Future PV Roundtable
at Solar Power International 2018

PV evolution at every level, from cells and modules to the grid

Initiative partner

Heraeus

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First Solar

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LONGi Solar

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Agenda

Introduction by Dr. Weiming Zhang, Heraeus

Presentation by Dr. Ilka Luck, Heraeus and Christian Prischmann, Ulbrich

Presentation by Dr. Hongbin Fang, LONGi Solar

Panel 1: Emerging directions in cell and module technologies

Fireside chat with Tristan Erion-Lorico, DNV GL

Panel 2: Grid integration of high levels of renewable energy

Introduction by Dr. Weiming Zhang, Heraeus

Presentation by Dr. Ilka Luck, Heraeus and Christian Prischmann, Ulbrich

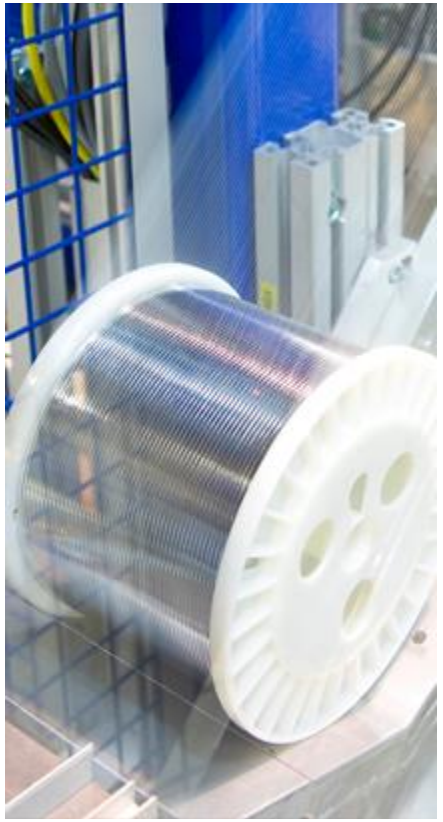
EMERGING DIRECTIONS AND TRENDS IN CELL AND MODULE DESIGNS

Solar Power International

Dr. Ilka Luck / Heraeus

Christian Prischmann / Ulbrich Solar Technologies

September 2018

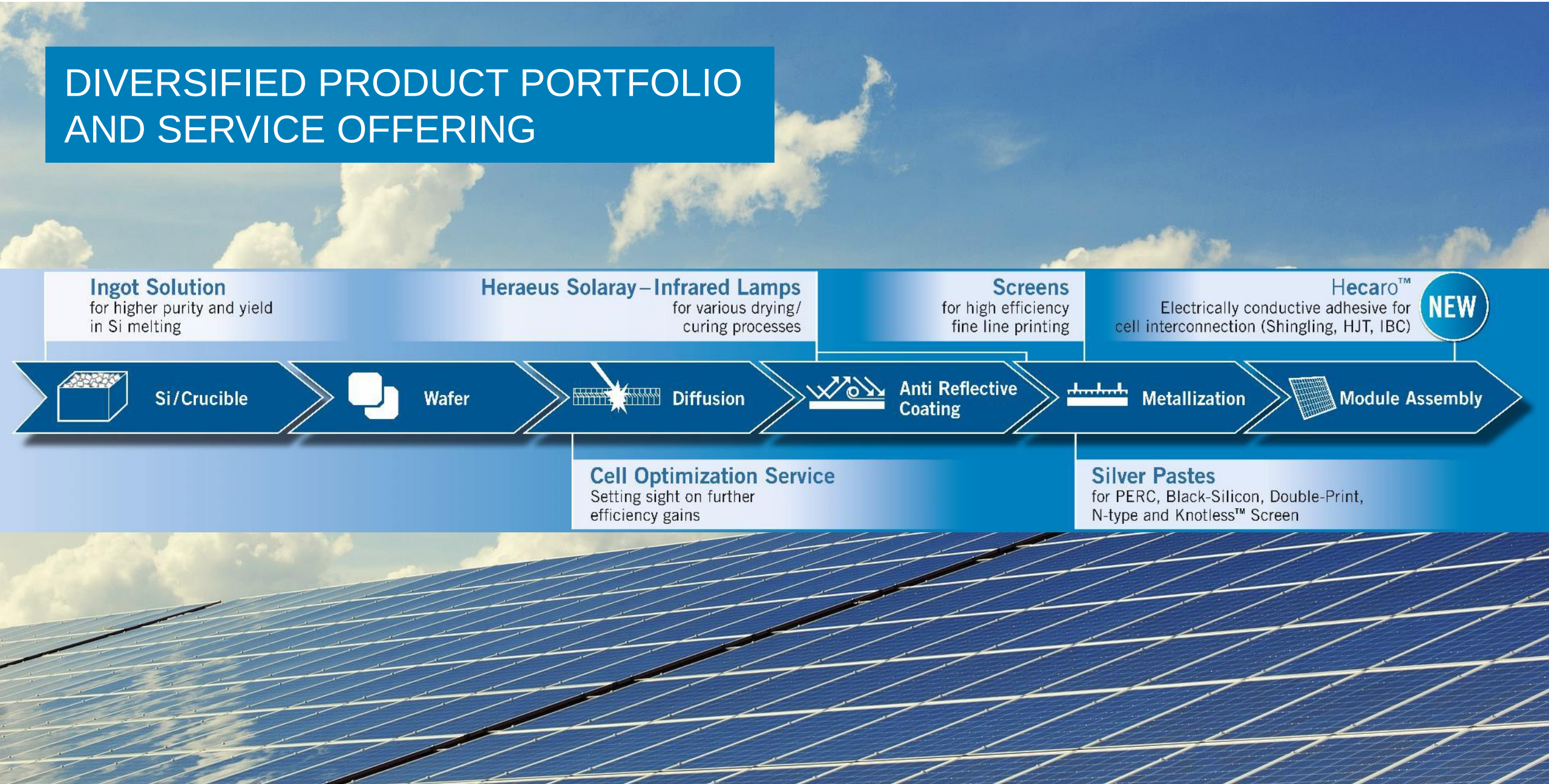


EMERGING DIRECTIONS IN CELL AND MODULE DESIGNS

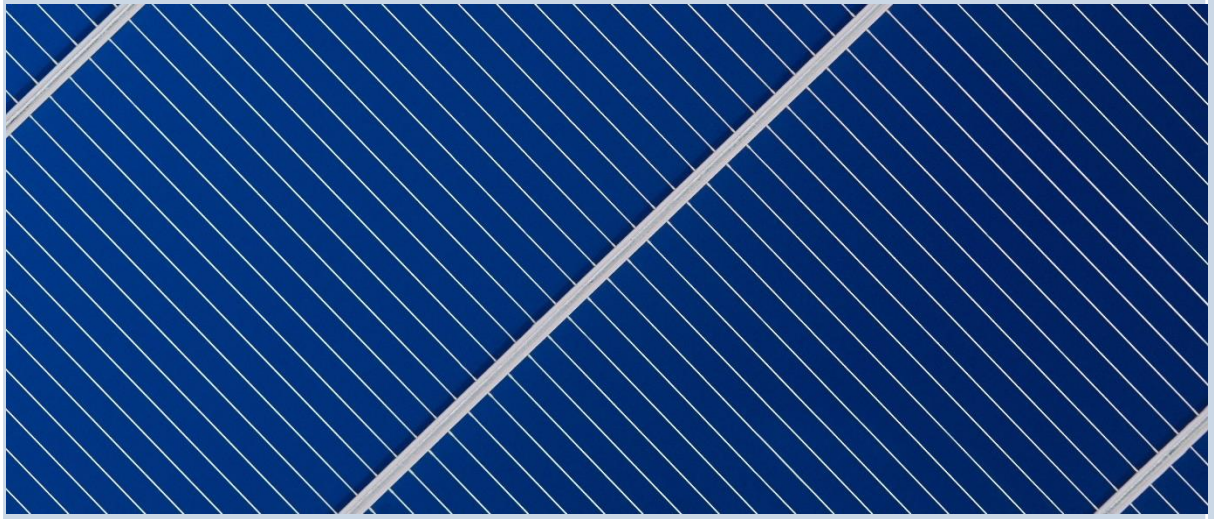
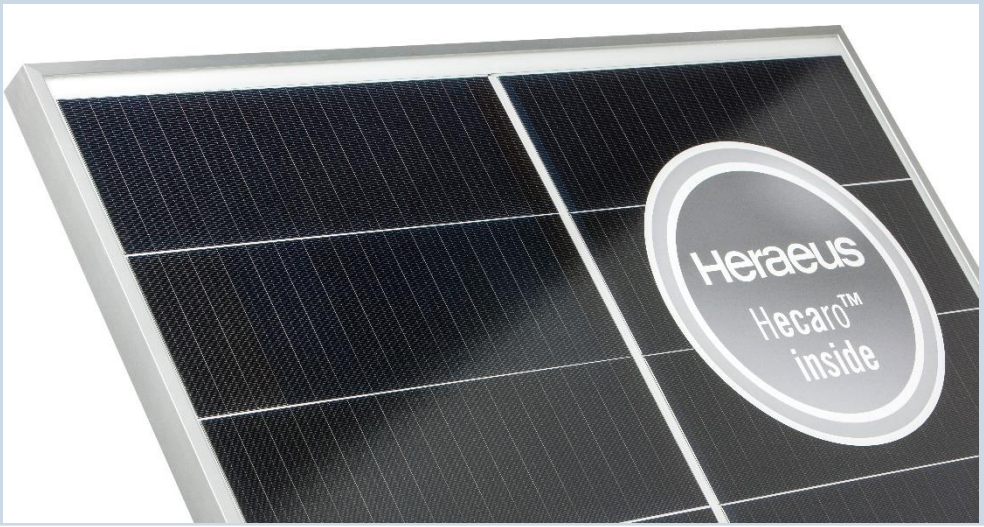
- Solar cell busbar designs
  - 4 / 5 / 6 traditional solar cell bus bar layouts
  - Multiple busbar
- High efficiency solar cells (HJT, PERC) and half-cut-cell modules
- Alternative bonding technologies
  - Conductive adhesive solutions
  - Low temperature soldering applications
  - Lead-free

Heraeus

DIVERSIFIED PRODUCT PORTFOLIO AND SERVICE OFFERING



HERAEUS CELL INTERCONNECTION MATERIALS

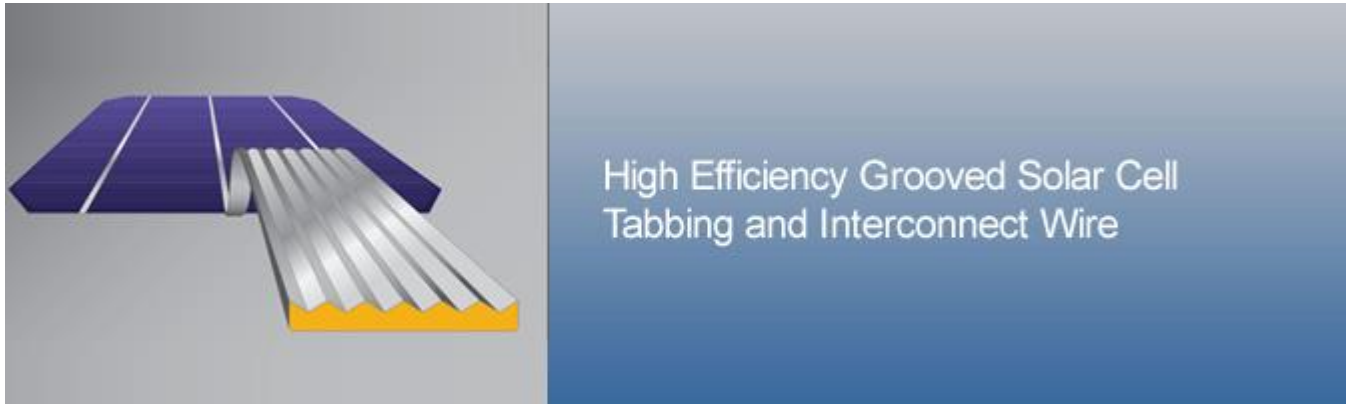
SCR™ **Selectively coated cell connector**	**HECARO™** **Electrically conductive adhesive**
For up to 6 BB cells	For high-efficiency module concepts (shingling, HJT, BC)
2 Watt module power gain due to reduced shading	5 W module power gain (shingling) due to better use of laminated module area and less ohmic losses
Plug & play (no additional process, no additional equipment)	Reliable production equipment available
Proven device reliability	Proven device reliability
	

LIGHT CAPTURING RIBBON LCR™

Solar Technologies

- Silver coated grooved copper flat wire
- Internal reflection to increase module power output by app. 2%

  → statistically proven!
- Emerging cell/module technologies
  - High efficiency solar cells HJT
  - Conductive adhesive bonding solution
  - Lead-free solution
- Module reliability proven!



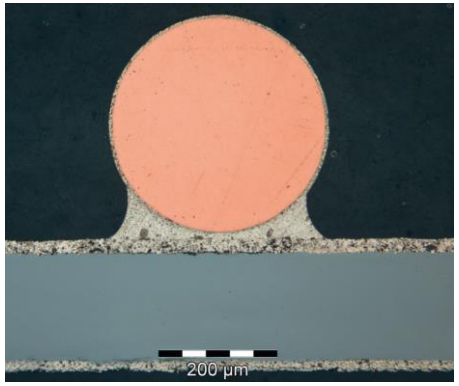
MULTI TABBING WIRE MTW

Solar Technologies

- Concentrically perfect solder coated round wire
- Silver cost reduction → busbar-less solar cells
- Module power increase because of internal light reflection
- Emerging cell/module technologies
  - High efficiency solar cells HJT / half-cut-cell
  - Multiple busbar design → 10 to 20 wires per solar cell
  - Lead-free solution, low temperature
- Module reliability proven!

MEYER BURGER

Smart Wire Connection Technology



Thank you!

Please visit us at booth # 1358

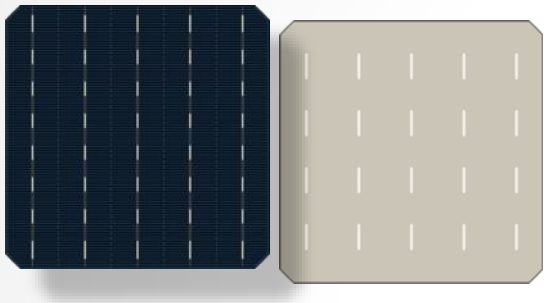
Presentation by Dr. Hongbin Fang, LONGi Solar

LONGi Solar

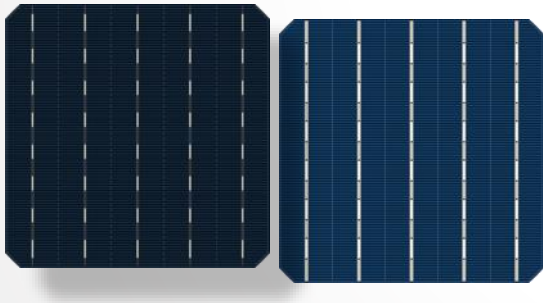
Bifacial PERC
Better LCOE Solution

Hongbin Fang
Director of Product Marketing
September 26, 2018

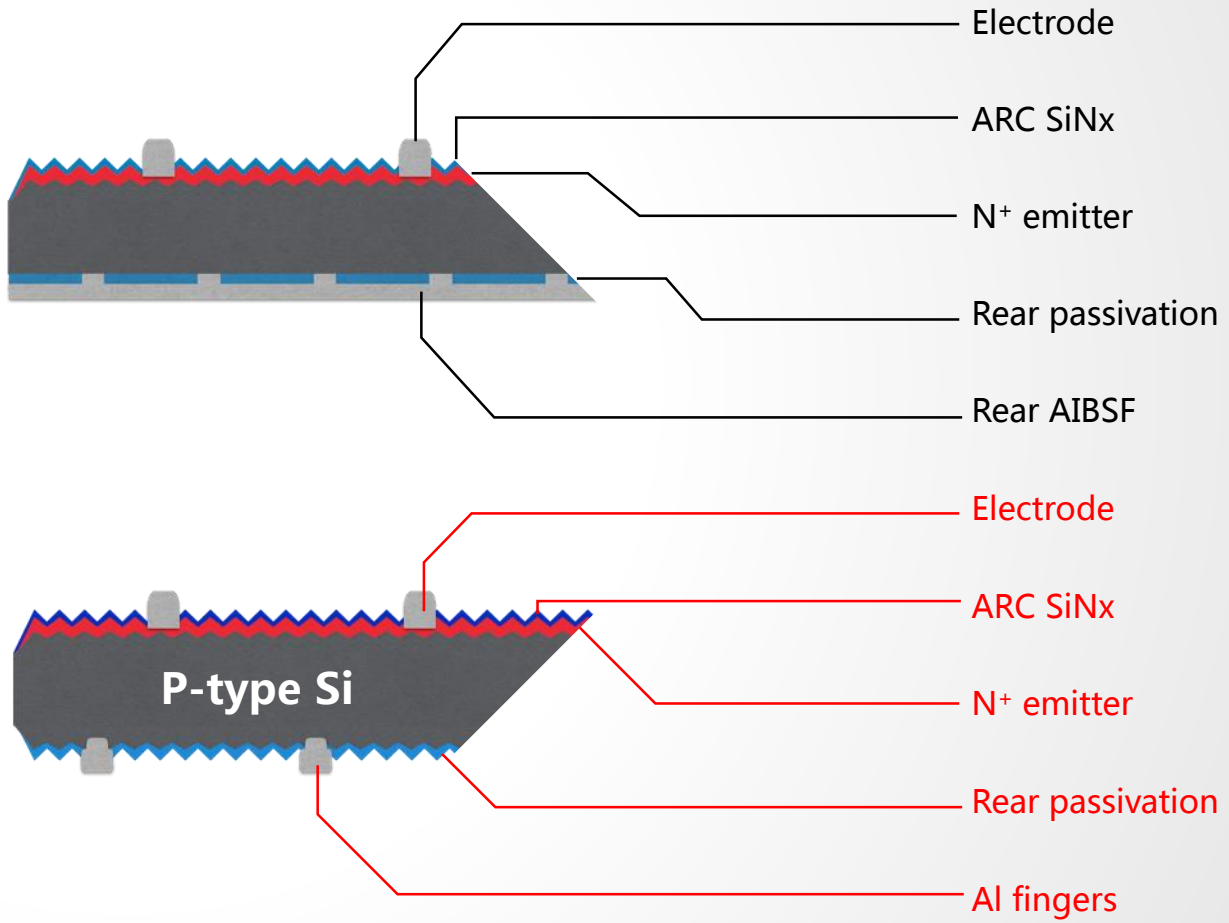
Mono PERC and Bifacial PERC



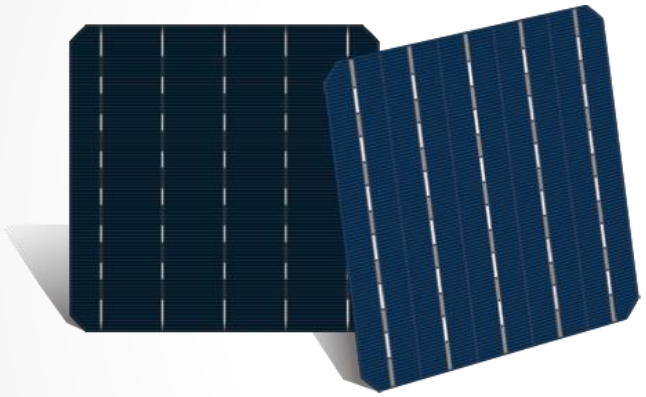
PERC

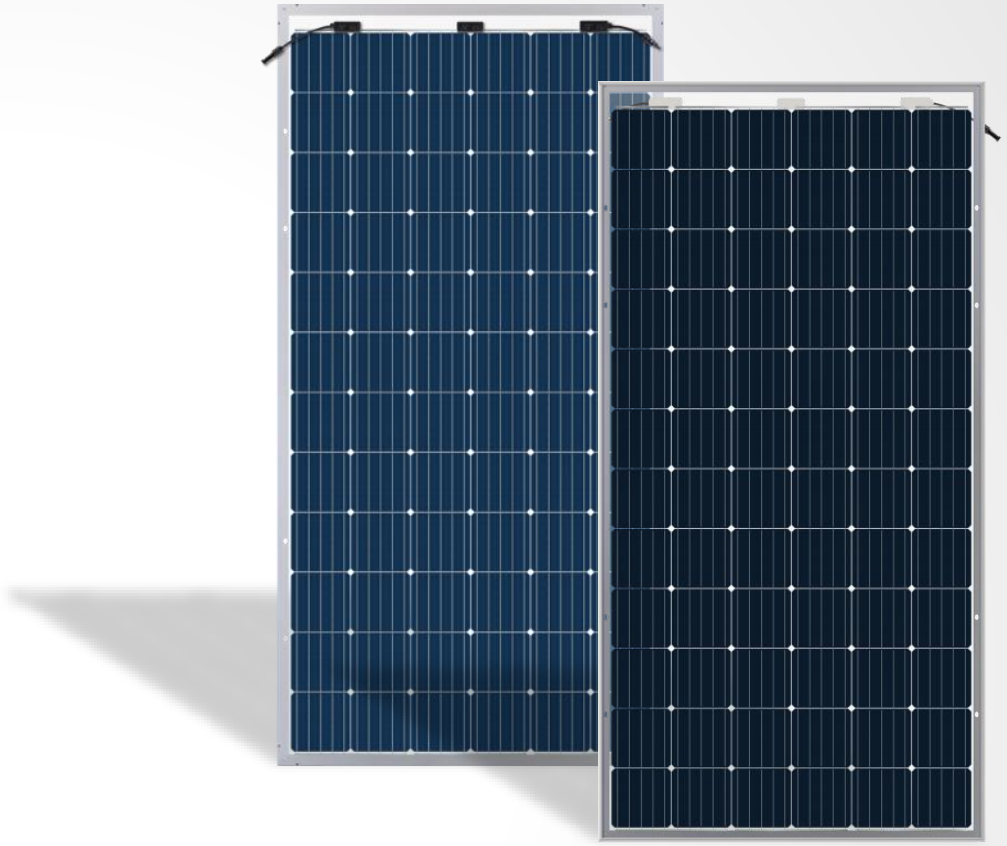


Bifacial PERC



Product Feature





Performance and cost

- Front side efficiency equivalent to conventional PERC
- Manufacturing cost comparable to conventional PERC
- Bifacial light harvesting, 8%-25% power gain from rear side

Application

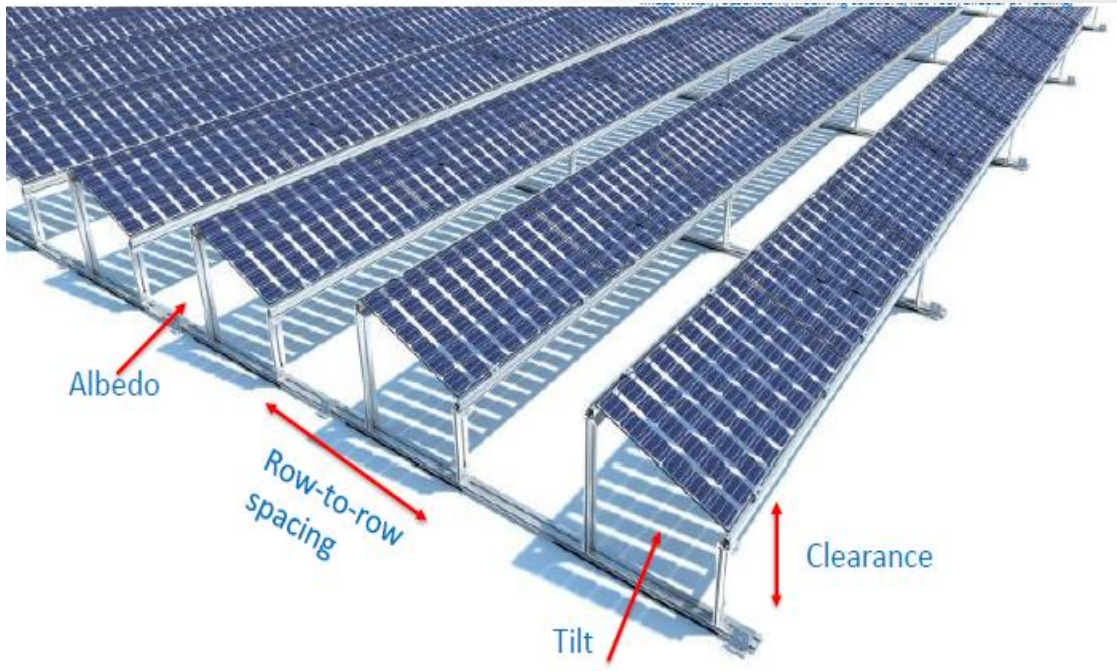
- Utility
- Commercial rooftop and carport

LONGi Solar

Optimize System Design to Improve Bifacial Energy Yield

System Design with Bifacial Module

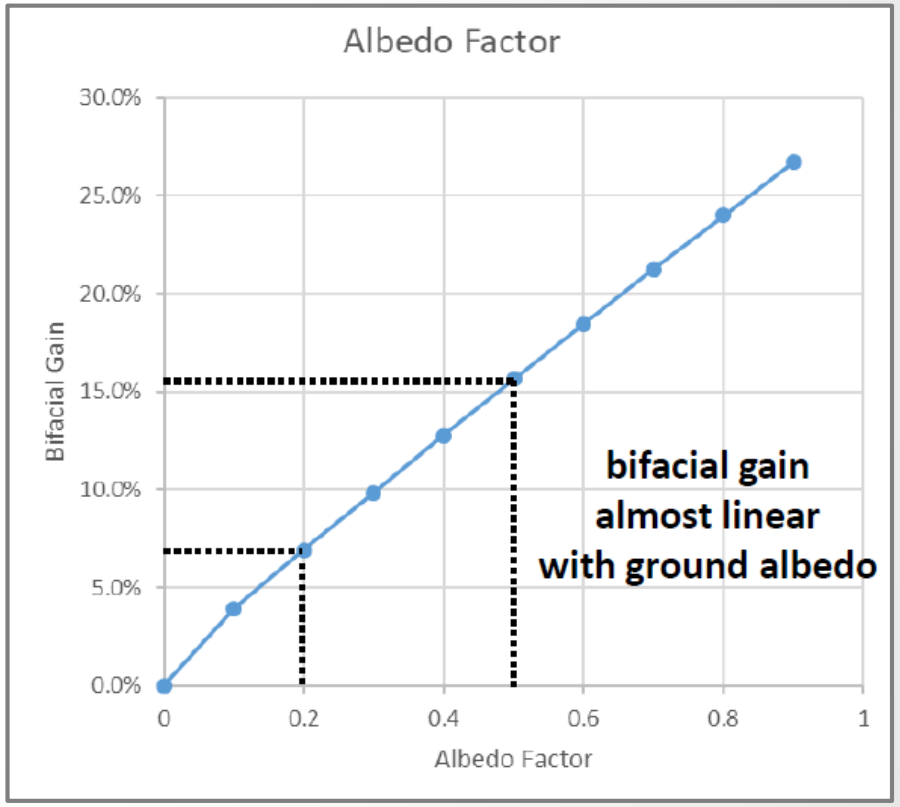
Main Parameters to consider:	
Albedo	↗
Clearance/height	↗
Racking	No backside shading
Row spacing (GCR)	↗ (↘)
Inverter DC/AC ratio	↘



Backside Energy Yield: Albedo

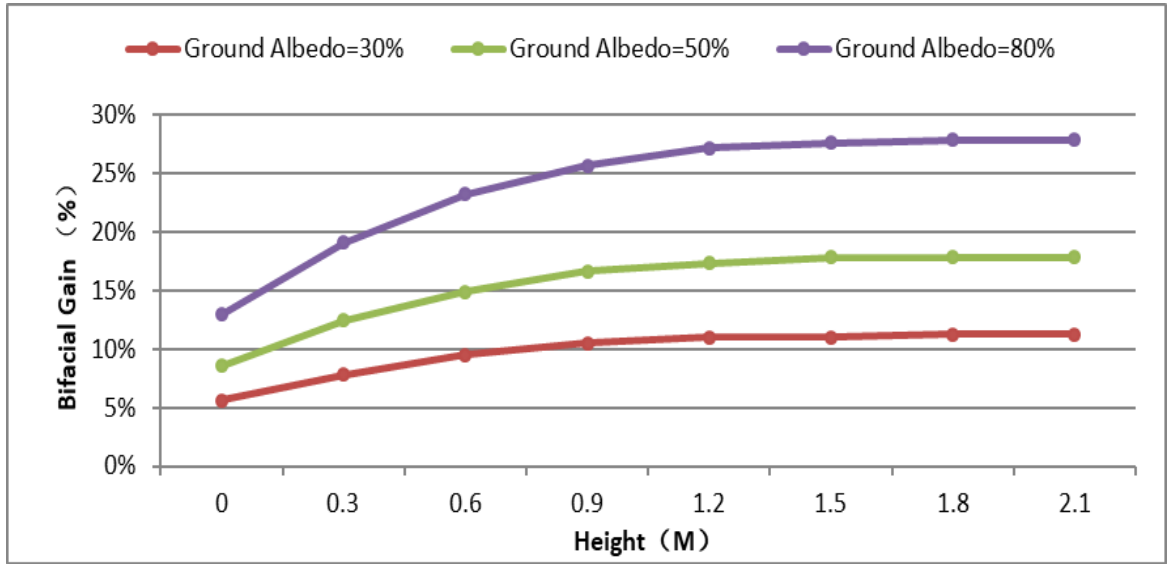
Bifacial gain improves with increasing ground Albedo

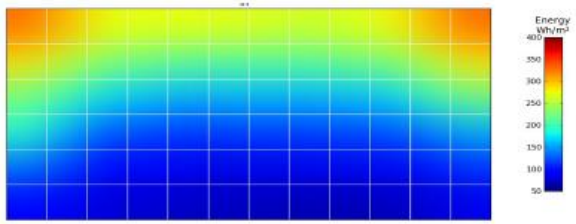
Surface type	Albedo
Green field (grass)	23%
Concrete	16%
White-painted concrete	60%–80%
White gravel	27%
White roofing metal	56%
Light-gray roofing membrane	62%
White roofing membrane	>80%



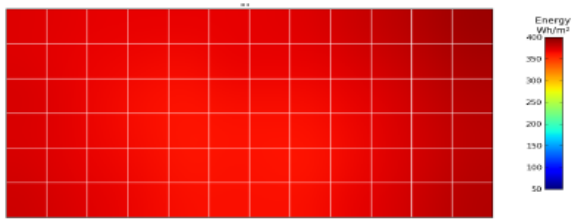
Backside Energy Yield: Albedo and Height

- Bifacial module backside energy yield improves with increasing Albedo (background reflectivity). Selecting site with more reflective background can improve overall system energy yield
- Increasing module height improves backside energy yield, as well as backside irradiance uniformity
- Module height (clearance from ground) of 1m and above is recommended





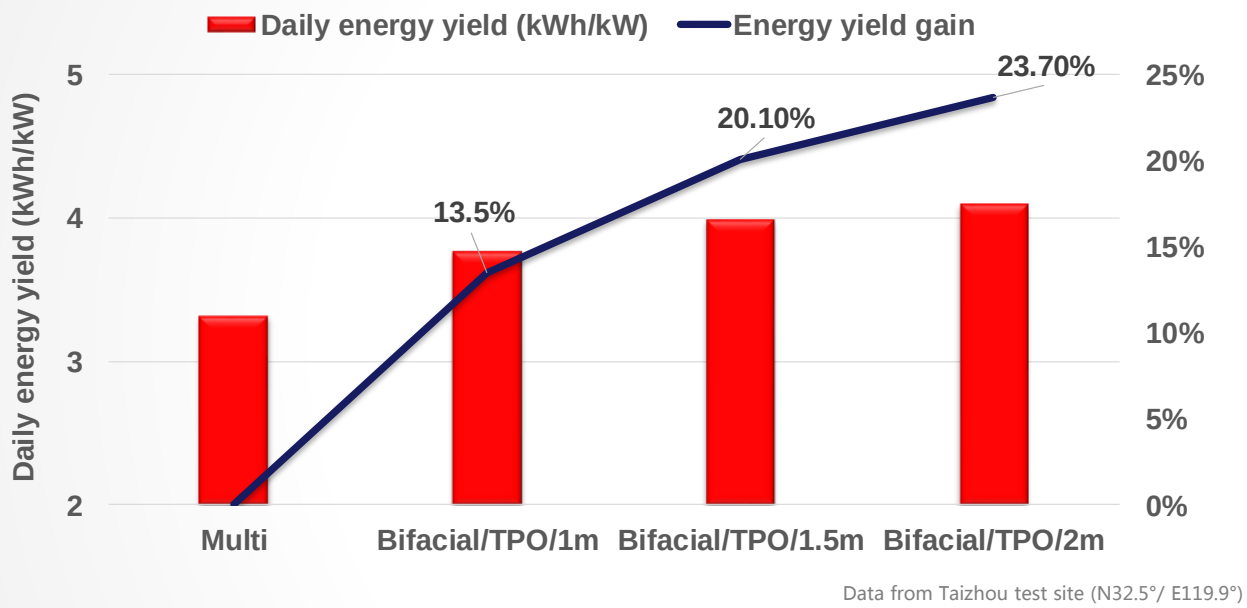
Irradiance at backside - Clearance 8 cm



Irradiance at backside - Clearance 108 cm

LONGi Solar

Bifacial PERC Module
Field Monitoring Data

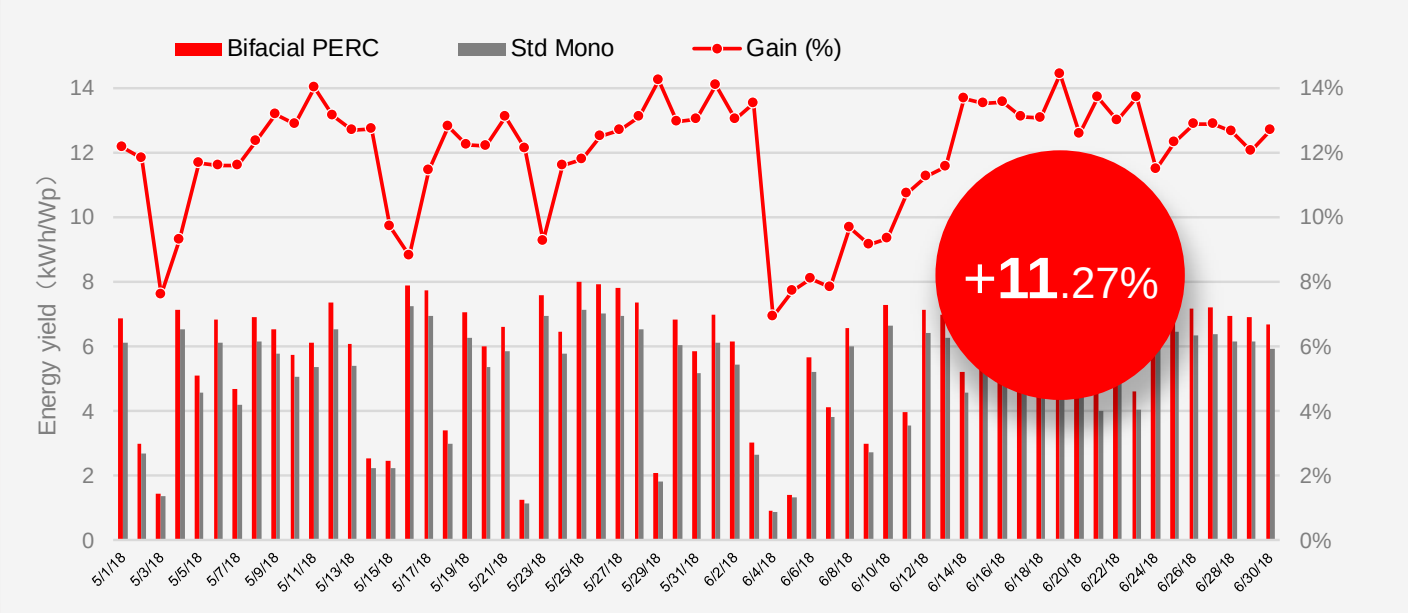


Data from Taizhou test site (N32.5°/ E119.9°)

- Bifacial PERC Capacity 2.8kw, multi capacity 2.7kw, project located in Taizhou test site (N32.5°/ E119.9°), China
- Fixed tilt configuration
- With same background condition, increasing backside energy yield with increasing racking height

LONGi Solar

Bifacial PERC Module
Field Monitoring Data



- Bifacial PERC Capacity 18.9kw, std. mono capacity 18.25kw, project located in Pucheng, Shaanxi (N34.97°/E109.59°), China
- Fixed tilt configuration (15 degree), distance to ground 1.6m
- Three month monitoring data showed 11.27% energy yield from backside

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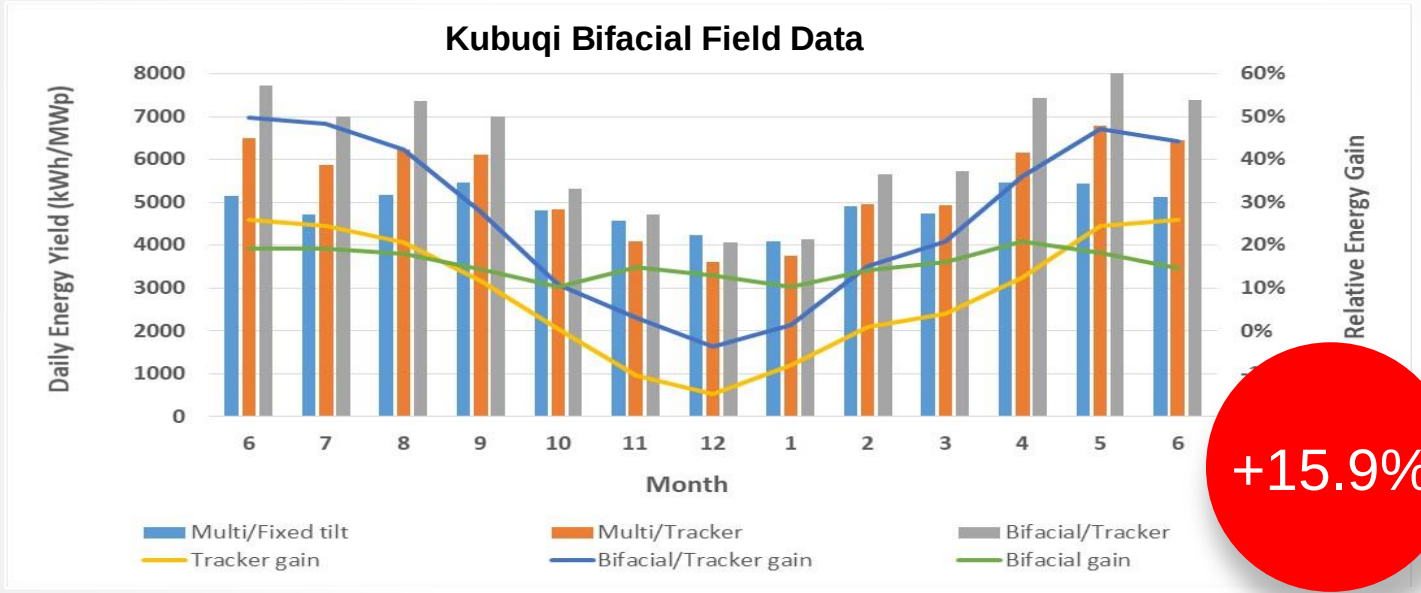
Bifacial PERC Module
Field Monitoring Data



- Bifacial PERC project (336kw on single axis tracker) in Kubuchi, Inner Mongolia (N45.36°/E118.36°), China
- 1Yr energy yield by Bifacial module + tracker is 26.7% higher than Multi module/fixed tilt and 15.9% higher than Multi/tracker

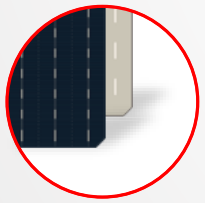
PERC Efficiency Improvement Potential

2017.10 — 2017.11 — 2017.12 — 2018.01 — 2018.04

Cell Efficiency

23.60%
Dec. 2017

22.71%

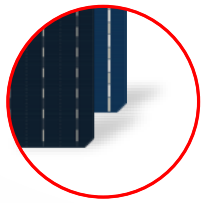


PERC Cell

Cell Efficiency

23.68%
Dec. 2017

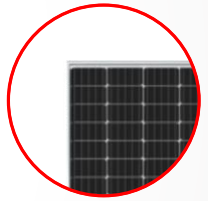
22.41%
82.15%
(Bifaciality)



Bifacial PERC Cell

Module Power

360.3W
(Half-cut) Apr. 2018



333.7W / 20.41%
Jan. 2018

PERC Module

Technology Strength

Through Consistent R&D Investment

$379 M

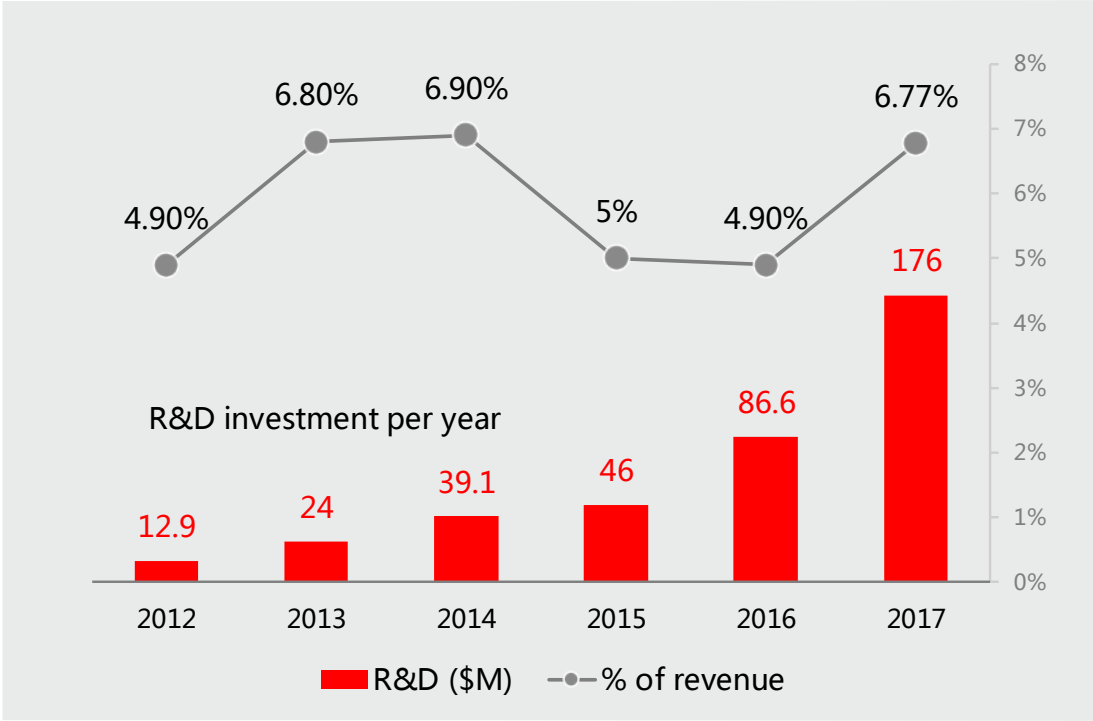
2012-2017 accumulated

R&D spending

5-7%(of revenue)

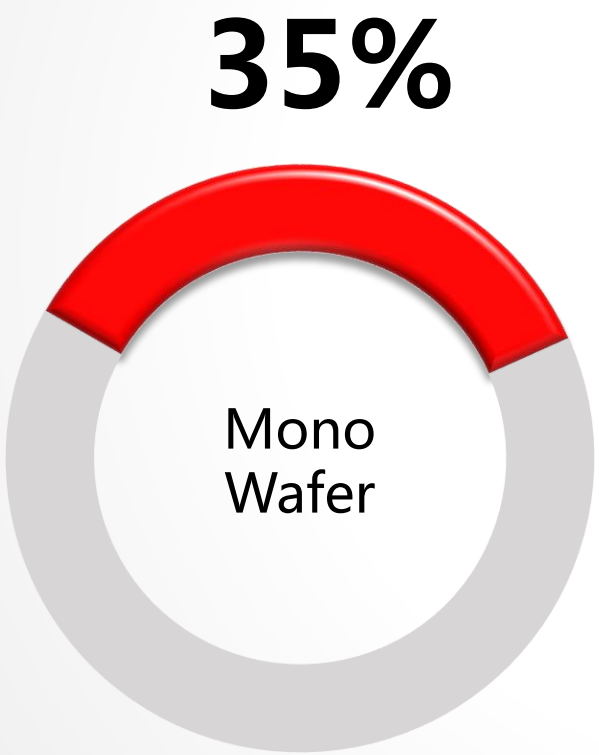
260 patents awarded

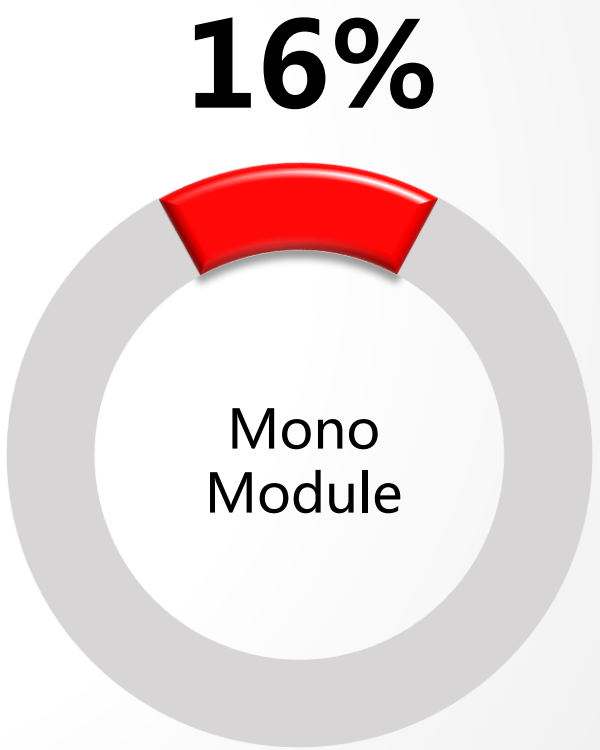
460 staff member



Largest Mono Wafer and Module Manufacturer

Global market share by LONGi






LONGi Solar
RELIABILITY
CREATES
VALUE
As certain as the sunrise
Thank You
for Your Attention
World's No. 1 monocrystalline module manufacturer • Solar's most bankable company • PV industry highest R&D investments • High power, high yield, high reliability

Panel I:
Emerging directions in cell and module designs

Panel I: Emerging directions in cell and module designs

Tristan Erion-Lorico
Head of PV Module Business, Laboratory Services

DNV·GL

Hongbin Fang
Director of Product Marketing

LONGi Solar

Ilka Luck
Global Head, New Product Development & Technology

Heraeus

Christian Prischmann
Director of Technology

Ulbrich Solar Technologies

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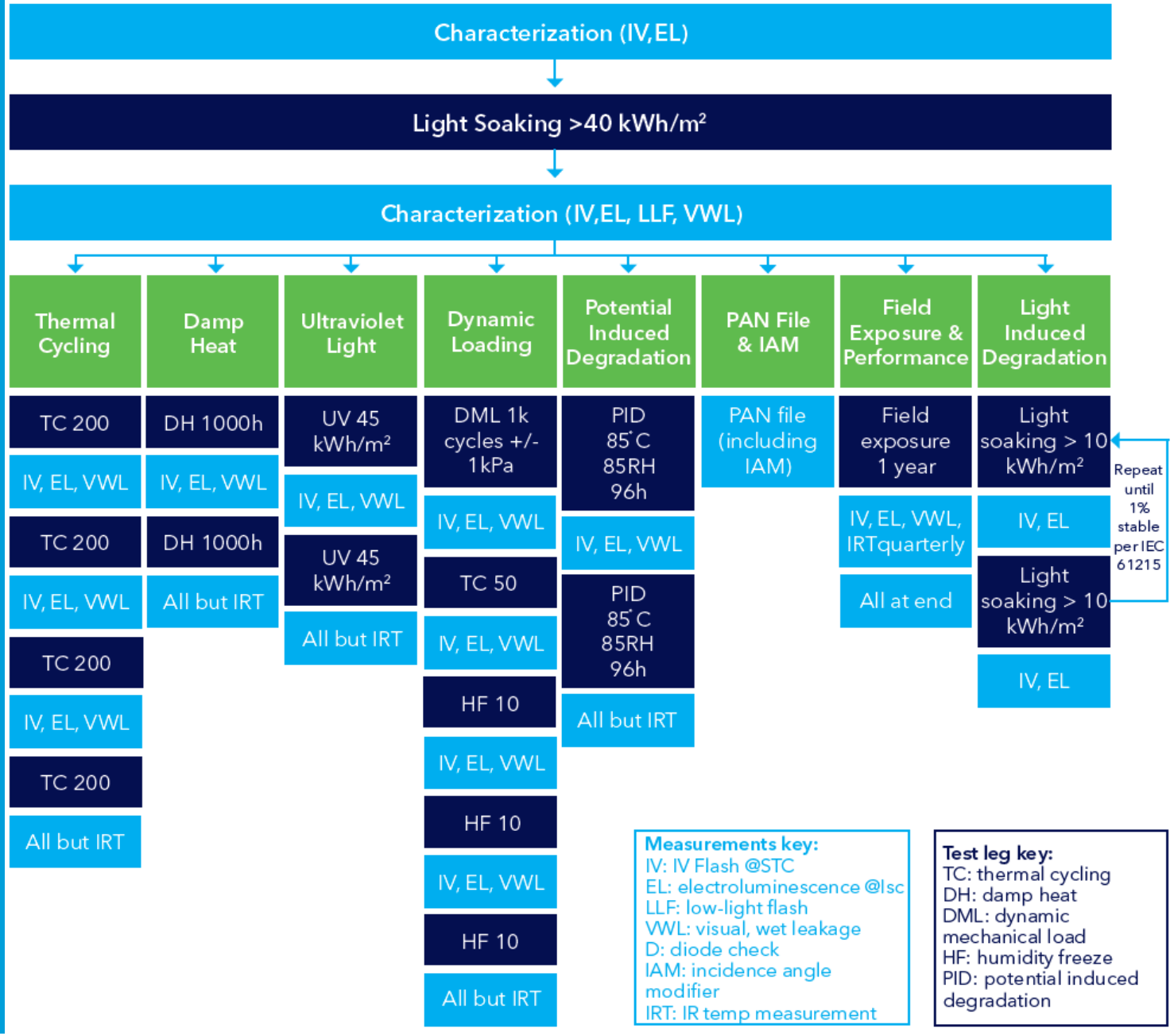
Fireside chat with Tristan Erion-Lorico, DNV GL

DNV GL's 2018 Product Qualification Program Test Sequences



Panel II:
Grid integration of high levels of renewable energy

Panel II: Grid integration of high levels of renewable energy

Marc Perez
Senior Researcher Clean
Power Research

Michael O'Boyle
Electricity Policy Manager
Energy Innovation

Mahesh Morjaria

First Solar

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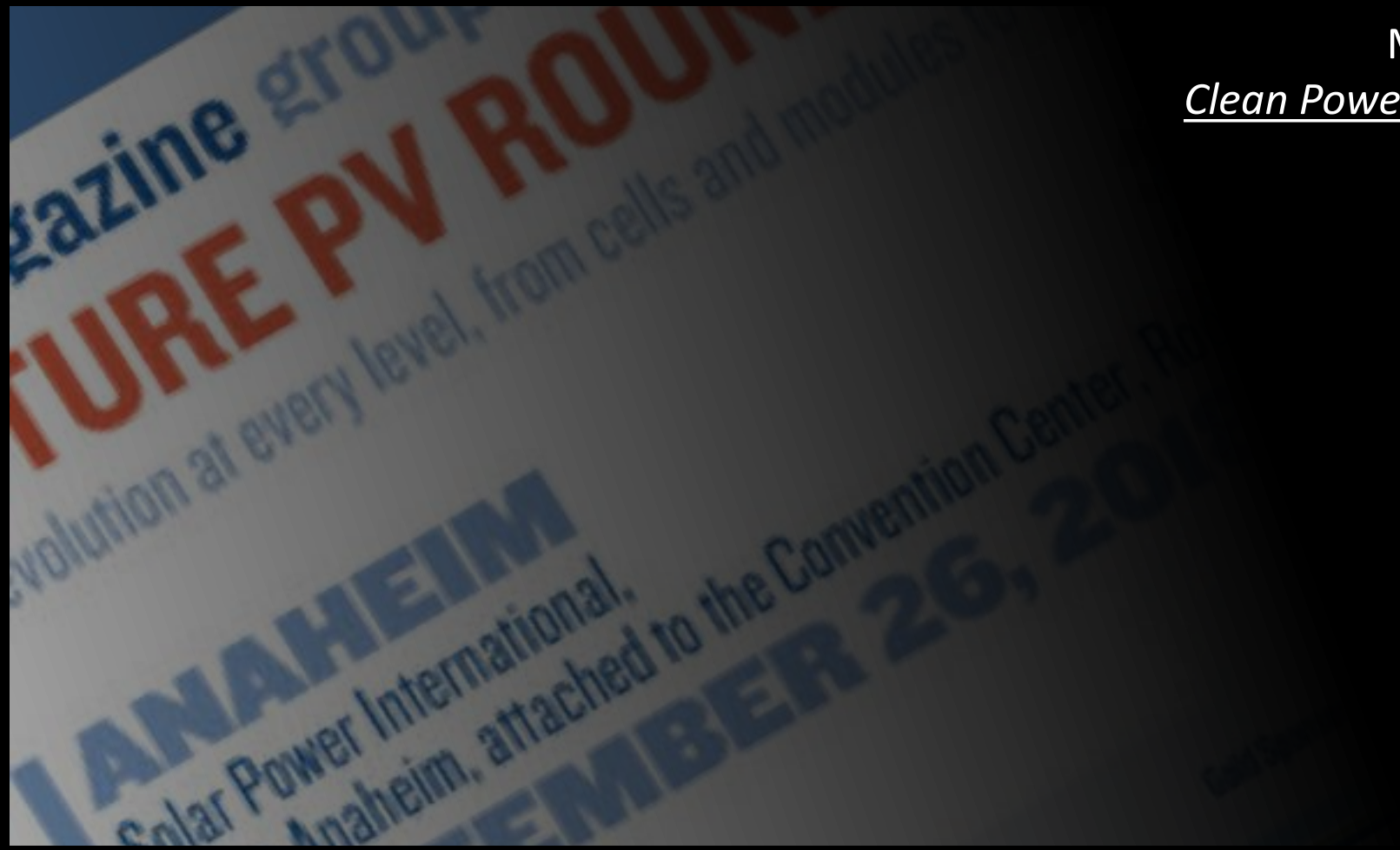
Grid integration of high levels of renewable energy

Supply-Side Interventions



Marc Perez

Clean Power Research

This study is based upon work supported by:

National Science Foundation GRF Grant No. DGE 1144155

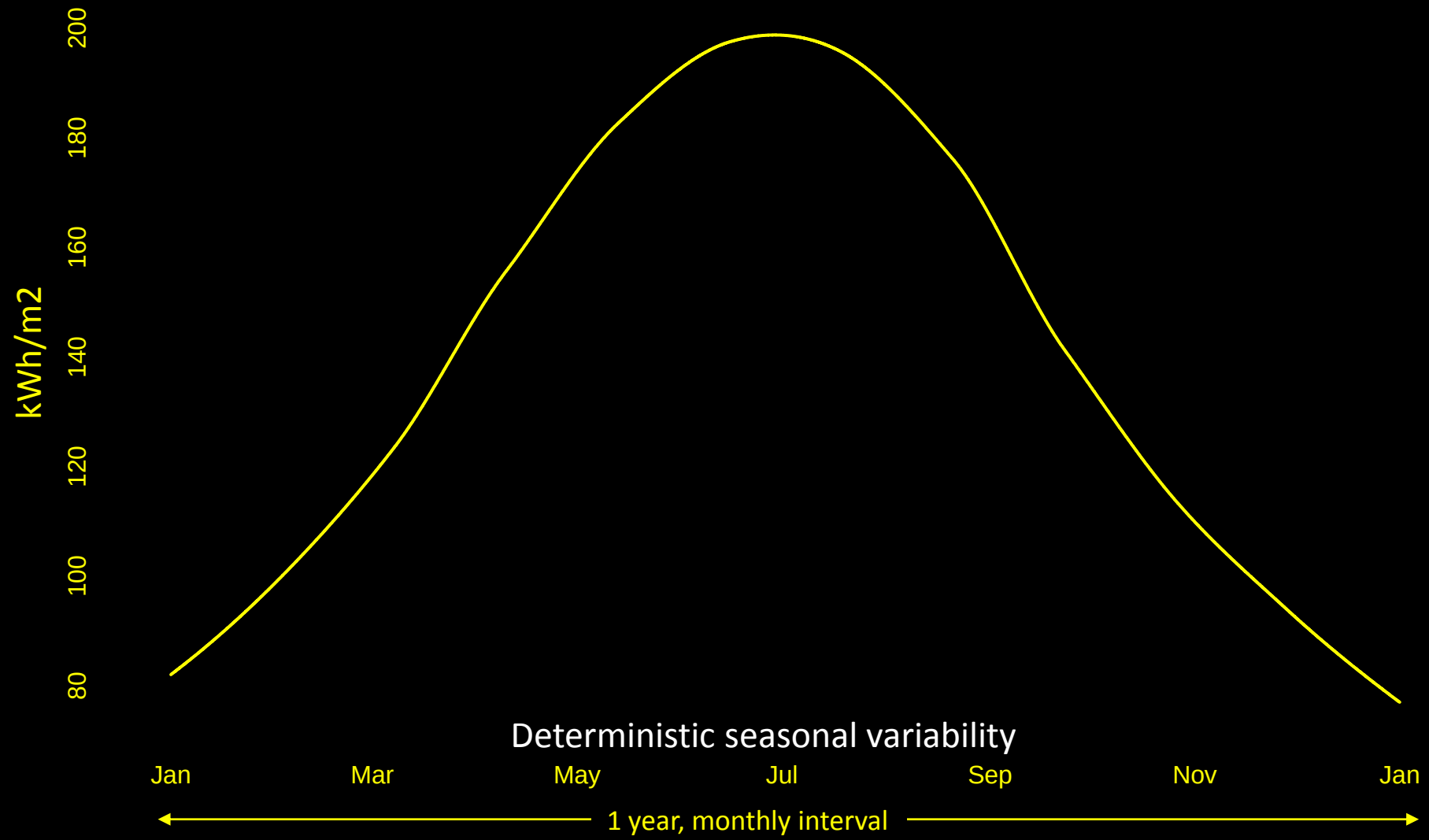
DoE Sunshot Grant No. DE-EE0007669

Columbia University Center for Life Cycle Analysis

Clean Power Research

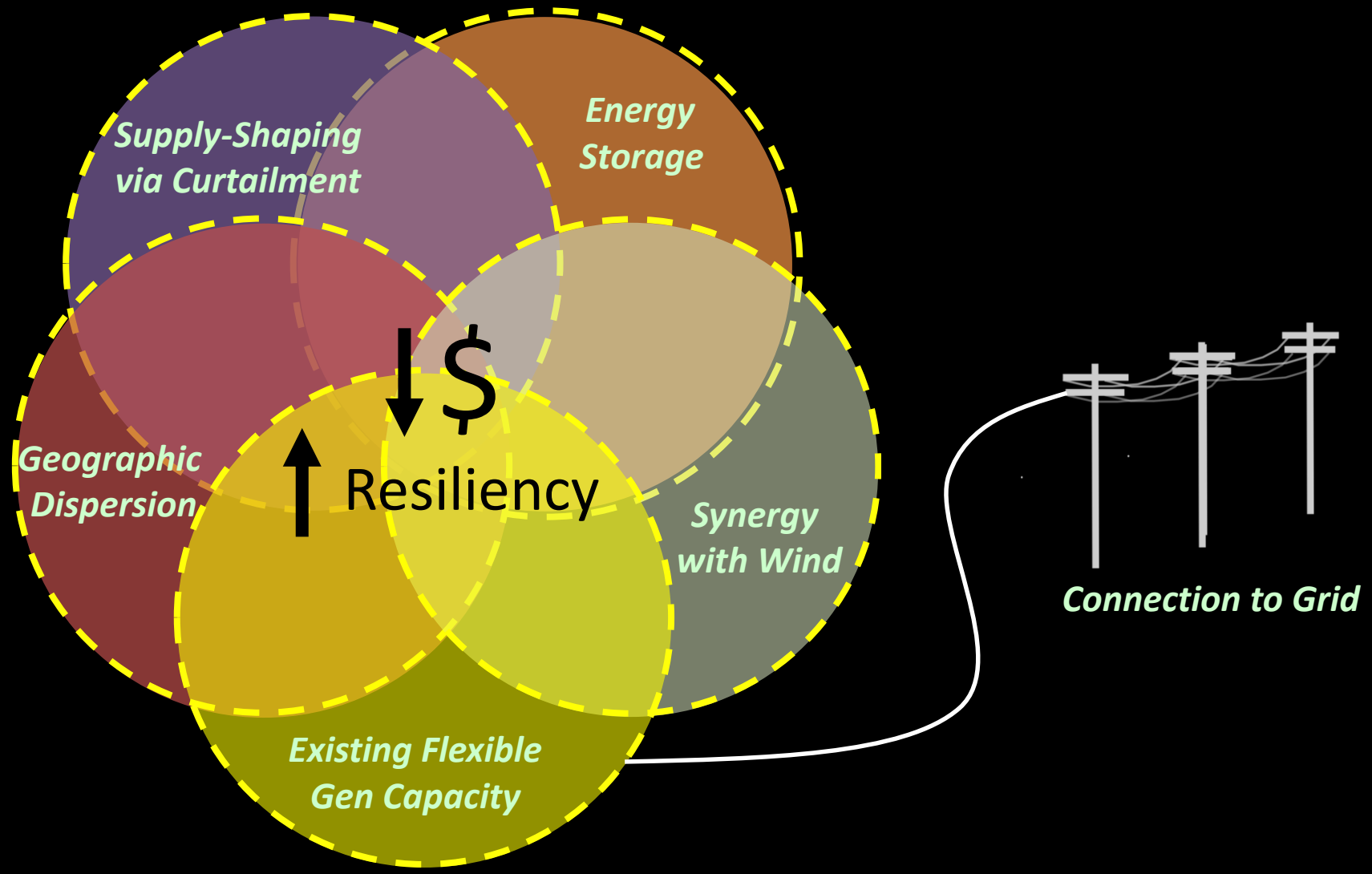
What is required to achieve high penetration Renewables?

Variability on multiple timescales needs to be addressed.

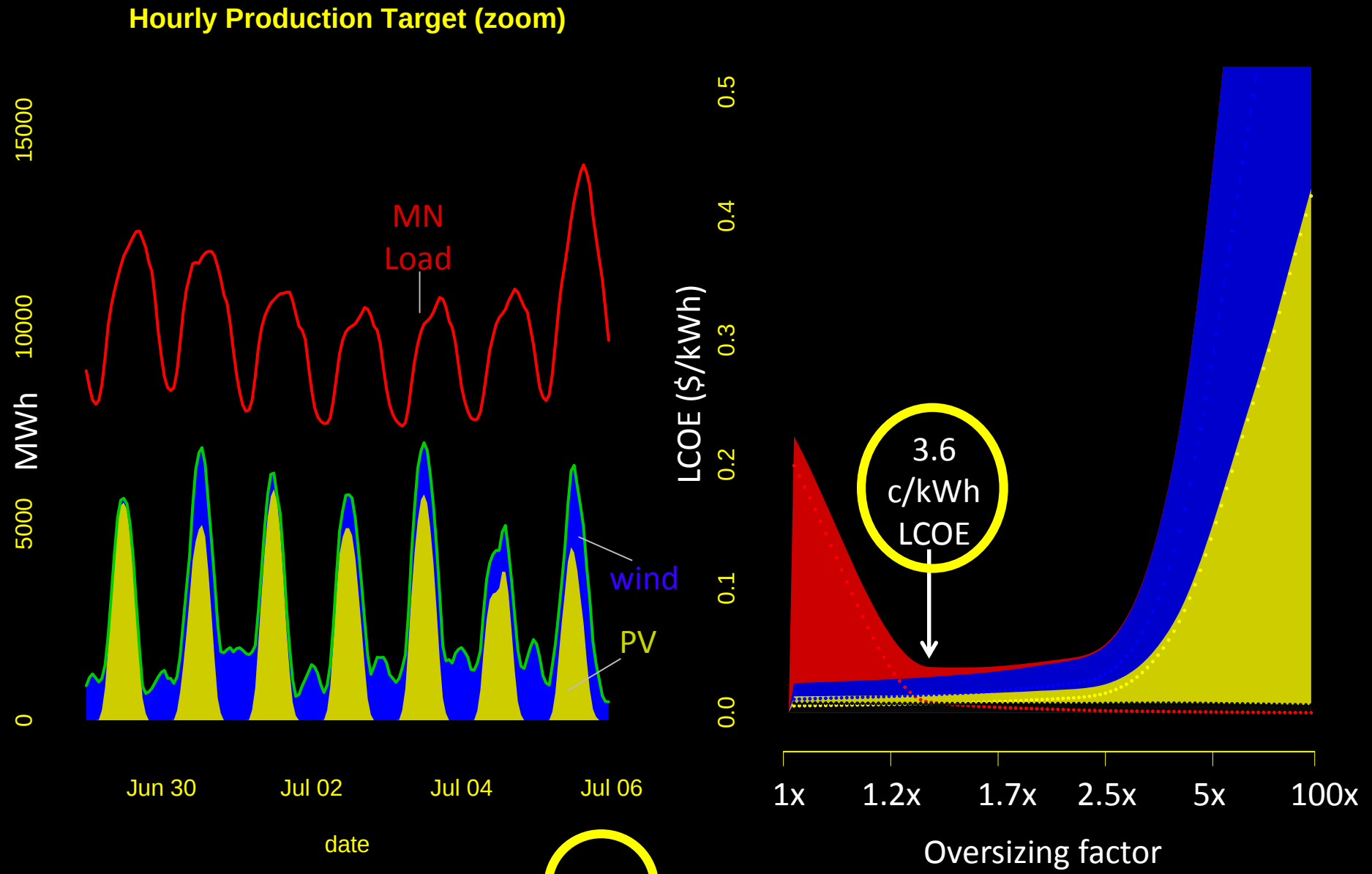


What is required to achieve high penetration Renewables?

Corresponding Supply/Demand Imbalances must be corrected



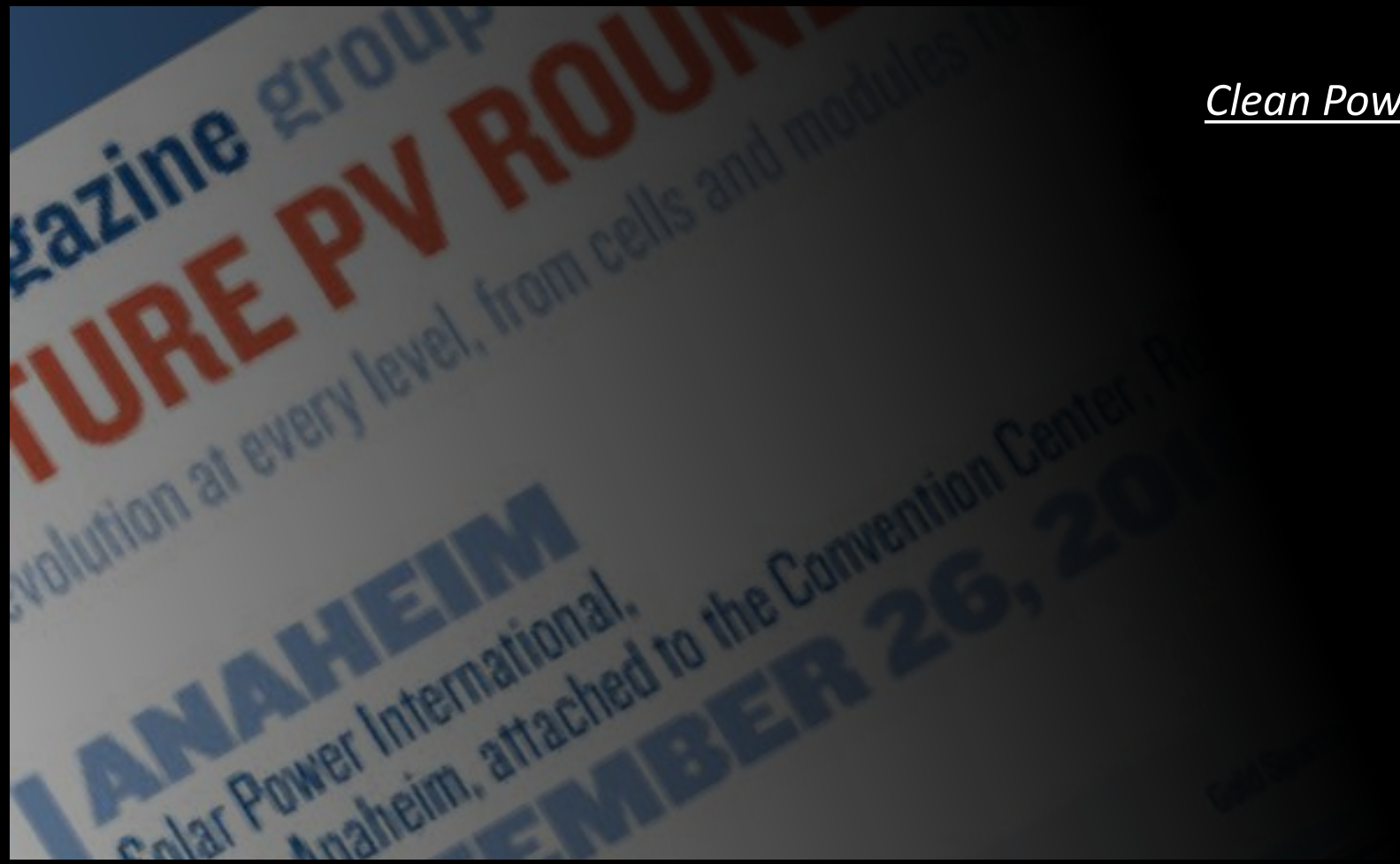
Sample results from MN Solar Pathways Study using CPR Integration model



Optimal Wind/PV + Storage Meeting 95% Hourly Load in MN, 5% met by gas Utility-scale-led,
High Technological Development in 2050, WACC of 3%

Grid integration of high levels of renewable energy

Supply-Side Interventions



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Clean Power Research

FLEXIBILITY:

SOLUTIONS TO INTEGRATE VARIABLE RENEWABLES

MIKE O'BOYLE

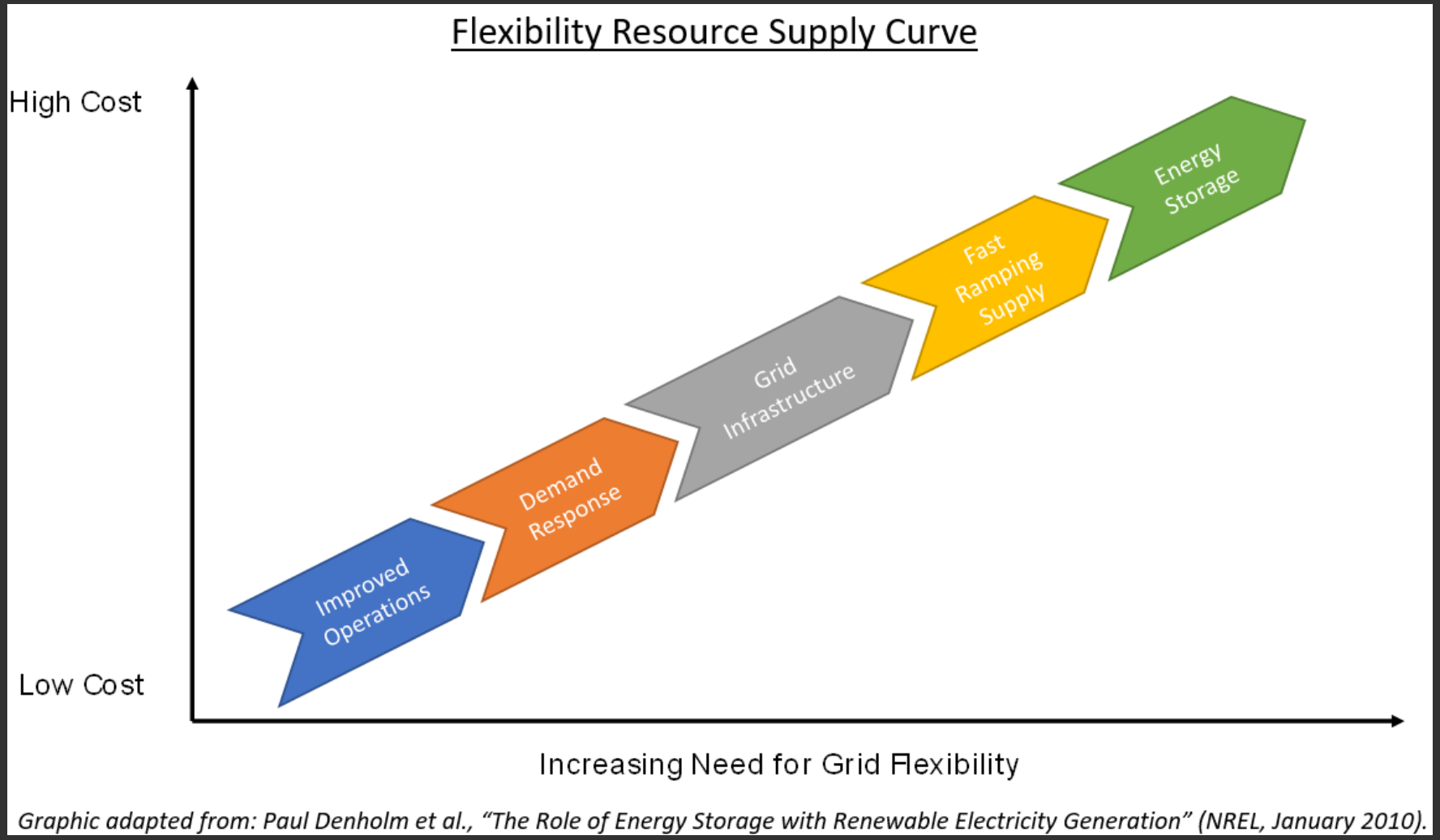
FUTURE PV ROUNDTABLE

SEPTEMBER 26, 2018

AMERICA'S POWER PLAN

ENERGY INNOVATION POLICY & TECHNOLOGY LLC

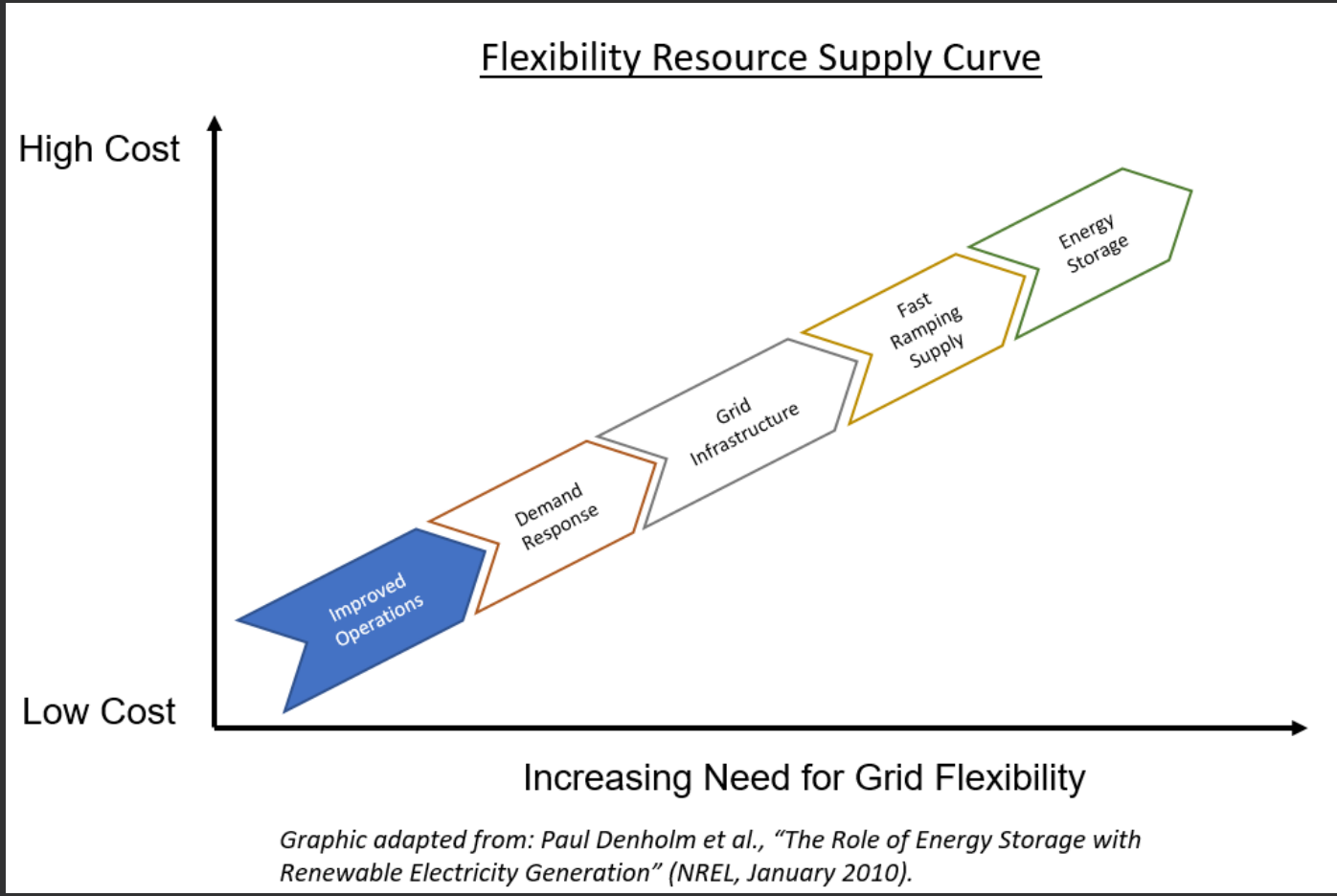
FLEXIBILITY INCLUDES A SUITE OF OPTIONS



Graphic adapted from: Paul Denholm et al., "The Role of Energy Storage with Renewable Electricity Generation" (NREL, January 2010).

IMPROVED OPERATIONS

- Expand the Energy Imbalance Market
  - Additional regions
  - Additional products
- Flexible imports
- RE providing reliability services



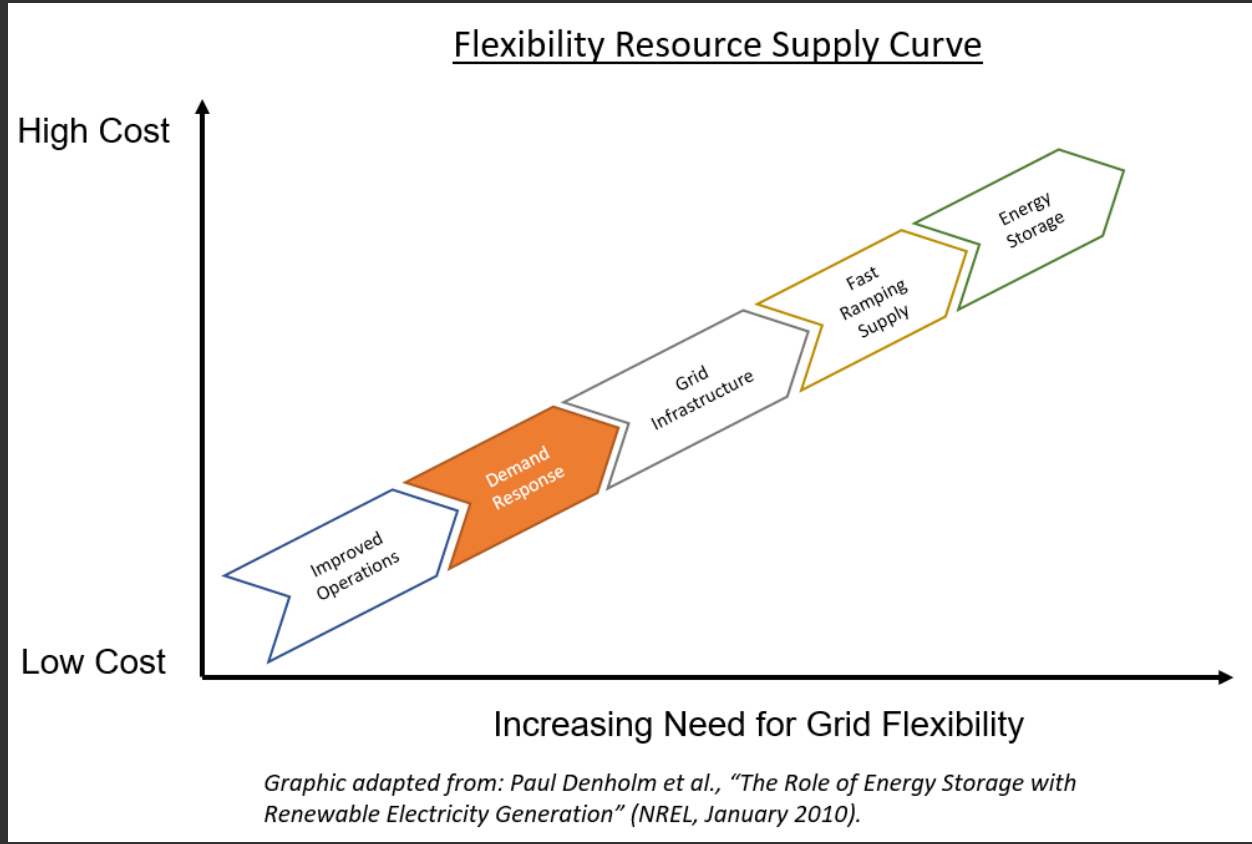
Graphic adapted from: Paul Denholm et al., "The Role of Energy Storage with Renewable Electricity Generation" (NREL, January 2010).

DEMAND RESPONSE

Two kinds of demand response:

- Dispatchable
- Price-responsive

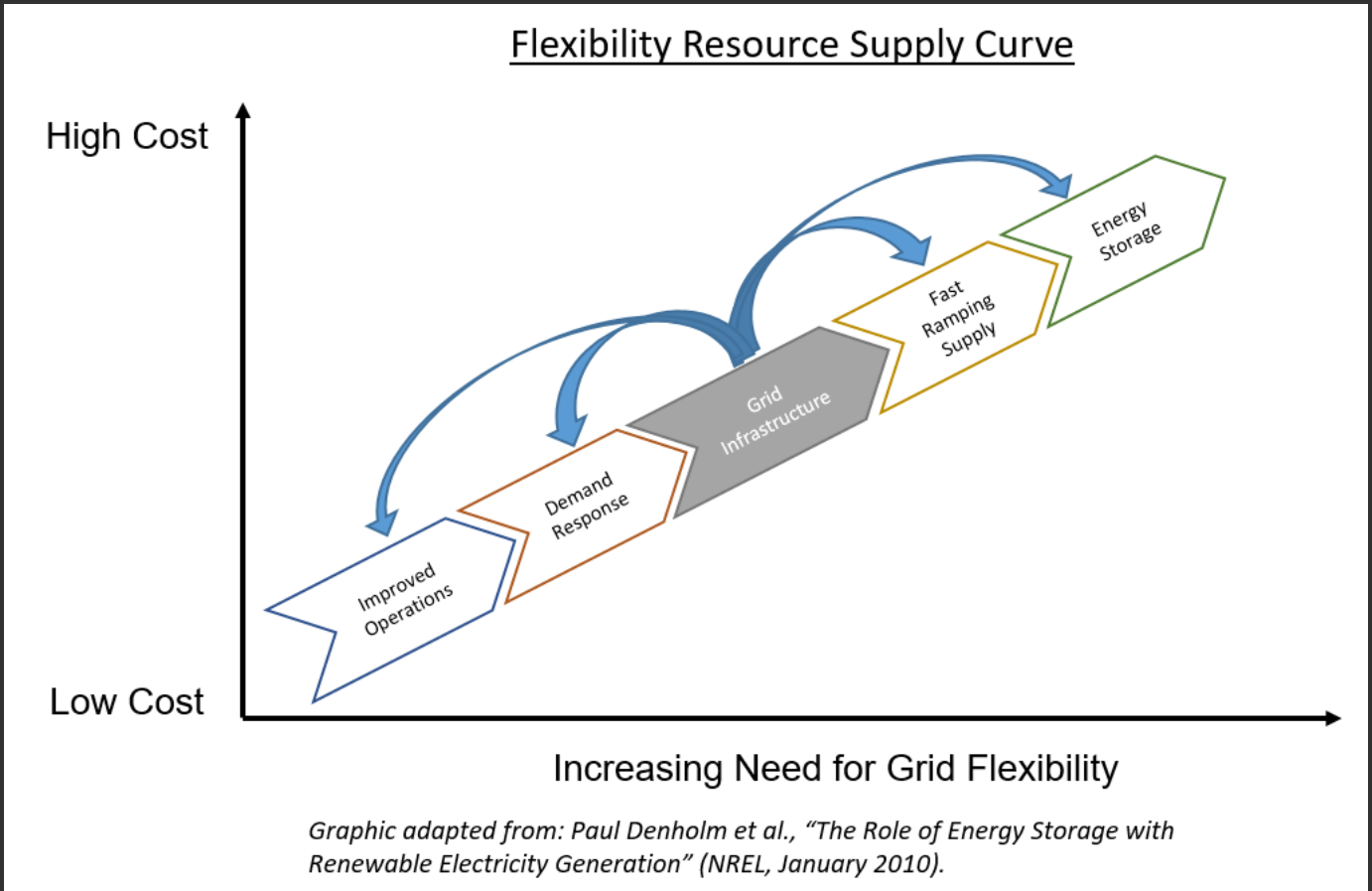
Potential for 6 GW in CA by 2025 (CPUC April 2016)



Graphic adapted from: Paul Denholm et al., "The Role of Energy Storage with Renewable Electricity Generation" (NREL, January 2010).

GRID INFRASTRUCTURE

Transmission enables regional optimization (e.g. EIM, market expansion) & geographic diversity

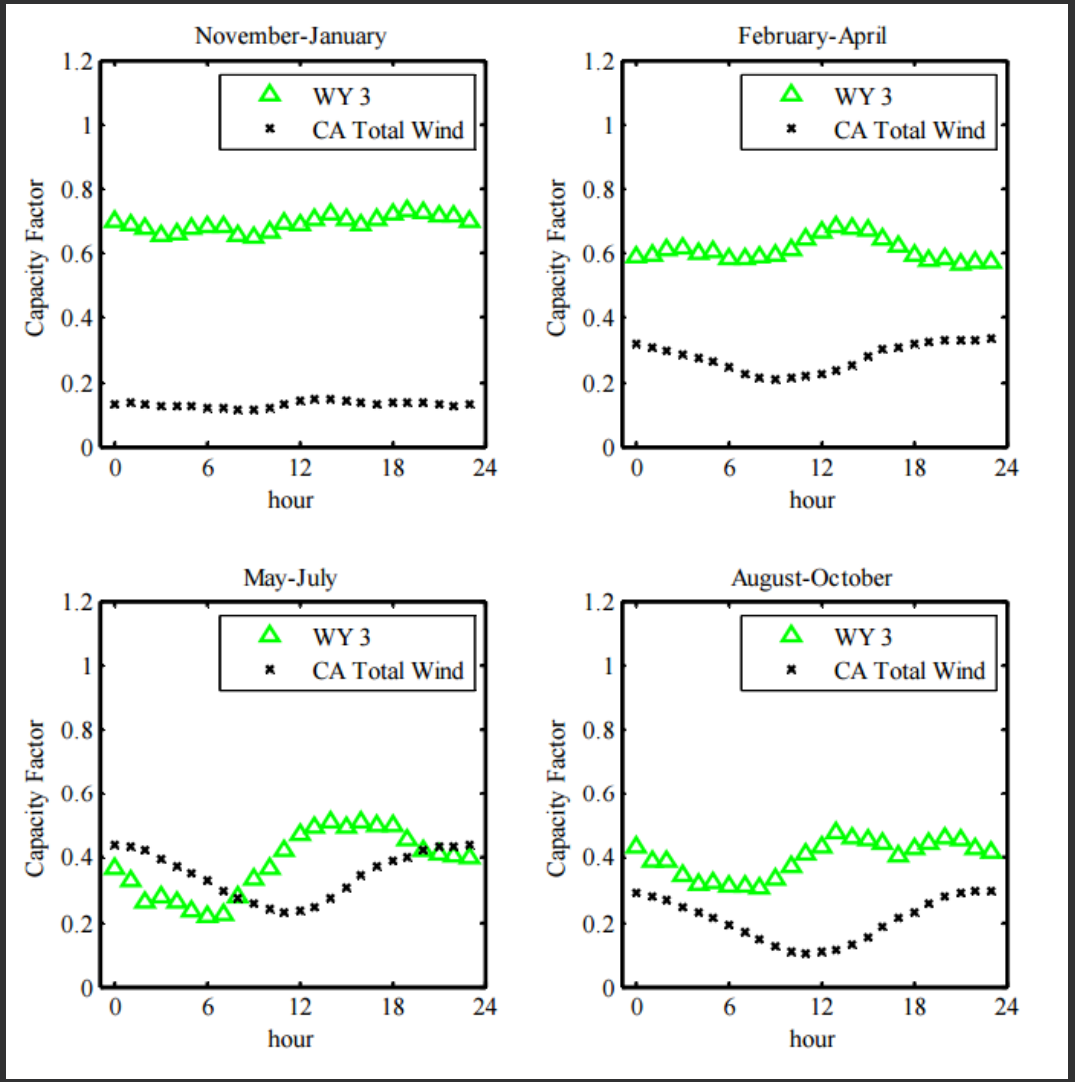


Graphic adapted from: Paul Denholm et al., "The Role of Energy Storage with Renewable Electricity Generation" (NREL, January 2010).

GEOGRAPHIC DIVERSITY

Managing predictable variations:

- Linking negatively correlated renewable energy reduces need for more expensive sources of flexibility, e.g. natural gas & storage



Source: J. Naughton, *Wind Diversity Enhancement of Wyoming, California Wind Energy Projects: Phase 2*, Univ. of Wyoming, Wind Energy Research Center, July 2015

Grid-Flexible Solar: Enabling Clean Energy Grid of the Future

Mahesh Morjaria, Ph.D.
VP, PV Systems

SPI Conference
Sept 26, 2018

First Solar®

LEADING THE WORLD'S
SUSTAINABLE ENERGY FUTURE

Tale of Two Days in Life of Solar … *(in New England)*

How solar power saved $6.7 million on a Tuesday

- Saves 14% Electricity Cost Over a Week

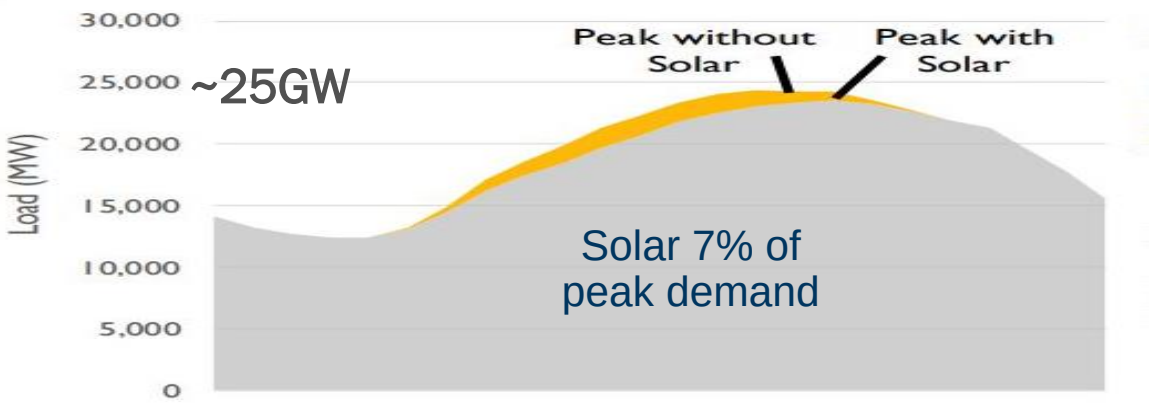
SEPTEMBER 4, 2018 JOHN WEAVER

The duck curve comes to New England

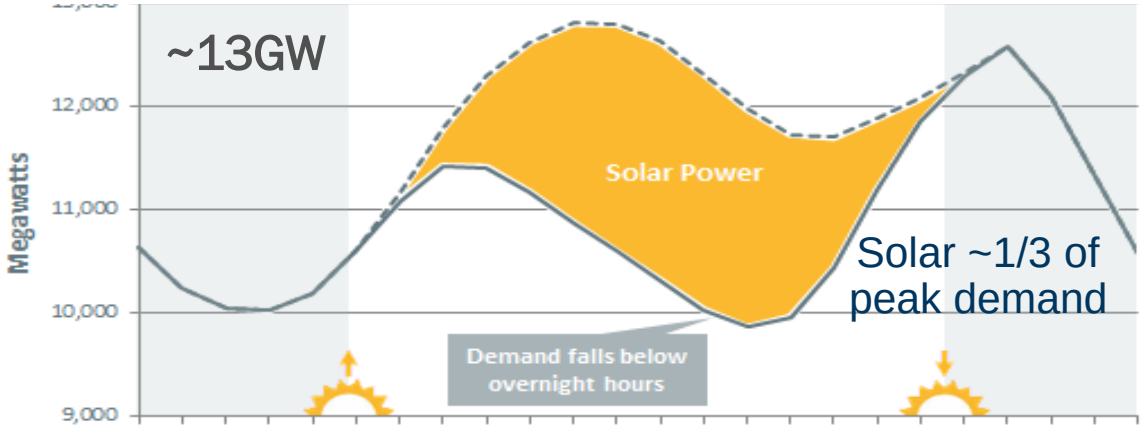
- Electricity price -$2.65/MWh at 3 PM.

MAY 8, 2018 CHRISTIAN ROSELUND

July 3, 2018



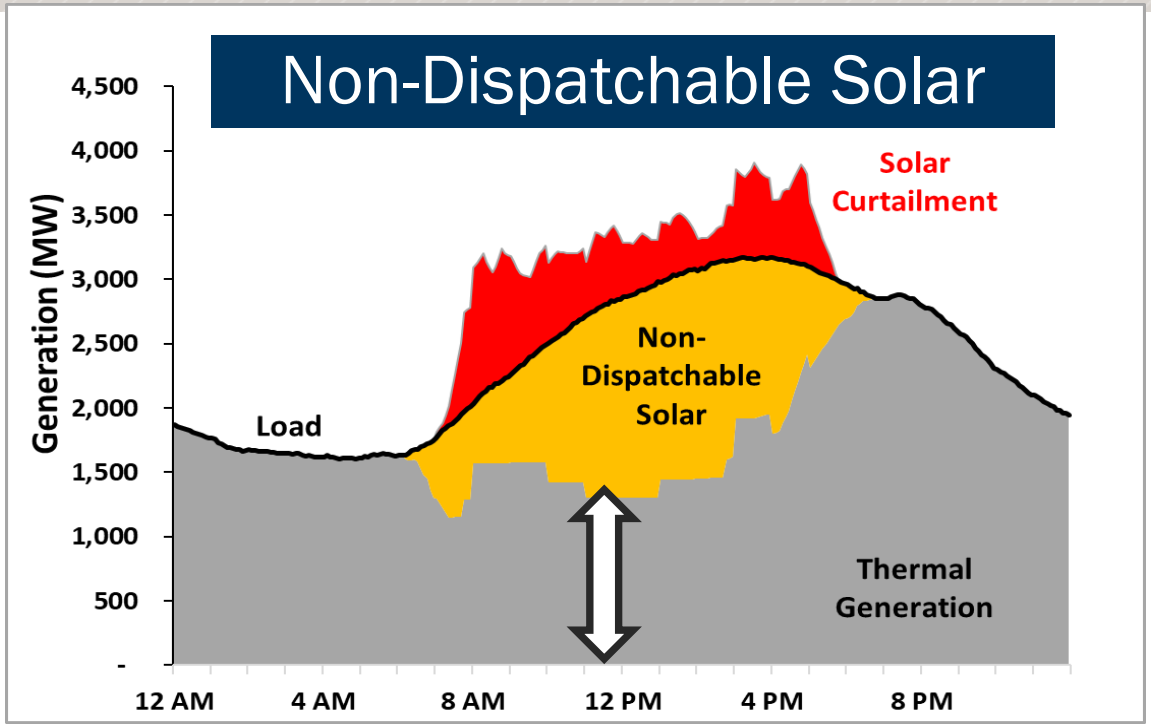
April 21, 2018

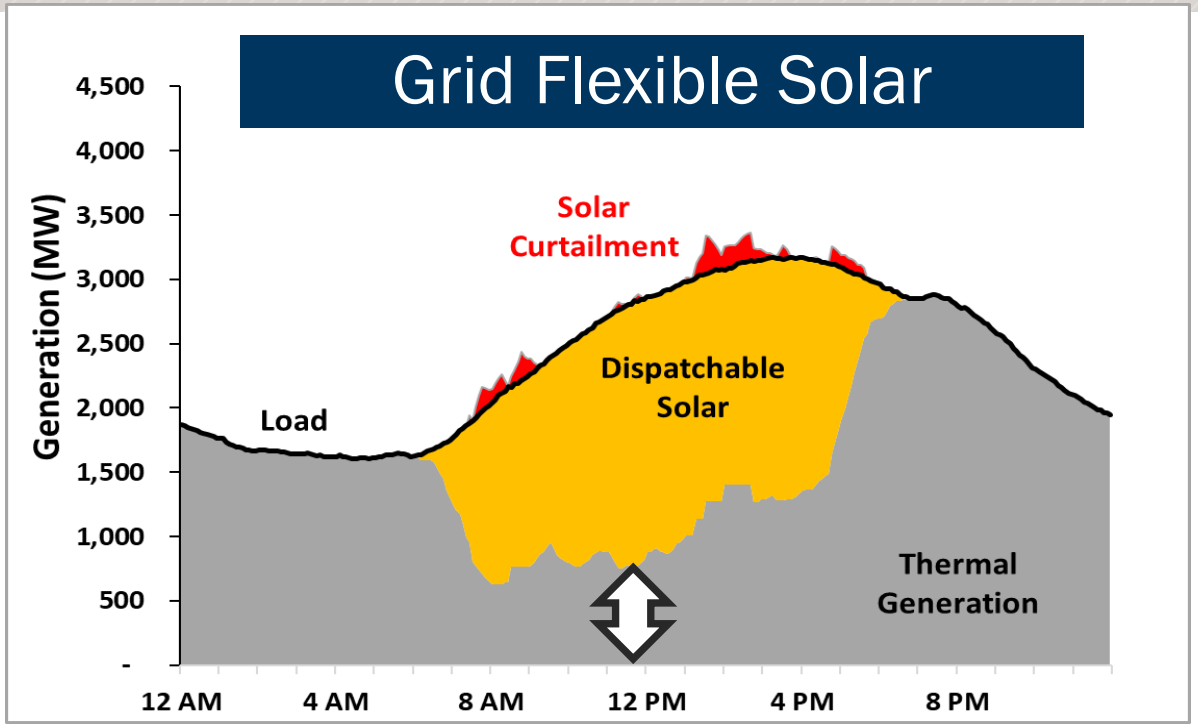


Goal: Integrate higher levels of solar… to increase system value
… while dealing with intermittency challenges on the grid …power system flexibility is critical

Sources: "How solar power saved $6.7 million on a Tuesday", by John Weaver, Sept 4, 2018, PV Magazine, https://pv-magazine-usa.com/2018/09/04/how-solar-power-saved-6-7-million-on-a-tuesday/; "The duck curve comes to New England", by Christian Roselund, May 8,2018, PV Magazine, https://pv-magazine-usa.com/2018/05/08/the-duck-curve-comes-to-new-england/

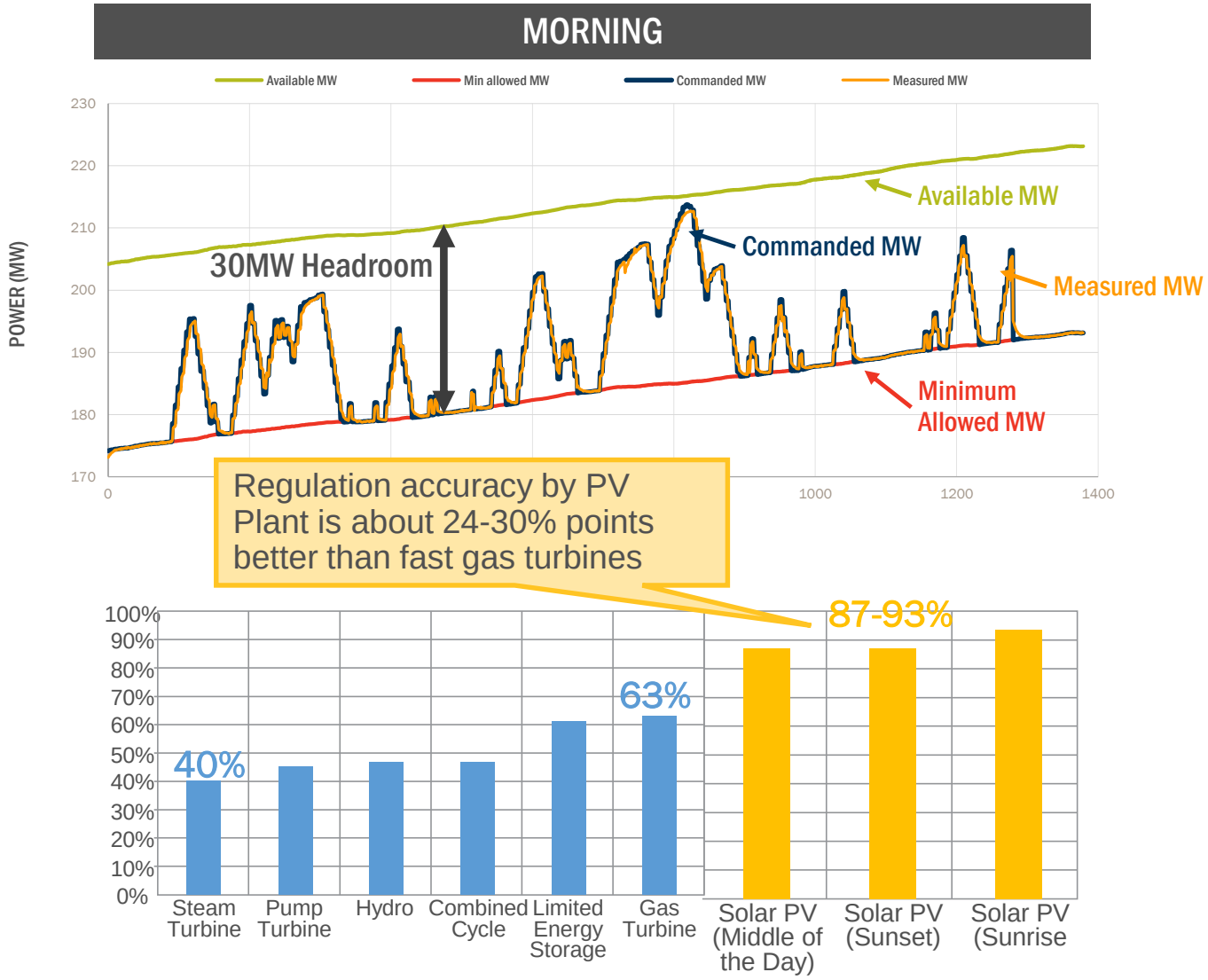
“Grid Flexible” Solar Reduces Curtailment – An Illustration





- Dispatchable (Grid Flexible) solar contributes to **regulation & balancing requirements**, and **reduces solar curtailment**
- **Needs less thermal generation for regulation & balancing**, which in turn results in lowered midday thermal generation

AGC (Automated Generation Control) Tests – 300 MW Utility-Scale PV Plant



Blue bars taken from the ISO's informational submittal to FERC on the performance of resources providing regulation services between January 1, 2015 and March 31, 2016

- 30MW headroom
- 4-sec AGC signal provided to Plant Controller
- Tests were conducted for
  - Sunrise
  - Middle of the day
  - Sunset

Source: http://www.caiso.com/Documents/TestsShowRenewablePlantsCanBalanceLow-CarbonGrid.pdf

Better Integration And Scale Through Flexibility

Solar Energy

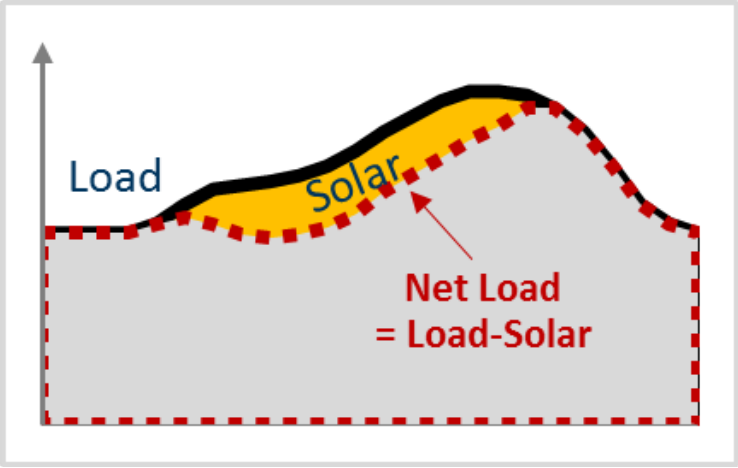
- Solar is part of mid-day load offsets peak or near-peak demand
- **Energy-Only Value**

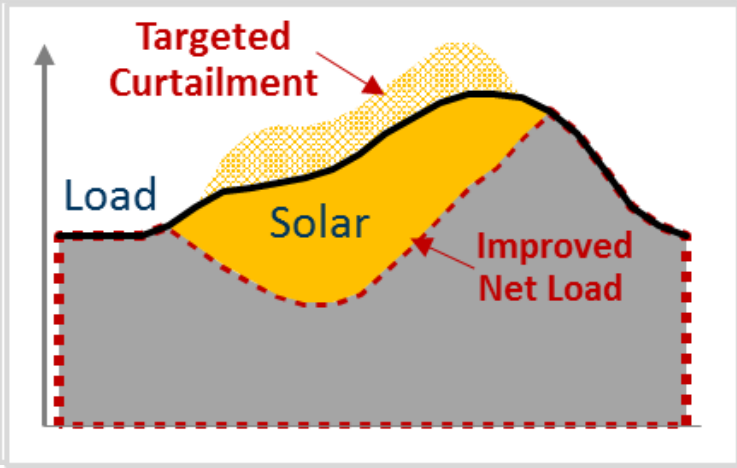
Grid Flexible Solar

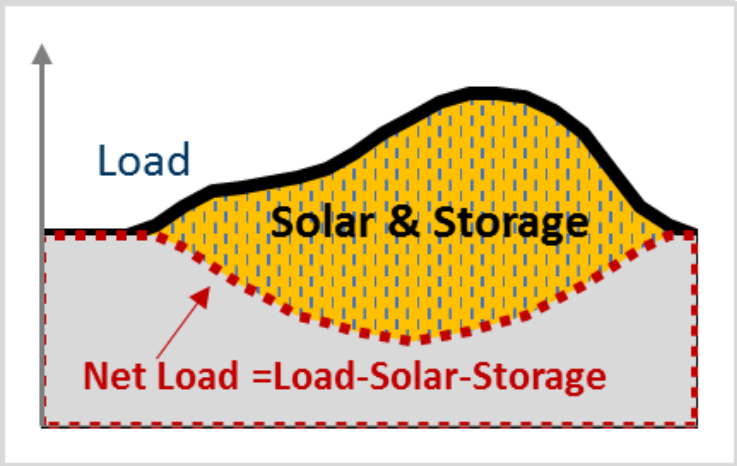
- Adds **Grid Reliability Services & Flexibility** Value

Fully Dispatchable Solar

- Storage (hours, not days) time-shifts solar – fully dispatchable
- Adds **Firm Generation Capacity** Value







Flexible & Dispatchable Solar … Key to Market Expansion & Value Retention

Key Messages – Grid Flexibility from Utility-Scale PV Plants

- Higher penetration of VRE (Variable Renewable Energy) need *Increased System Flexibility* to manage in variability and uncertainty on the grid and VRE curtailment

- Utility-scale PV Plants Can Provide *Grid Flexibility & Essential Reliability Services*

- "VREs with *the right operating characteristics* are necessary to decarbonize the grid" … CAISO

Source: Using Renewables to Operate A Low-Carbon Grid, CAISO, NREL, First Solar Report.
http://www.caiso.com/Documents/TestsShowRenewablePlantsCanBalanceLow-CarbonGrid.pdf

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