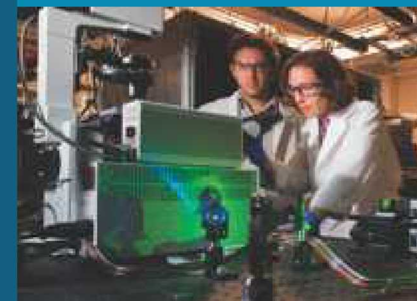
SAND2019-4390PE

Bifacial Photovoltaic Performance Optimization Using Ray Tracing and High Performance Computing



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PRESENTED BY

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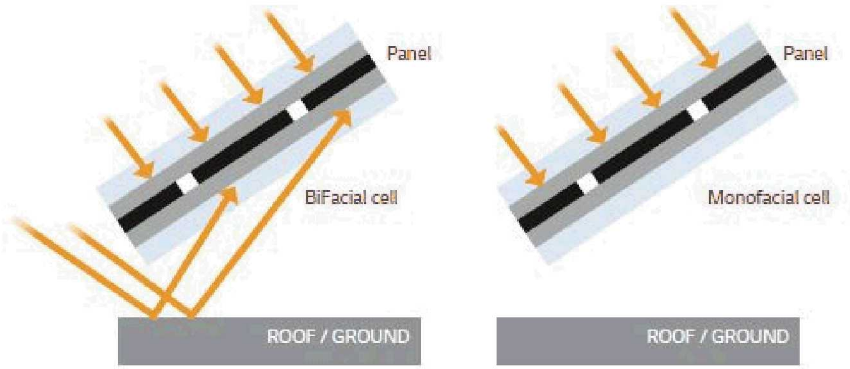
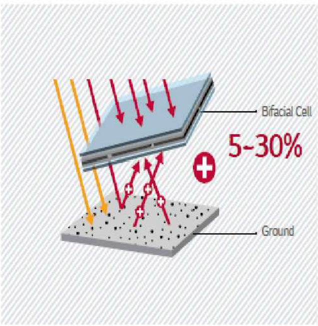
Bifacial Photovoltaics

- Newer PV cell designs (e.g., PERC, PERT) do not have monolithic rear metallization and can be made "bifacial" with a few additional processing steps.
- Light can enter bifacial PV cells from the front and rear.
- Bifacial modules can produce more energy than monofacial modules.
- Not new technology BUT now more cost effective and rapidly gaining traction in the market.





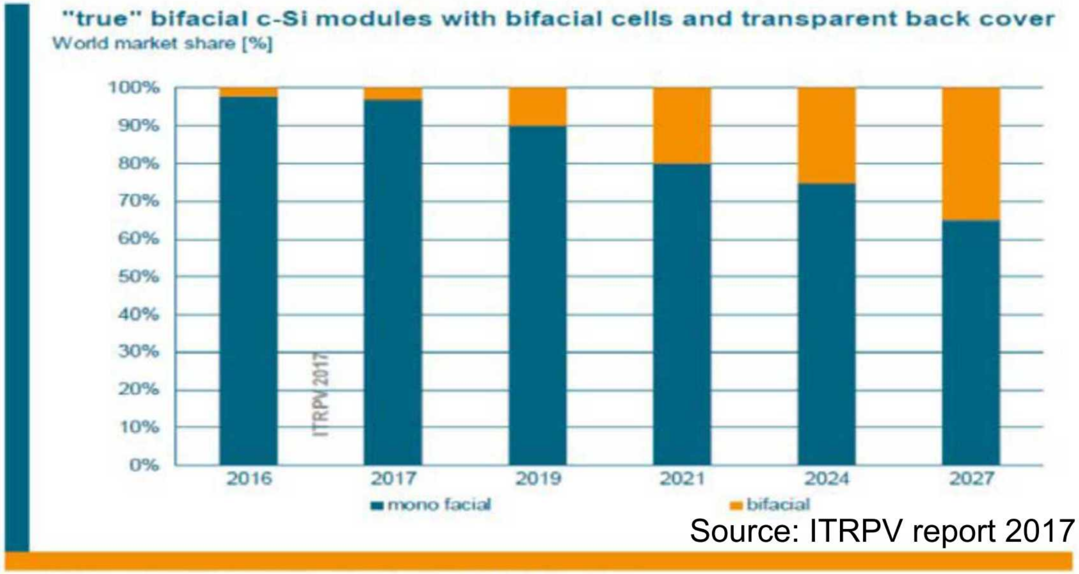


Fig. 42: Worldwide market shares for monofacial and "true" bifacial modules.

Bifacial PV Research at Sandia

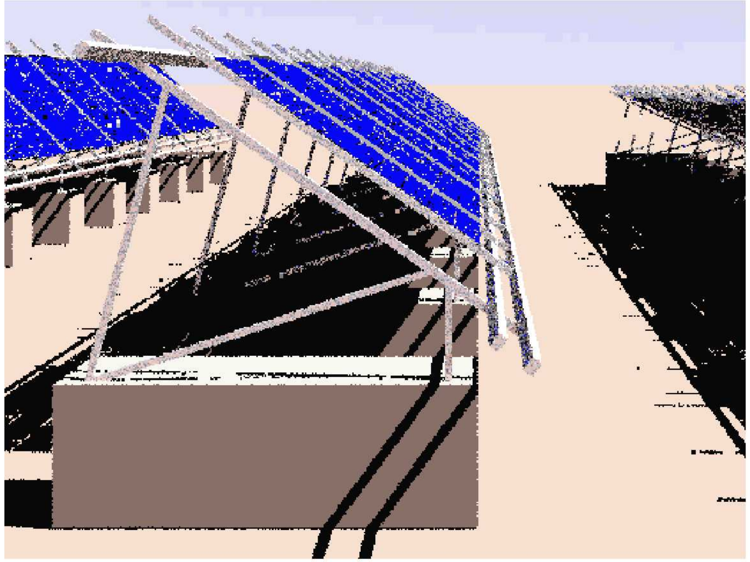
Sandia is the lead for a project with NREL to develop bifacial performance modeling capabilities.

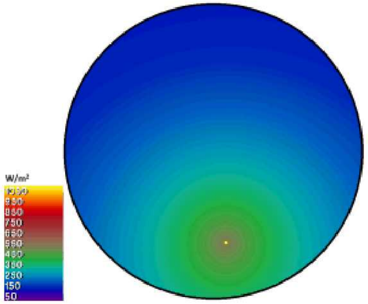
Sandia also has a NMSBA project with Albuquerque based Array Technologies to study bifacial PV performance on single axis trackers.

- 2016- present: Deployed numerous field test arrays at PSEL and offsite locations (VT, NV, AK, Finland)

3D Ray Trace Model for Bifacial PV

- Based on RADIANCE (reverse ray tracing model from LBNL)
- Can include complex objects (racking, ballast, equipment racks, etc.)
- Computationally complex
  - Run times are slow
- Single Processor 8760 hr annual simulations not practical unless….
  - CumulativeSky approach[1] integrates time varying irradiance into annual insolation.
- Each simulation is independent so the problems is perfect for multi processing on a cluster.





Single hourly Perez sky (W/r

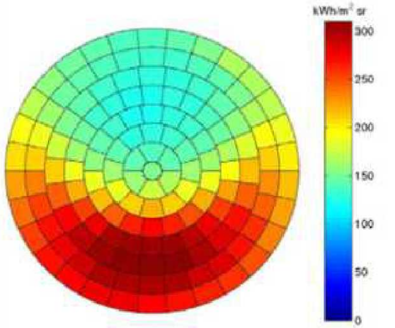


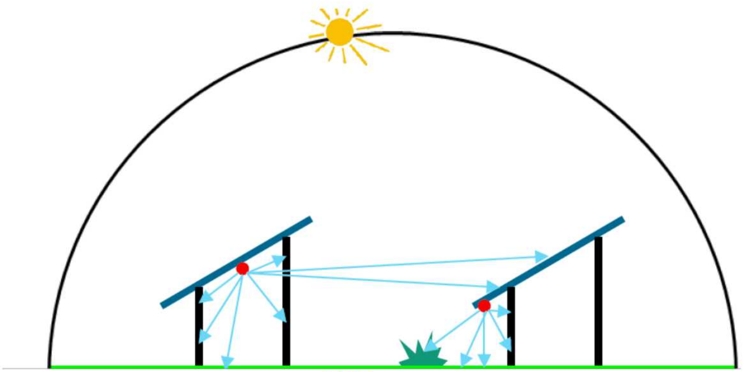
Figure 1 Cumulative diffuse sky radiance distribution for Oslo (based on 10yr mean solar data).

Annual cumulative sky conditions (kWh/m²)

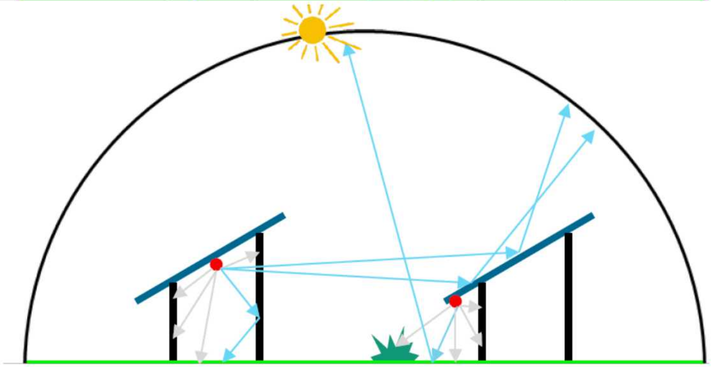
[1]Robinson, Stone "Irradiation modelling made simple: the cumulative sky approach" 2004

Backward Ray Tracing Primer

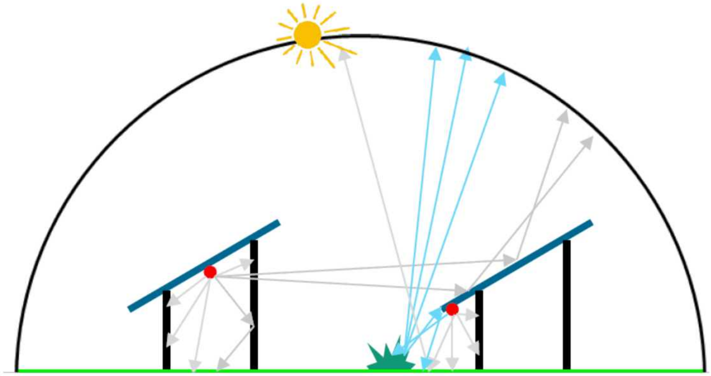
1. Model starts at the point(s) of interest (e.g., point on back of bifacial PV module). Rays are traced in all directions from that point. The sky dome is a heterogeneous light source.



2. Rays that hit a surface that is not a light source bounce off depending on the optical properties of the surface. Specular and diffuse reflections are considered. Multiple bounces are allowed.

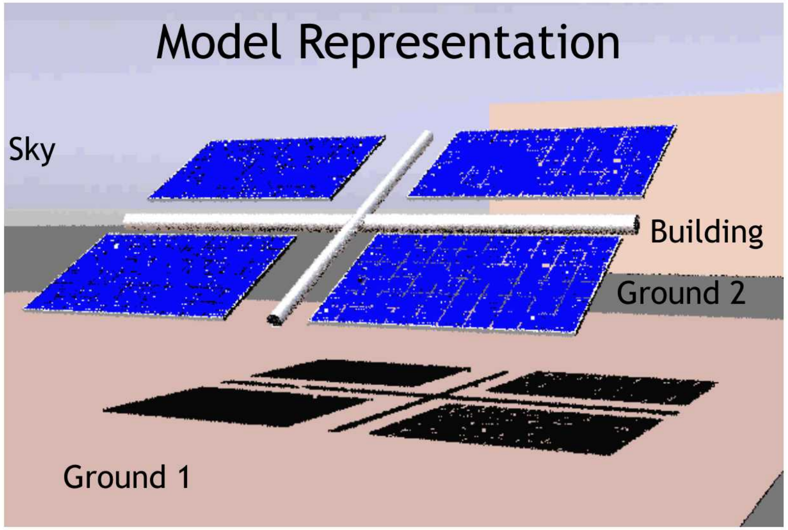


3. The light reaching the point of interest is calculated by adding up all the rays that reach a light source and considering losses from absorption. The more rays the higher the resolution

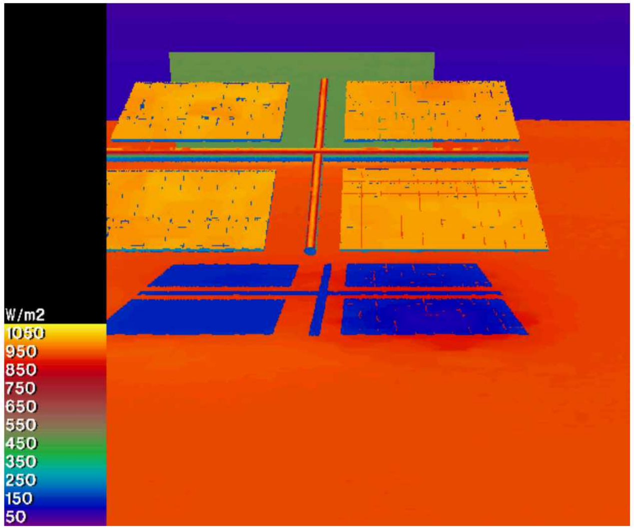


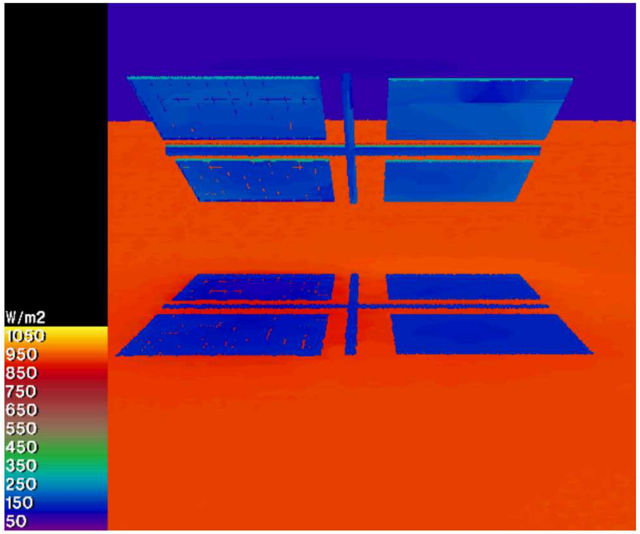
Example Ray Trace Results

Real system

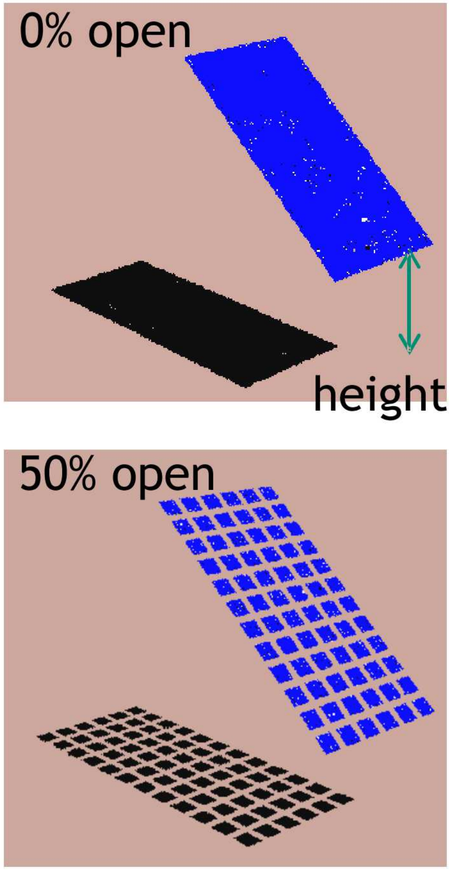


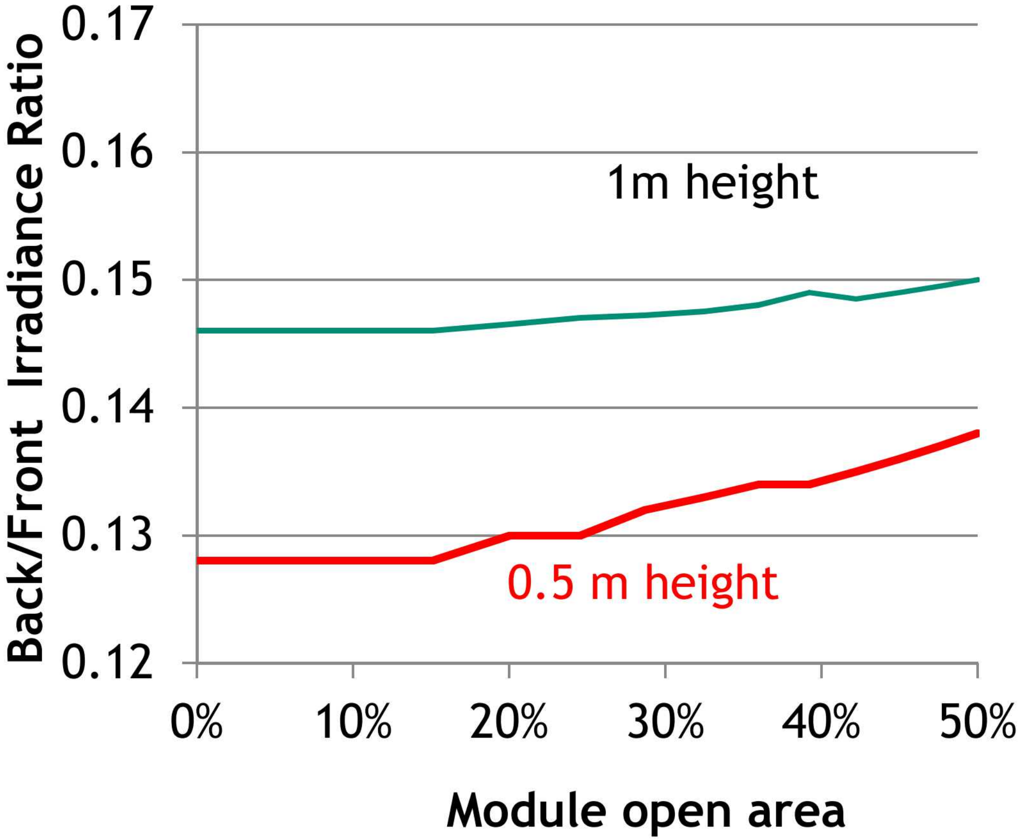
Irradiance Results





Effect of height and cell spacing on back + front irradiance





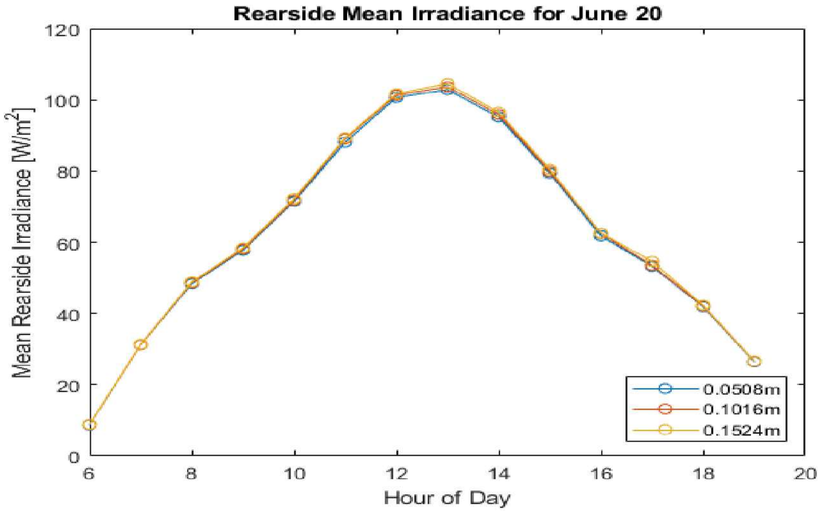
Bifacial PV on Single Axis Trackers

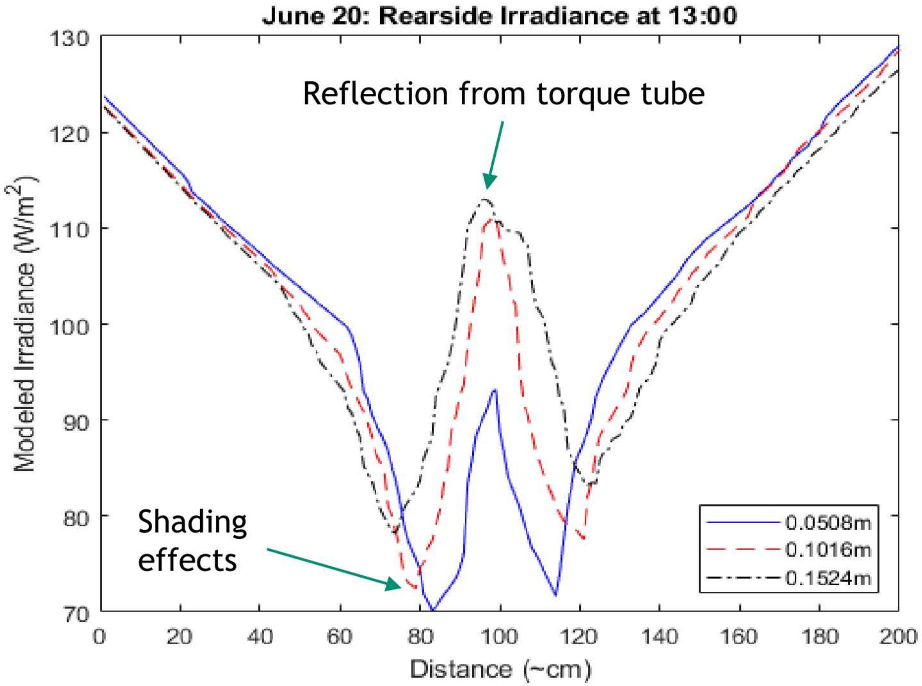
Sandia is working with Array Technologies to help determine the best way to mount bifacial modules to a tracker.

- Torque tube shading is a concern.

Initial ray tracing calculations were run to test the effect of different spacings between the torque tube and the PV module.

- Runs took several hours on a desktop machine.
- Only able to run single days at hourly intervals.





High Performance Computing

We have transferred the bifacial radiance model to Sandia's HPC environment.

- We chose to use UNO since our problem does not require MPI (each time step is independent)
- This has required some code changes to address race conditions (e.g., files being read by multiple processors at the same time). We are currently addressing these issues.

Our current goal is to run an entire annual simulation (e.g., 8760 hourly timesteps) in approximately 5-10 minutes.

Next we plan to use DAKOTA to run sensitivity studies and optimizations.

Question include:

- How do design parameters effect annual bifacial PV performance in different locations (e.g., latitudes)?
- How much more energy might one produce by engineering the ground surface to be more reflective?
- Innovative system designs for various applications such as:
  - Fixed tilt, ground mount
  - Single axis tracking
  - Elevated parking structures
  - White flat commercial roofs

Questions??

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