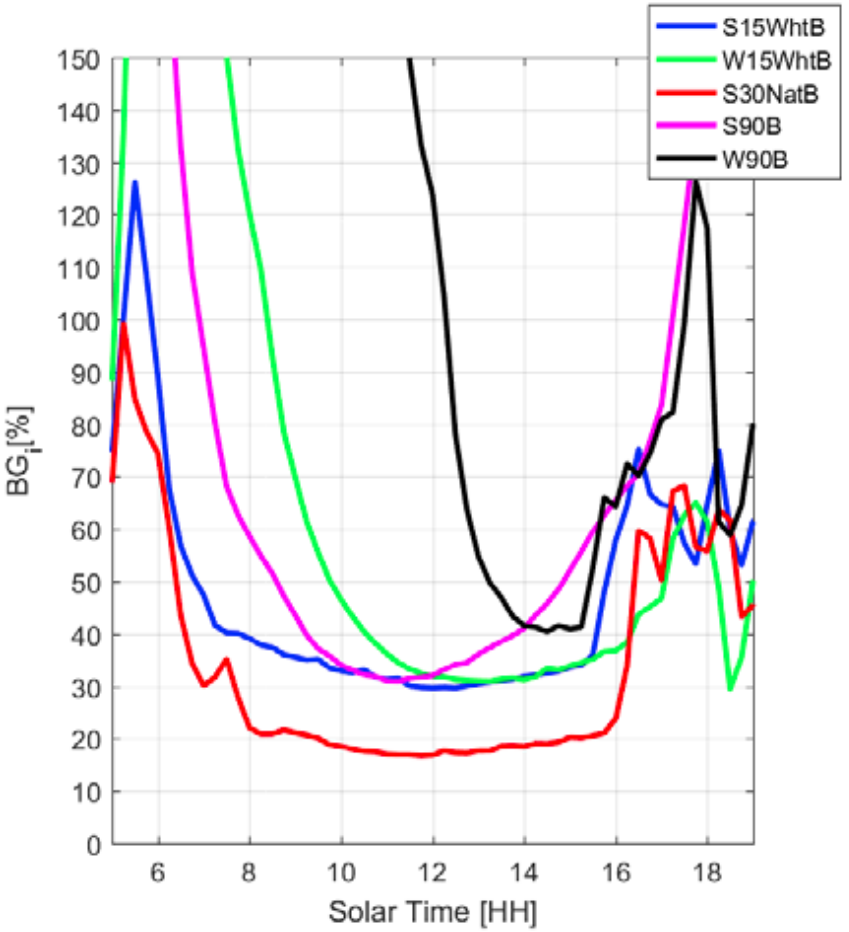
Average power for one year




Average BG (power) for one year

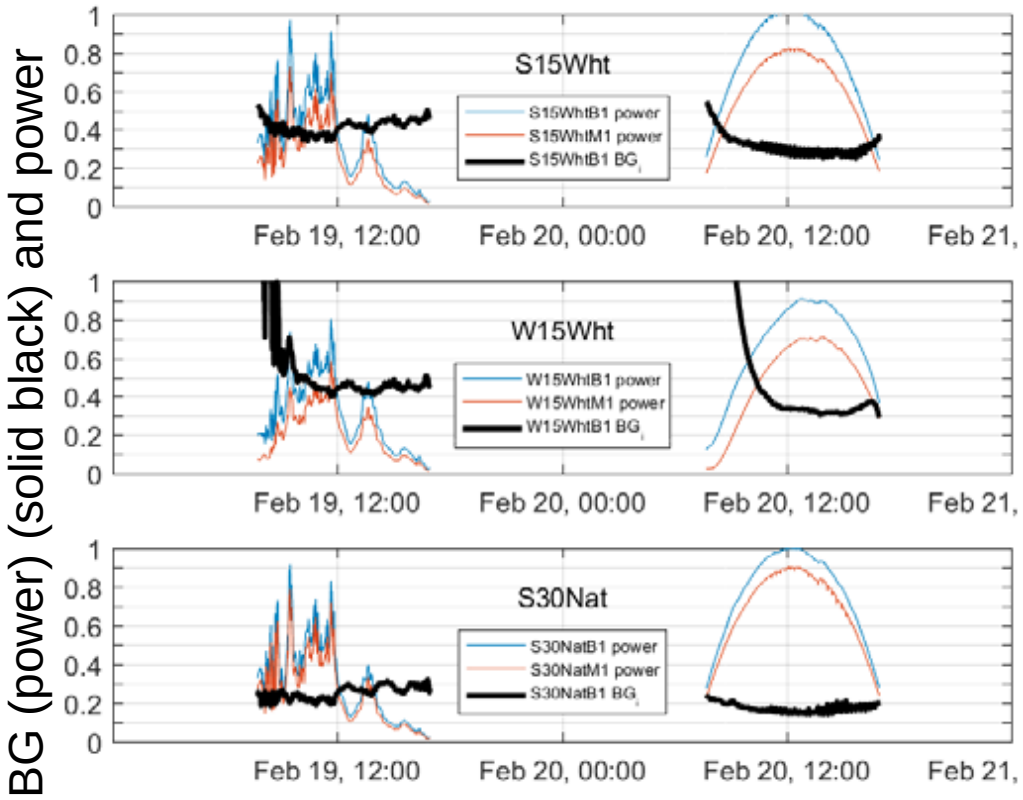


# BG vs. weather condition

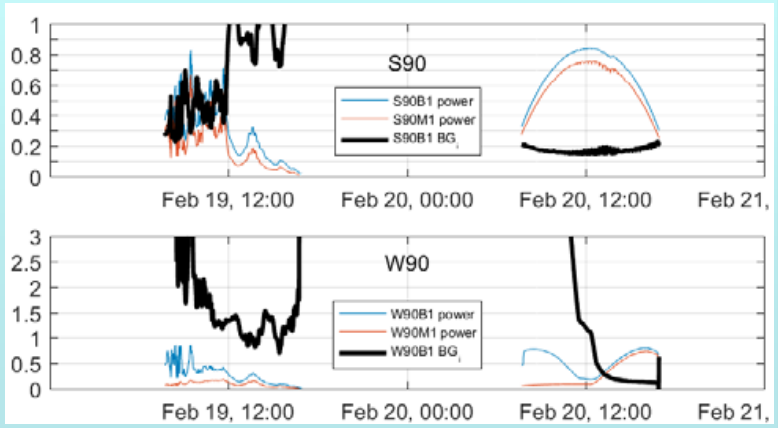
BG relatively stable for south and west tilted systems

Cloudy day

Clear day



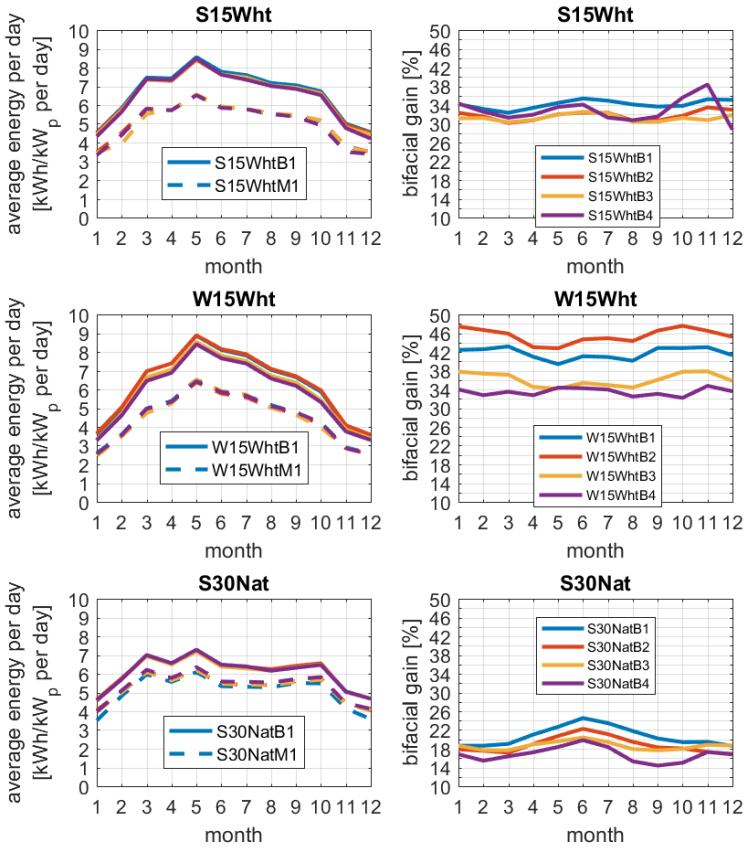

BG varies significantly with weather for vertical orientations



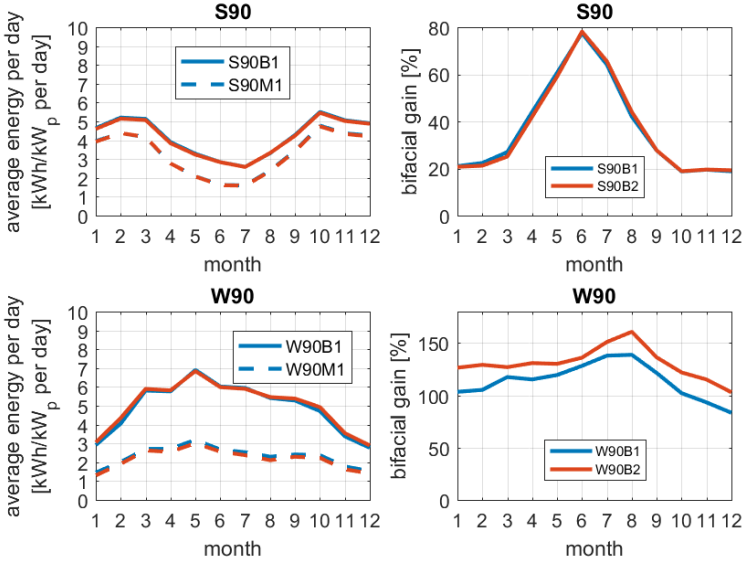
# Monthly energy for Prism modules (NM)

BG relatively stable over seasons, except for vertical orientation

## South and west tilted systems




## Vertical oriented systems



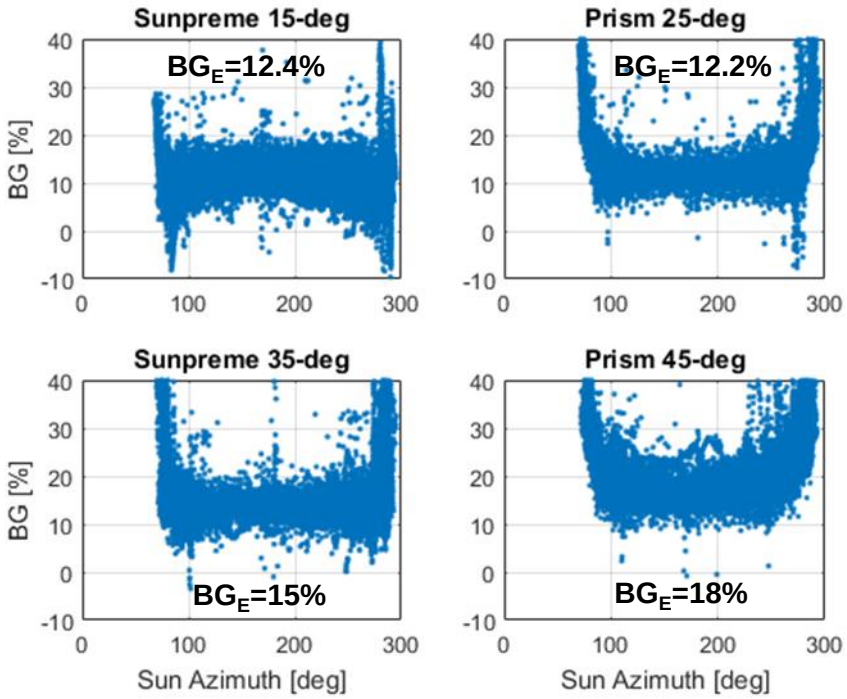
# Small-system Performance

Four fixed-tilt String-level Arrays

- Four rows at 15˚, 25˚, 35˚,and 45˚ tilt.
- Each row has one bifacial and one monofacial string of 8 modules.
- Modules alternate to minimize backside spatial irradiance bias.
- Bifacial: Prism Solar (n-Type c-SI) : Rb ~93%
- Bifacial: SunPreme (HJT/HIT) : Rb ~95%
- Monofacial: SolarWorld

- BG less for system than for single modules
- BG increases with increasing tilt

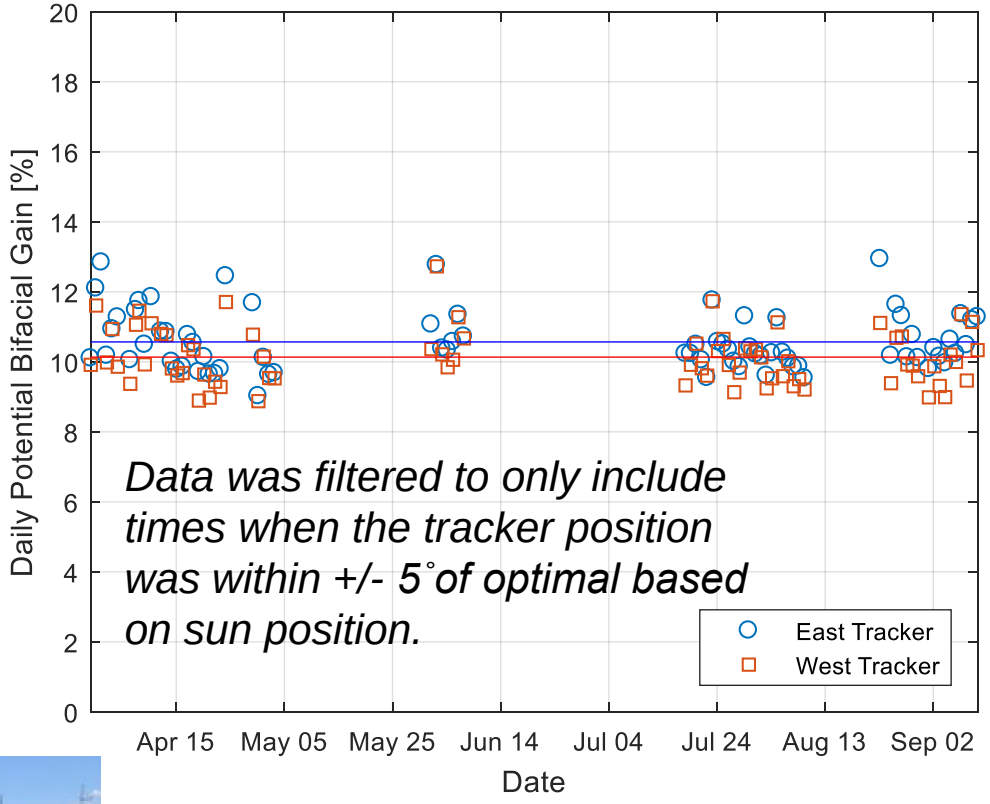
*BG ~ 20% for 30-deg single module*




*Data from June 1 – Aug 31, 2017*

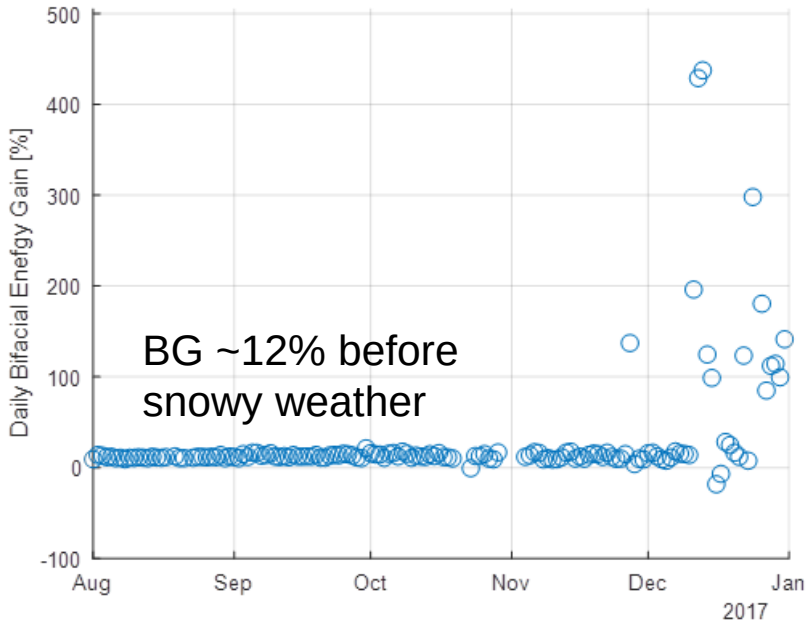
# Bifacial on Single Axis Tracker (NM)

- Daily *Potential* Bifacial Energy Gains were estimated from front and back irradiance data using reference cells.
- Potential gains increase when tracker is off-track, but energy decreases




# Bifacial on 2-Axis Trackers (VT)

- Two 2-axis trackers each have two **strings** (one of monofacial and one of bifacial)
- Significant obstructions behind bifacial modules from tracker rack




Performance advantage during snow:
- Rear side is generally clear
- Promotes shelf-shedding
- Not always but trend appears

1 Jan 2018

# Conclusions

**Bifacial performance always exceeds monofacial performance** in the same orientation

- 10% seems to be a floor value for Bifacial gain (for a bifacial module with Rb ~ 93%)
- Bifacial advantage (measured by BG) increases substantially when monofacial modules are not optimally deployed
- Extreme example: vertical, E-W bifacial modules have similar yield as latitude tilt, southward monofacial modules

However

- Bifacial advantage decreases from single modules (BG ~20%) to systems (BG ~12-15%) due to shading of nearby ground from the modules themselves
- Bifacial gain (BG) is not an ideal metric
  - LCOE may be more meaningful for two systems each designed to optimize yield within the same constraints (area, budget, obstructions)
- Optimizing bifacial yield will require careful attention to Balance of System effects such as shadows from racking

# Questions?

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