# Best Practices for Bifacial Energy Modeling

May 15, 2019 | PV Systems Symposium | Albuquerque, New Mexico

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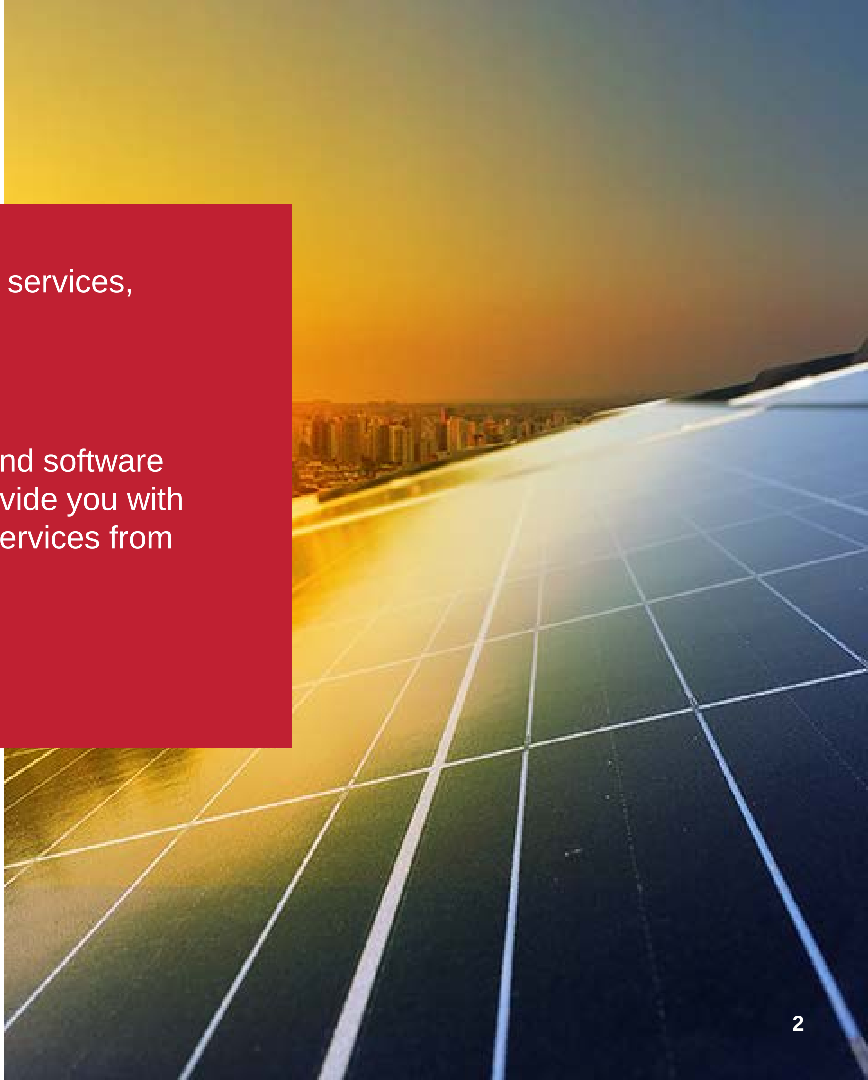


As the first round of utility-scale bifacial projects approach financing, developers, lenders, and stakeholders are concerned about energy modeling risk.

This presentation outlines practices for bifacial energy modeling and uncertainty associated with current approaches.

# Presentation Outline

- System Design Optimization
- Solar Resource Input Data
- Energy Modeling Considerations
- Sources of Energy Uncertainty

# Bifacial Design Optimization

# Differences between Monofacial and Bifacial Designs

- Several design differences are common between monofacial and bifacial systems.
- For bifacial projects:
  - DC-AC ratio is lower by ~5% to achieve optimal inverter limitation loss
    → *Bifacial advantage is often realized as a combination of DC capacity cost reduction and energy gain.*
  - Greater row spacing (GCR reduction by ~5% absolute)
  - Tracker/mounting structure height is significant, up to a point, with increased mounting structure costs
- Optimized design is situation-dependent (considering PPA rate, land availability, climatology, etc.)

| Parameter | Monofacial Example | Bifacial Example |
|---|---|---|
| DC-AC Ratio | 1.30 | 1.25 |
| Ground Cover Ratio | 40% | 35% |
| Structure Height | Minimal impact on energy | Influences back-side irradiance |
| Module-to-Module Clearance | 1-2 cm is typical | May be expanded for light to pass through |
| Mounting Structure | Traditional | Design minimizes back-side shading |
| **Bifacial Advantage** | **3-9%, realized as DC system cost reduction and/or energy gain** | |

# Solar Resource Input Data

# Contributors to Solar Resource

- **Front-side global plane of array (Front POA)**
  - Driven by global horizontal irradiance (GHI)
  - Influenced by diffuse horizontal irradiance (DHI)
- **Back-side global plane of array (Back POA)**
  - Influenced by albedo
- **Total POA = Front POA + Back POA**

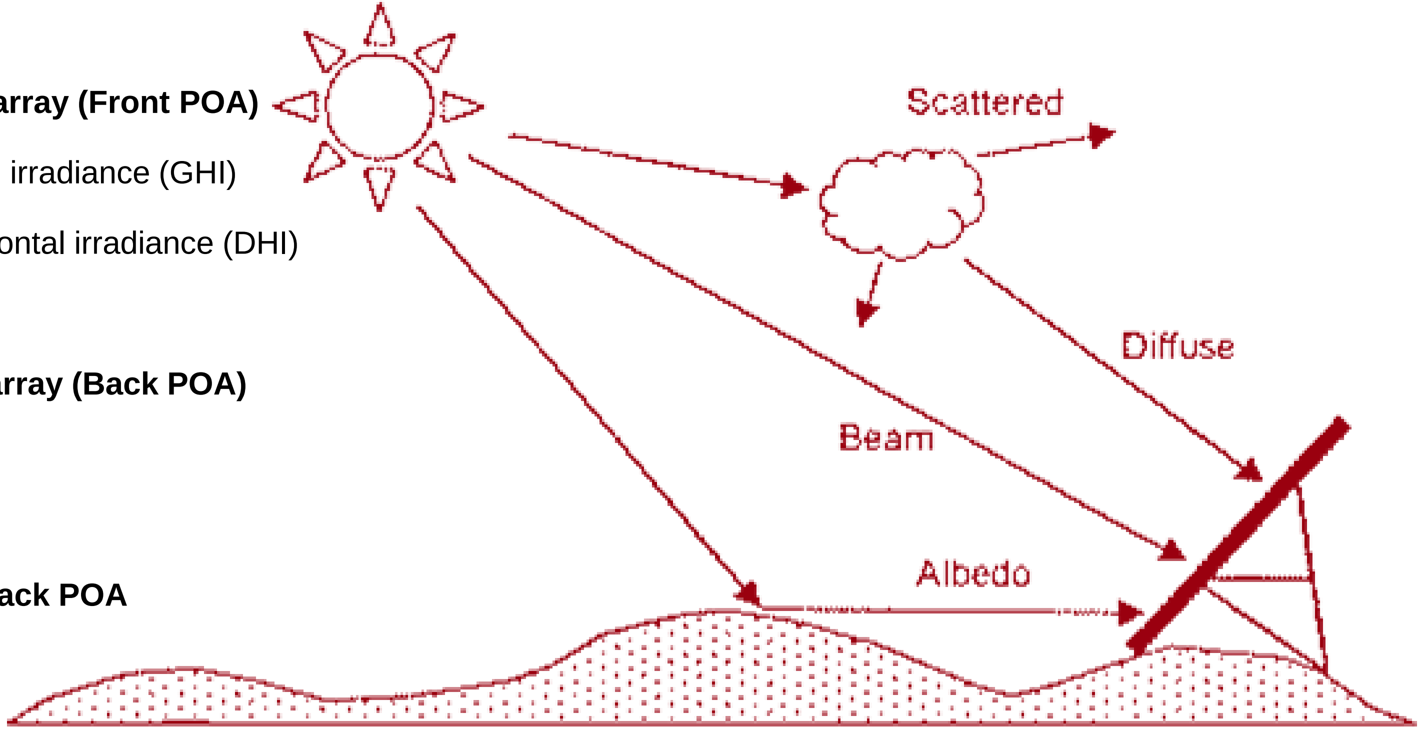
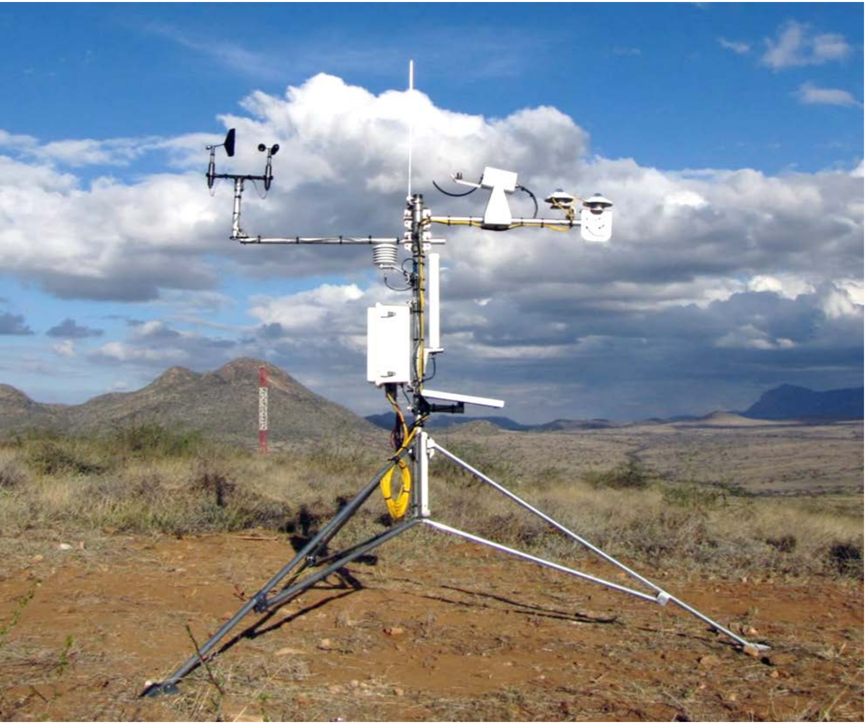



Diagram from: Cuevas, Andres. "The Irradiation Data." Australian National University, April 1998. Retrieved May 2019 from website: https://users.cecs.anu.edu.au/~Andres.Cuevas/Sun/Irrad/Irradiation.html.

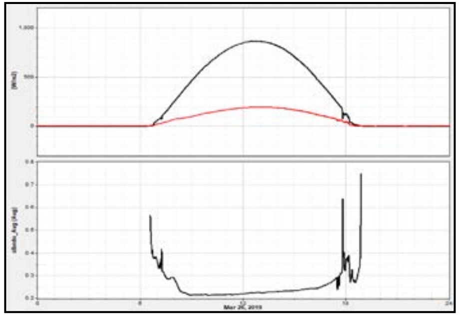
# Measurements: Reduce Uncertainty in Front and Back POA

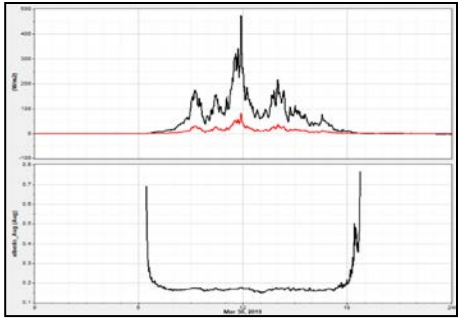


- Redundant “Class A” GHI measurements expected
- DHI is beneficial for all sites to reduce POA uncertainty (measured DHI is twice as accurate as most models)
- Albedo measurements are recommended for bifacial
    - Modeled data sources (PSM, Meteonorm, SolarGIS) have more uncertainty
- Additional meteorological measurements
    - Temperature
    - Wind speed
    - Relative humidity
    - Precipitation
- Best practices for bifacial measurement collection are outlined in supplementary poster presentation

# Albedo Measurement Considerations

- **Ground Conditions.** Prepared and maintained on a regular basis.
- **Mounting**. Proper mounting ensure that downward instrument has unobstructed field of vision. Regular levelness checks are needed.
- **Height Above Ground.** Approximate the PV array's height. Avoid shading on upward facing instrument.
- **Azimuthal Orientation.** 180° orientation (sunward side) to prevent shadows.
- **Shadow Mitigation.** Structures to south, east, and west sufficiently far away to prevent shadows on albedometer or in field of vision.



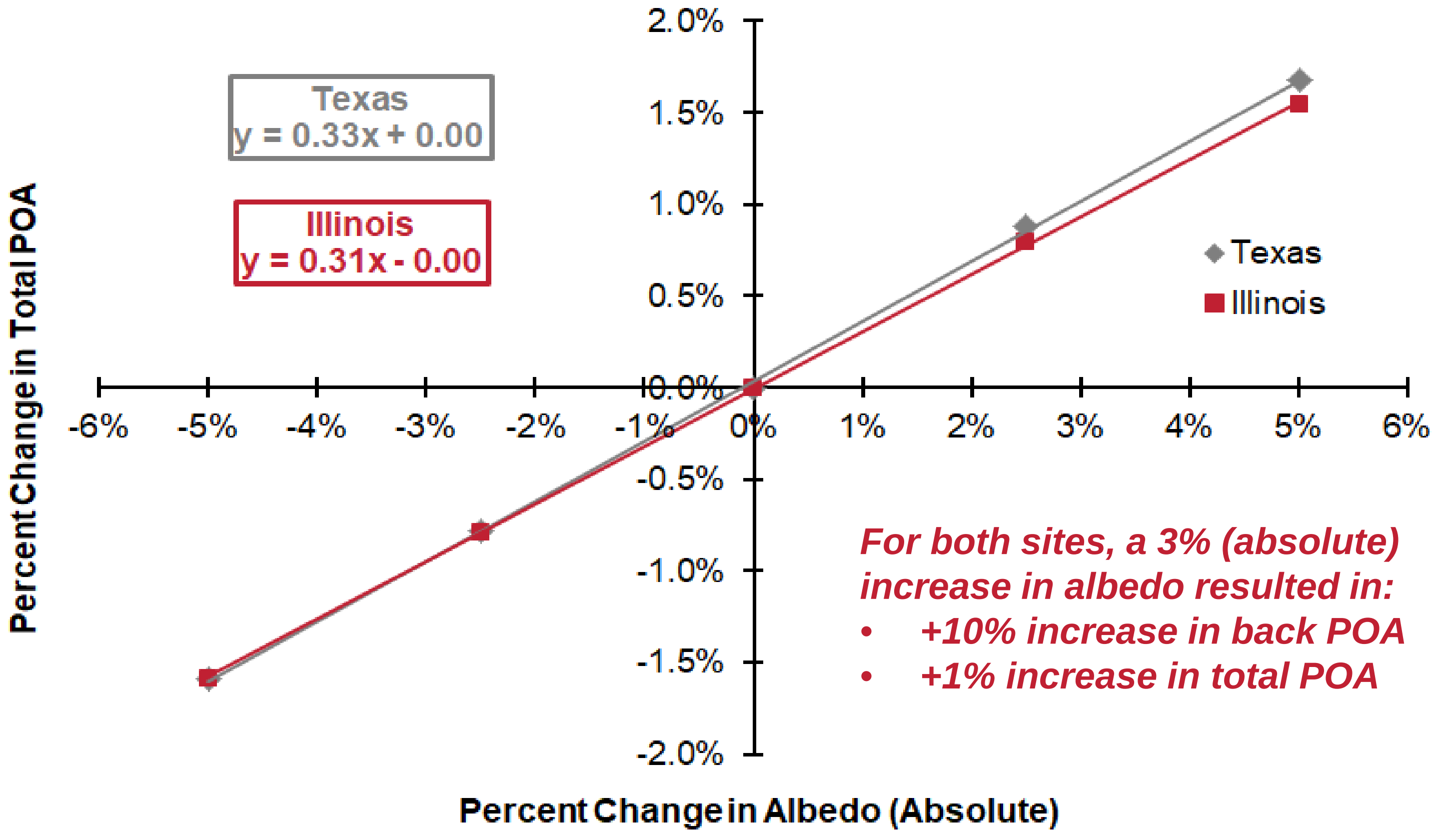


# Impact of DHI and Albedo on Bifacial (Total) POA

| **Site Characteristics** | | |
|---|---|---|
| Location | Texas | Illinois |
| GHI ($kWh/m^2/yr$) | 1746 | 1504 |
| Base Case DNI ($kWh/m^2/yr$) | 1642 | 1488 |
| Base Case DHI ($kWh/m^2/yr$) | 675 | 618 |
| Base Case Albedo (%) | 20.0% | 23.2% |
| Average Temperature (°C) | 21.7 | 12.1 |
| Average Wind Speed (m/s) | 4.5 | 3.7 |
| Snow | No | Yes |
| **Project Design** | | |
| Equipment | Crystalline Bifacial | Crystalline Bifacial |
| Configuration | Tracking | Tracking |
| DC-AC Ratio | 1.24 | 1.30 |
| GCR | 35-40% | 35-40% |
| **Results: Summary of Energy-to-Resource Relationships** | | |
| DHI/Back-Side POA | 0.4% | 0.4% |
| DHI/Total POA | -0.1% | -0.1% |
| Albedo/Back-Side POA | 3.8% | 3.5% |
| Albedo/Total POA | 0.3% | 0.3% |

- Case study to determine bifacial POA sensitivity to resource
  - Adjust DHI in increments of 5% and re-compute POA
  - Adjust Albedo in increments of 2.5% (absolute)
- Results:
  - Similar relationships for Texas and Illinois
  - DHI has small direct impact to back-side POA
  - DHI has minimal impact to total POA
    → *Bifacial advantage, since there's an inverse relationship for monofacial projects*
  - Albedo has meaningful direct impact on total POA
    → *Modeled albedo can be 2-5% different from measured albedo (absolute)*

# Impact of Albedo on Bifacial (Total) POA




***For both sites, a 3% (absolute) increase in albedo resulted in:***

- ***+10% increase in back POA***
- ***+1% increase in total POA***

# Resource Impacts on Bifacial Energy Estimates

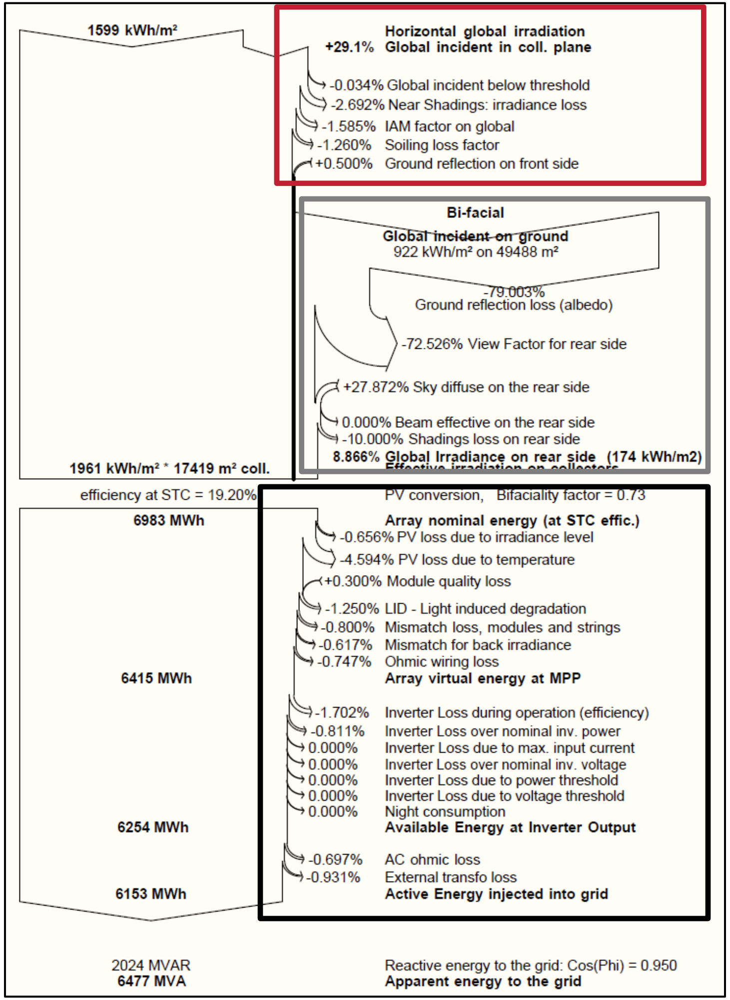
| Measurement Type | Purpose | Measurement Accuracy | Percent Impact on Energy |
|---|---|---|---|
| **GHI** | Principle measurement for solar resource assessment | 1-2% | A 2% increase in GHI corresponds to about 1.5% increase in energy |
| **POA** | Assists with verifying POA transposition model accuracy | 1-2% | A 2% increase in POA corresponds to a similar increase in energy |
| **DHI** | Increases accuracy of POA transposition for energy modeling | 4-6% | A 5% decrease in DHI corresponds to a 1-2% increase in energy (because of DNI relationship) |
| **Albedo** | Improves characterization of back-side POA for bifacial projects | 2-4% | For tracking system, 3% increase corresponds to about 10% increase in back-side irradiance, about 1% increase in overall energy |
| **Temperature** | Improves accuracy of non-STC temperature loss for PV projects | 0.5°C | A 3°C increase in temperature corresponds to a loss increase of about 1% |
| **Wind Speed** | Improves accuracy of non-STC temperature loss for PV projects | 0.5 m/s | (Dependent on site conditions) |
| **Relative Humidity** | Improves accuracy of spectral performance modeling | 3% | (Dependent on PV technology) |
| **Precipitation** | Frequency of rain/snow events for module cleaning | 1% | Informs soiling and snow loss |
| **Soiling System** | Power loss due to dirt, debris, snow | (Dependent on system design) | Informs soiling and snow loss |

# Energy Modeling Considerations

# Energy Modeling in PVsyst

- Detailed light modeling:
  - Back-side irradiance modeling
  - Front-side 3D shading losses

- Less detailed loss modeling:
  - Back-side shading (2D, simple generic factor for mounting structure impact)
  - Back-side soiling
  - Back-side condition-based “mismatch” contributors (irregular shading and soiling)
  - Correlation of monthly albedo with snow loss?
  - Bifacial degradation assumption




**Front-Side POA Modeling**

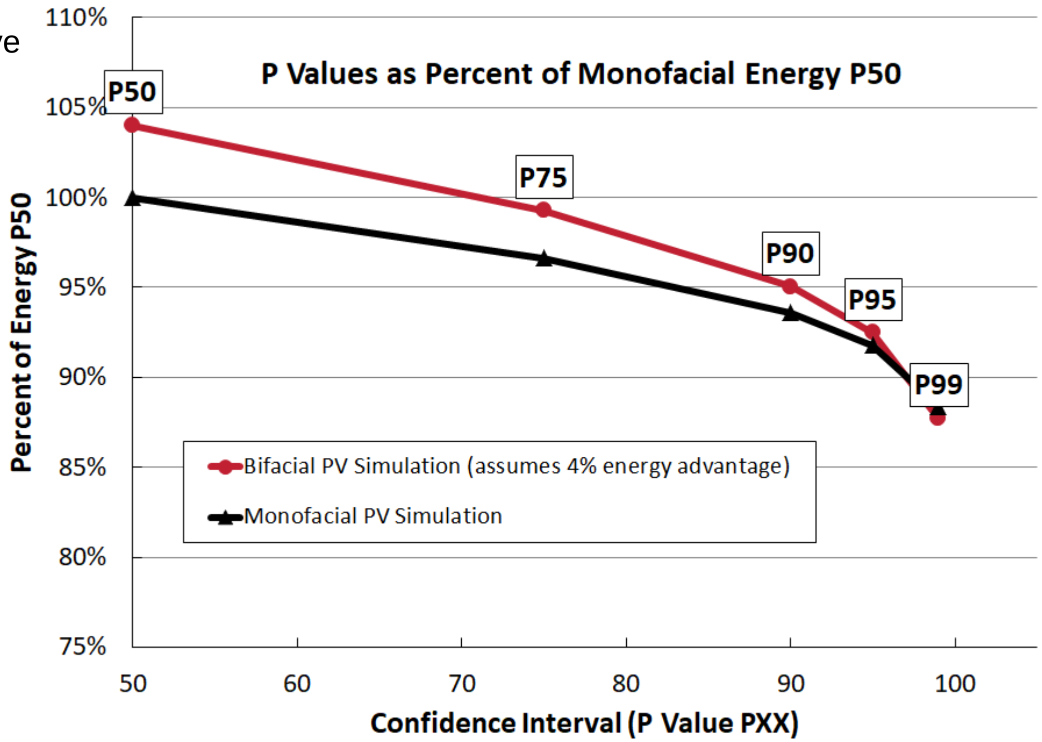
**Back-Side POA Modeling**

**Full-System Loss Modeling**

# Sources of Energy Uncertainty

# Bifacial Energy Uncertainty

- The back-side energy contribution is expected to have more uncertainty than the front side for the following reasons:
  - Albedo and DHI accuracy
    (measured more accurate than modeled)
  - Bifaciality factor uncertainty in the field
  - Back-side loss modeling
- The back-side energy contribution may be between 20-40% uncertain (1σ). Examples with respect to total energy:
  - Back-side contribution of 5%, ± 1.5%
  - Back-side contribution of 8%, ± 2.4%



# Summary and Conclusions

– Optimal bifacial system designs tend to have:
    - Lower DC-AC ratios and lower ground cover ratios
    - Taller mounting structures and more clearance between modules
    - Situation-specific cost-benefit analysis (ratios, structures, electrical, etc.)

– Typical bifacial advantage of 3-9%, realized as DC system cost reduction and/or energy gain

– On-site albedo and diffuse horizontal measurements can reduce uncertainty in the back-side POA
    - A 3% increase (or decrease) in albedo can result in a 1% increase (or decrease) in total POA

– In the future, bifacial energy modeling uncertainty can be reduced by the following:
    - More complex simulation and loss models
    - Field performance data to calibrate model assumptions

# Thank you for your attention.

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