

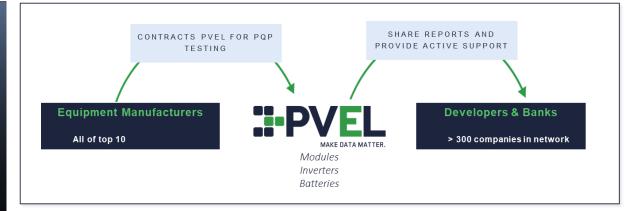
BIFACIAL WORKSHOP 2019

PV Evolution Labs (PVEL) Jenya Meydbray, CEO

September 2019

PVEL is the Independent Lab for the Downstream Solar Market

Our mission is to support the worldwide PV buyer community by generating data that accelerates adoption of solar technology.





In the solar plants there are two things of critical importance

> Reality



> What you can finance



Source: philosophytalk.org

Source: dgkgrouppc.com



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MAKE DATA MATTER.

Reality vs. Financial Assumptions

- > Ideally there is no difference between actual future production and financial assumptions
- > However, in the absence of **data** many assumptions are made
- > Without field **Validation** assumptions trend to conservatism
- Cypress Creek Renewables and PVEL have been awarded a DOE grant for \$1.7 mm to study and validate bifacial modeling best practices
- > We believe today financing is conservative due to lack of data

Objective of studies

1. Deploy bifacial systems with monofacial reference in the field to validate energy modeling practices

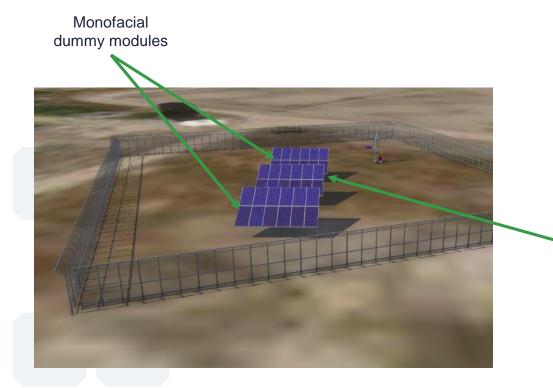
- Bifacial Test Stations: single module IV curves, 2-portrait single axis trackers
- 4 manufacturers side by side with 1500V Strings on 2 albedos
- Impact of spectral albedo and temporal change in albedo
- 2. Measure bifacial mismatch on MW scale systems
 - Tracking and Fixt Tilt
 - Bifacial vs. monofacial
- 3. Partner with Energy Modeling community for field validation on reduced order models
 - PVSyst, TNO, SAM, Solar Farmer, Plant Predict
- 4. Develop and validate ray tracing based model
 - Partnership with PV Lighthouse: inter and intra module mismatch, spectrum, albedo, mechanical design considerations, etc.
- 5. Stakeholder Engagement
 - Provide updates and share data with banks, developers, engineering firms

Assumptions made today

- LID / LeTID on front and back
 - > Infinite row length
 - Albedo
 - > Albedo Spectrum
 - Mismatch losses
 - Obstructions
 - > Portrait vs. landscape
 - > Split cell vs. full cell

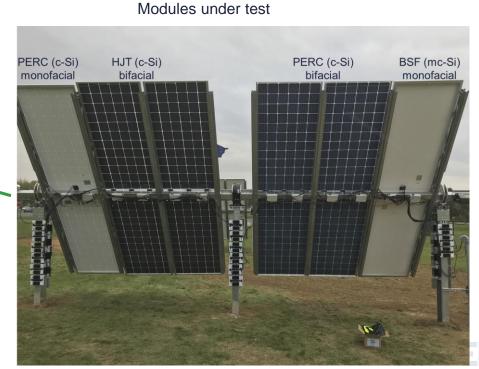
- Same??
 Bad assum
 - Bad assumption but what is the impact?
- > Ok to assume a single number?
- > Big enough effect to matter?
 - Larger than monofacial?
- Impact of near vs far shading?
 - → Does it matter?
 - > What's interaction with 1 P vs. 2 P trackers?
- > Tracker height >
- Magnitude of impact vs added cost?

Bifacial Test Site Description



Status

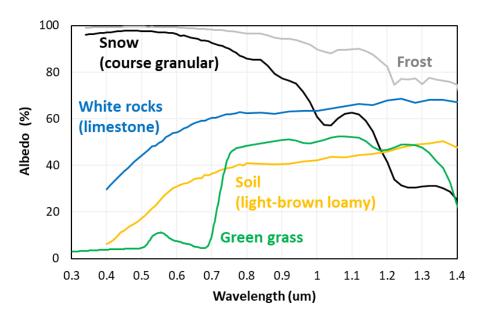
- Michigan: snowy and cold, installed early 2019
- Oregon: hot and dry, late 2019
- o South Carolina: arid climate, late 2019



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Spectral Measurement

- > Does the spectrum of the albedo matter enough to measure it?
- Installing EKO spectroradiometers on all 3 bifacial test sites
 - 300 1100 nm
- > 2 per site: One facing up and one down
- > Installation in late 2019 / early 2020





1500V testing in Davis, CA



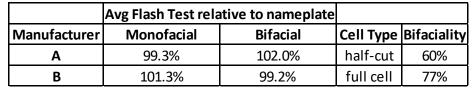
- > 4 manufacturers
- > NEXTracker
- → 0.35 GCR
- > 2 x Albedos
 - Dirt
 - White Sheet
- > Monofacial vs. Bifacial
- → 1500V strings

Results for Sunny Day

Module BiFi Gain Output over Sunny Day



• Dirt • White

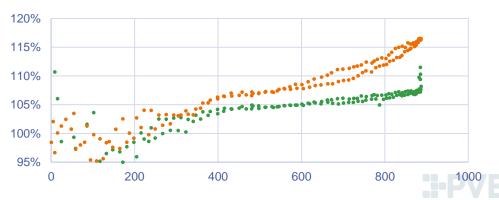












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Module to Module Mismatch

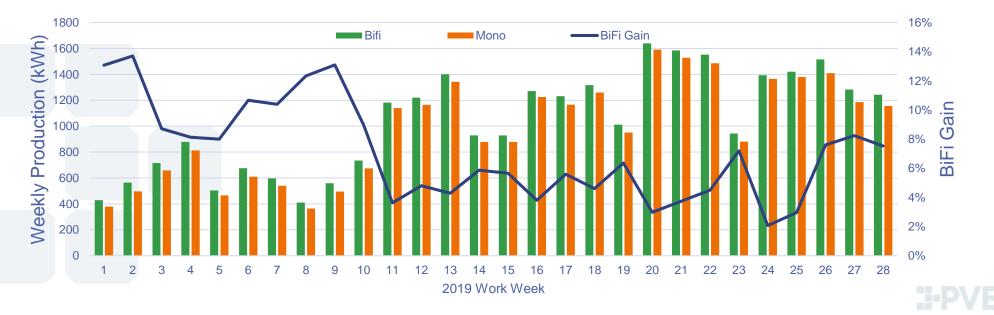
- > 2 MW bifacial site in North Carolina
- > 1 monofacial reference block (25kW)
- Will instrument each module in a string and the string with IV curve tracers to directly measure mismatch losses

> Target Q2 2020



North Carolina Yield Results

- > So far ~6% bifacial yield gain year to date
- > However, DC / AC ratio is 1.3 so summer sees lots of clipping
- > Untreated grass ground, albedo is roughly 15%

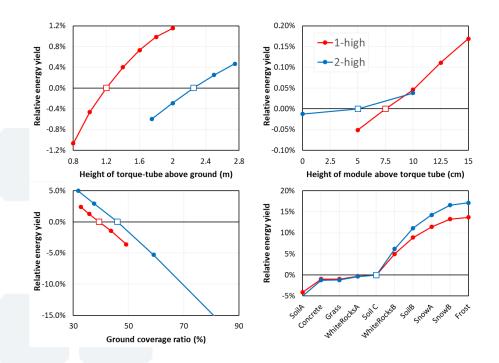


- > Initial modeling process is about to get underway
- > PV Lighthouse has completed initial ray tracing models
- > Roughly +/- 2% irradiance non-uniformity modeled, next step is to validate
- Once ray tracing model is validated with field data we can run it iteratively across many conditions: racking, backtracking algorithm, ground cover, split vs. full cell, etc.

(a) 8	AM	AM (b) 10 AM									(c) 12 PM							(d) 2 PM							(e) 4 PM							
1.0%	1.6%	2.0%	1.3%	1.3%	1.8%		1.2%	1.6%	1.1%	1.9%	1.0%	1.5%	1.4%	1.2%	1.8%	1.5%	1.4%	1.1%		1.2%	1.1%	2.0%	0.9%	1.0%	1.8%		1.5%	0.9%	1.7%	1.3%	1.5%	2.5%
0.6%	0.8%	1.2%	1.1%	1.4%	0.9%		1.1%	1.5%	1.6%	1.3%	0.7%	1.2%	1.3%	1.0%	1.1%	0.6%	1.4%	0.9%		1.2%	0.5%	0.8%	0.8%	1.5%	1.5%		1.3%	0.6%	1.3%	1.0%	0.9%	1.4%
0.8%	0.7%	0.4%	-0.2%	0.4%	0.5%		0.5%	1.1%	1.1%	0.5%	0.8%	0.8%	0.9%	1.1%	0.8%	0.9%	1.0%	0.2%		0.6%	0.4%	0.8%	1.4%	1.4%	1.2%		0.4%	0.3%	-0.2%	0.7%	1.1%	0.5%
0.0%	0.2%	0.1%	-0.1%	0.6%	0.3%		0.2%	0.0%	0.4%	0.1%	0.9%	0.6%	0.8%	0.4%	0.1%	0.2%	0.2%	-0.3%		0.5%	0.6%	0.3%	0.0%	-0.5%	0.1%		1.0%	0.2%	-0.1%	0.0%	0.5%	0.0%
-1.5%	-1.1%	-0.7%	-0.6%	-0.6%	-1.0%		-1.0%	-1.5%	-0.8%	-1.0%	-1.2%	-1.0%	-0.9%	-0.7%	-1.0%	-1.2%	-0.2%	-0.8%		-1.4%	0.0%	-1.3%	0.0%	-0.9%	-1.8%		-0.6%	-0.5%	-1.1%	-0.8%	-1.3%	-1.19
-2.4%	-2.9%	-1.9%	-2.4%	-3.7%	-2.6%		-2.0%	-3.0%	-2.7%	-3.0%	-2.0%	-2.5%	-2.7%	-3.5%	-2.3%	-3.1%	-2.1%	-3.1%		-2.1%	-2.7%	-3.4%	-2.4%	-2.4%	-2.3%		-2.7%	-2.3%	-2.9%	-2.8%	-2.6%	-2.09
-2.6%	-3.0%	-2.5%	-3.2%	-3.4%	-3.0%		-2.4%	-3.1%	-3.1%	-2.7%	-2.2%	-3.4%	-3.4%	-2.9%	-2.7%	-2.6%	-2.8%	-2.4%		-1.7%	-3.5%	-2.8%	-2.5%	-2.4%	-2.9%		-2.2%	-2.7%	-3.4%	-2.6%	-3.2%	-3.29
0.8%	-0.9%	-1.0%	-1.1%	-1.1%	-0.7%		-0.9%	-0.6%	-1.0%	-1.1%	-0.8%	-1.1%	-0.6%	-0.5%	-0.6%	-1.3%	-0.5%	-0.9%		-0.5%	-1.2%	-1.0%	-1.4%	-0.6%	-0.6%		-1.3%	-1.2%	-0.3%	-0.5%	-1.1%	-0.59
0.1%	0.0%	0.0%	0.4%	0.4%	1.2%		0.5%	0.1%	0.3%	0.6%	-0.2%	0.8%	0.4%	0.4%	0.6%	0.0%	0.4%	0.2%		-0.4%	0.1%	0.3%	1.2%	0.3%	0.3%		0.6%	0.2%	0.4%	0.1%	0.1%	0.69
1.4%	0.7%	1.3%	1.1%	0.5%	0.8%		0.0%	0.7%	1.3%	0.7%	0.4%	0.6%	0.6%	1.1%	1.1%	0.2%	0.6%	1.0%		1.0%	0.6%	-0.1%	0.3%	1.0%	0.7%		0.8%	0.6%	0.5%	0.8%	1.1%	0.09
1.8%	1.0%	1.7%	1.0%	2.0%	1.2%		1.1%	1.7%	0.9%	1.6%	1.2%	0.5%	0.8%	1.0%	0.7%	1.8%	1.6%	0.6%		1.1%	1.2%	0.7%	1.1%	1.6%	1.5%		1.2%	1.0%	0.7%	1.5%	0.8%	1.5
1.3%	2.0%	1.7%	1.1%	1.4%	1.9%		1.9%	1.2%	1.6%	1.1%	1.0%	1.6%	0.9%	1.7%	1.4%	1.3%	1.6%	2.0%		1.5%	1.3%	1.0%	0.7%	1.9%	1.5%		1.5%	2.0%	1.6%	1.4%	1.5%	1.89



Ray Tracing



- Initial ray tracing results
- All of these techniques to increase yield have a cost so the returns have to be high enough
- Today likely can't finance full value of these without some field validation





THANK YOU