A Solar Industry Perspective on *Beyond LCOE*

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Key Takeaways – A Solar Industry Perspective on *Beyond LCOE*

- Higher penetration of VRE (Variable Renewable Energy) *leads to VRE curtailment … reducing energy value…increasing LCOE*
- Utility-scale PV Plants Can Provide *Grid Flexibility & Essential Reliability Services* that adds value beyond LCOE
- "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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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

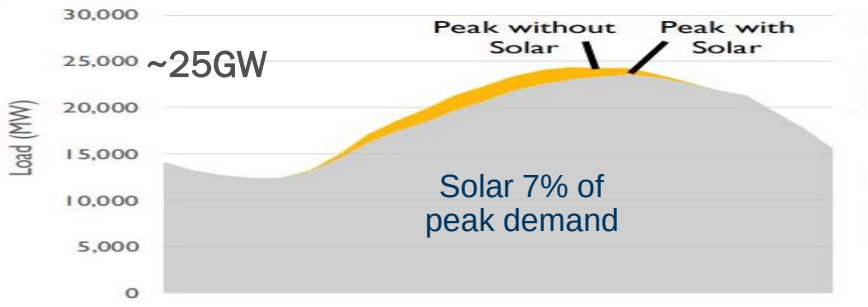
SEPTEMBER 4, 2018 JOHN WEAVER

The duck curve comes to New England

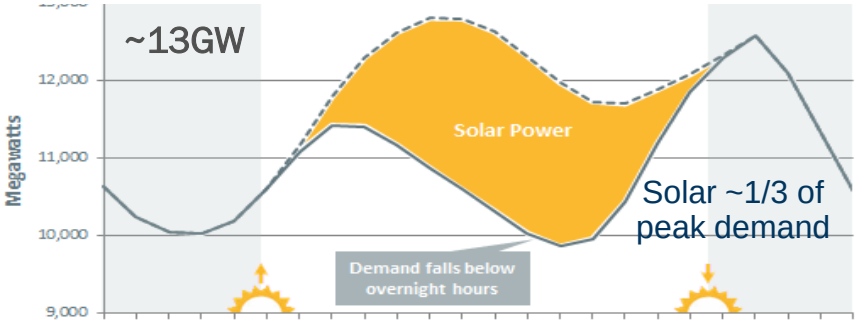
- Electricity price -$2.65/MWh at 3 PM.

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

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/

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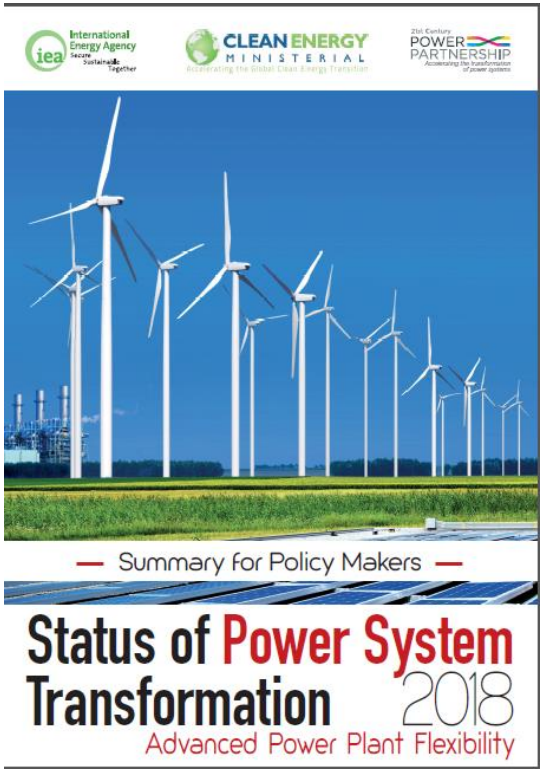
Power System Transformation … *Need Higher Level of System Flexibility*

- Low-cost Variable Renewable Energy (VRE) & electrification drive change in power system planning and operations
- *Increased system flexibility is needed* to manage variability & uncertainty in both supply & demand in a cost-effective and reliable manner
- *Poor system flexibility* can increase curtailment of VRE and reduce resiliency



Source:"Status of Power System Transformation", 2018, IEA Report, https://webstore.iea.org/status-of-power-system-transformation-2018
VRE: Variable Renewable Energy

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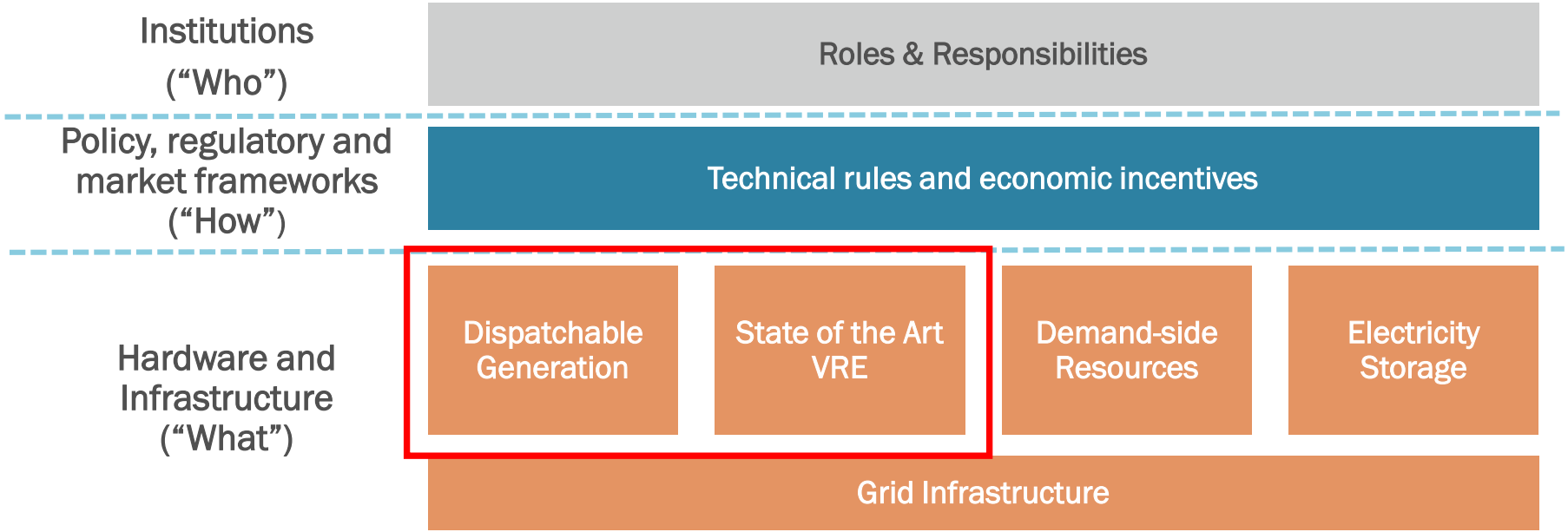
Relevant Dimension for Understanding and Unlocking System Flexibility



Source:"Status of Power System Transformation", 2018, IEA Report, https://webstore.iea.org/status-of-power-system-transformation-2018
VRE: Variable Renewable Energy

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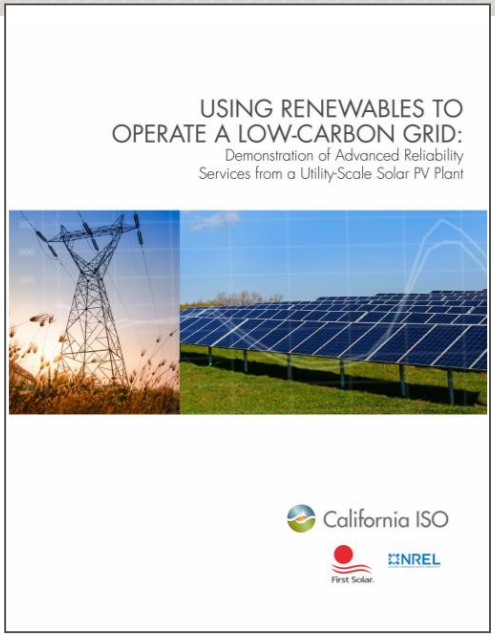
Can Solar Provide Essential Reliability Services?

- NERC identified essential reliability services to integrate higher levels of renewable resources, including:
  - Frequency Control
  - Voltage Control
  - Ramping capability or flexible capacity
- Reduces need for services from conventional generation
  - Goes beyond simple PV energy value
  - Enables additional solar
  - Reduces need for expensive storage

CAISO: "Grid Friendly Utility-Scale PV Plants are Essential for Large-Scale PV Integration"



2018 Intersolar Outstanding Project Winner

California ISO

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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

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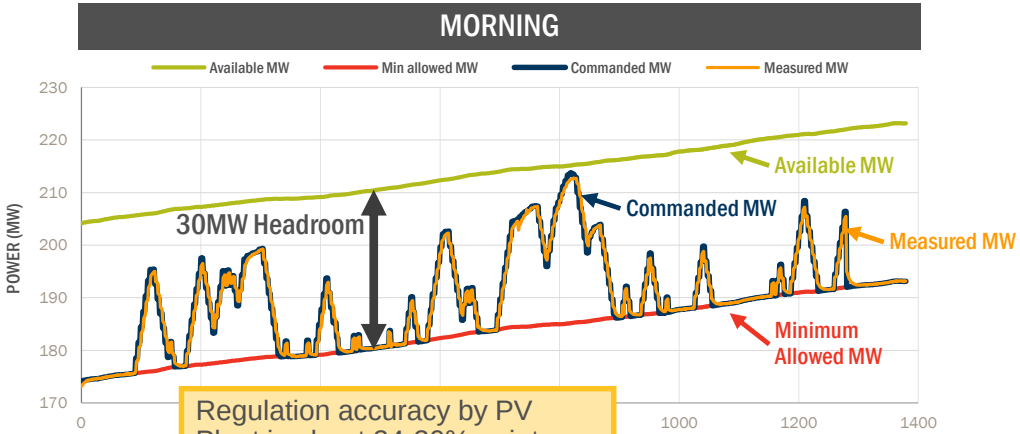
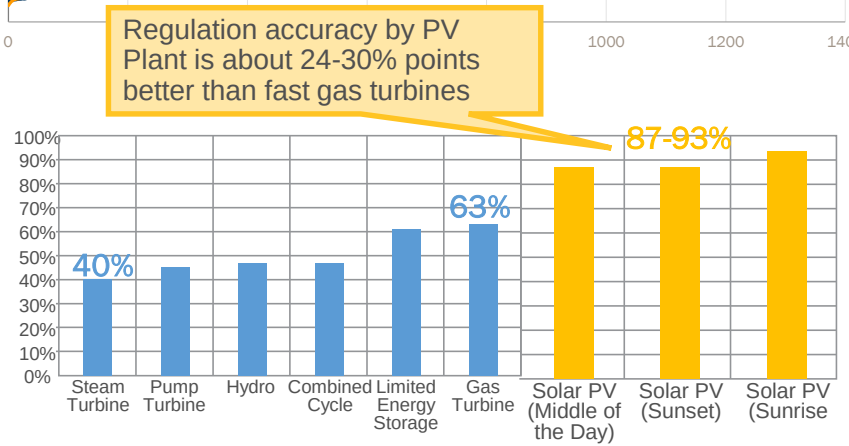
AGC (Automated Generation Control) Tests – 300 MW Utility-Scale PV Plant





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

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Dispatachable ("Flexible") Solar Maintains Value with Increased Penetration

Energy+Environmental Economics

TECO ENERGY AN EMERA COMPANY

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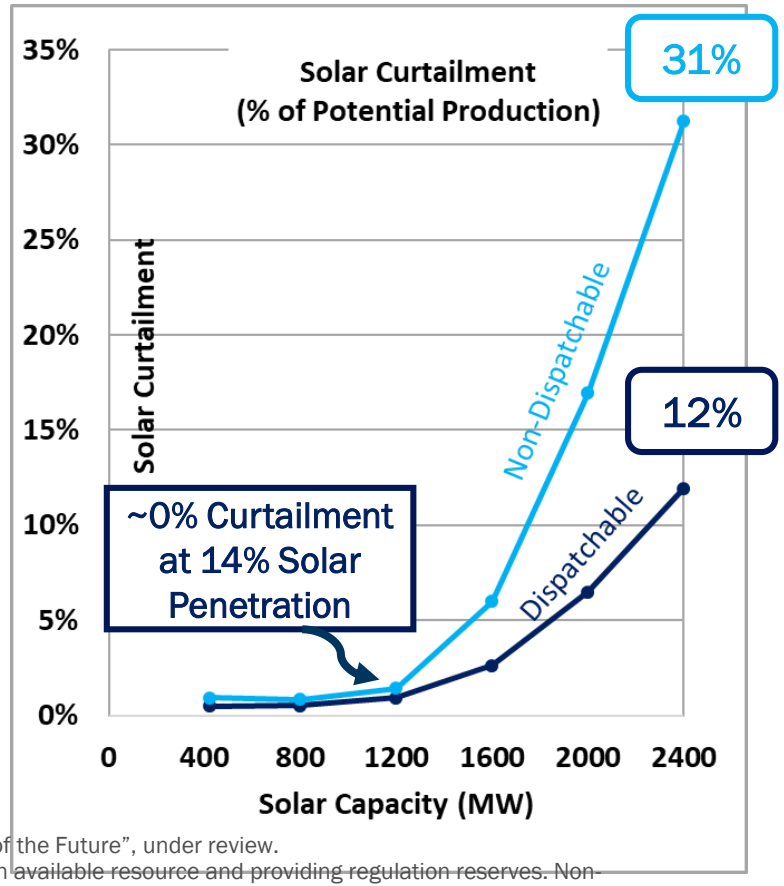
E3/TECO/FS Study Goal

- To quantify value of dispatchable (flexible) solar at an **integrated utility (~5GW peak) adding solar** to its generation portfolio

Key Study Results

- 2019 thermal fleet has **adequate flexibility** to integrate up to of 14% penetration of solar (1,200MW) **with nearly zero solar curtailment**
- Solar curtailment **rapidly increases to 31%** by doubling solar penetration (at 2,400MW)
- Dispatchable solar **reduces curtailment to 12%** (i.e. retains higher value even)



Source: E3,TECO, First Solar Report "Dispatchable Solar: The Key to Unlocking the Clean Energy Grid of the Future", under review.
Dispatchable or Grid Flexible Solar: operating solar plants at an optimal point which may be lower than available resource and providing regulation reserves. Non-dispatacbable solar refers to where solar plant is only used to avoid oversupply and not provide any reserves.

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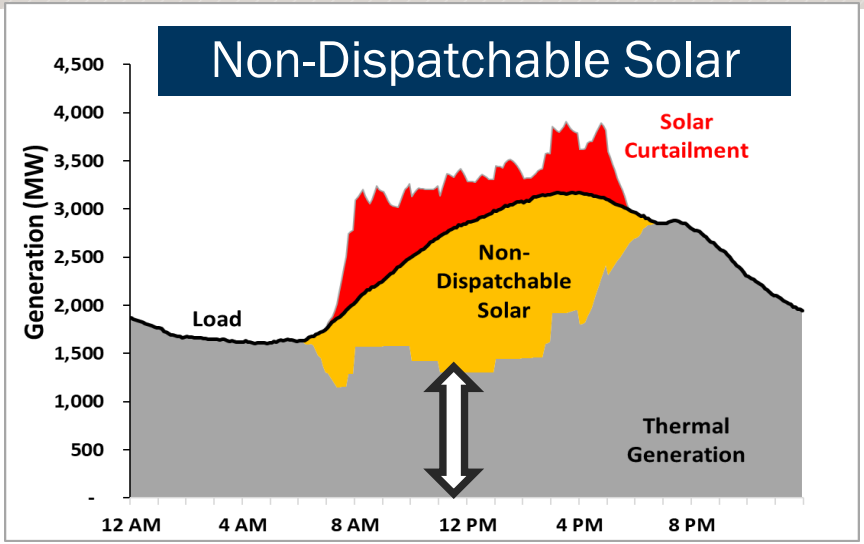
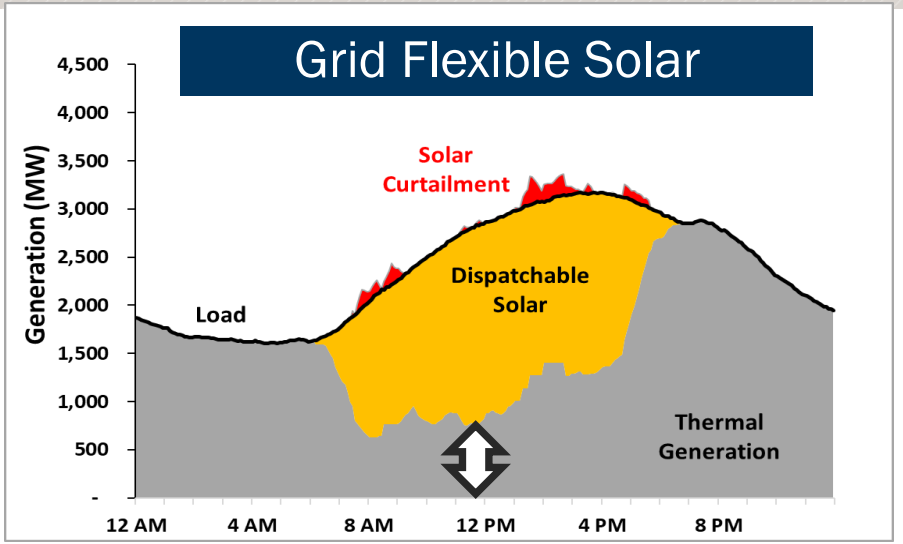
“Grid Flexible” Solar Reduces Curtailment – An Illustration





- 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

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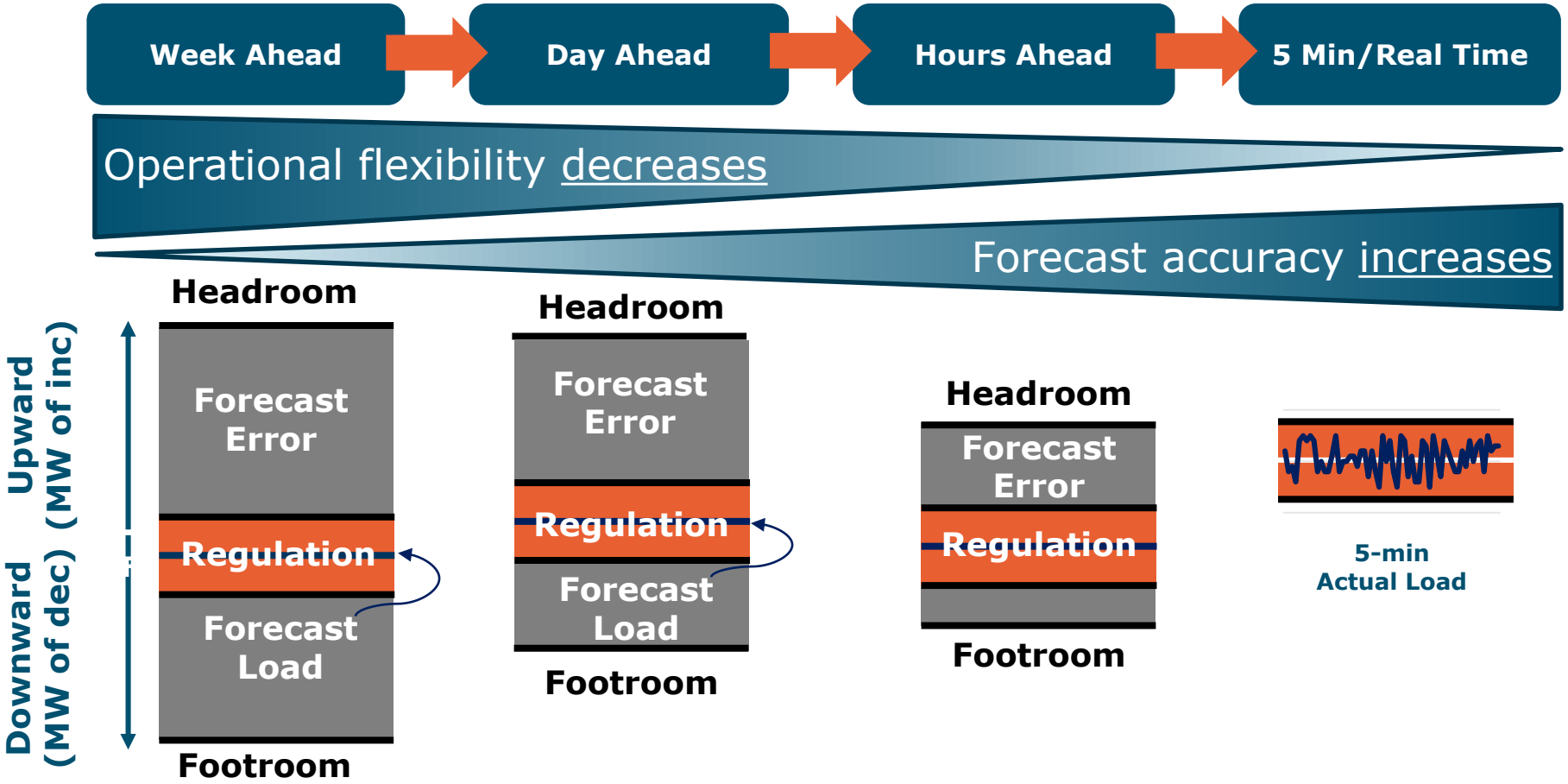
Head Room and Foot Room Released Closer to Real-Time



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“Dispatchable or Grid Flexible” Solar Contributes to Reserves

A:Thermal Generation Only

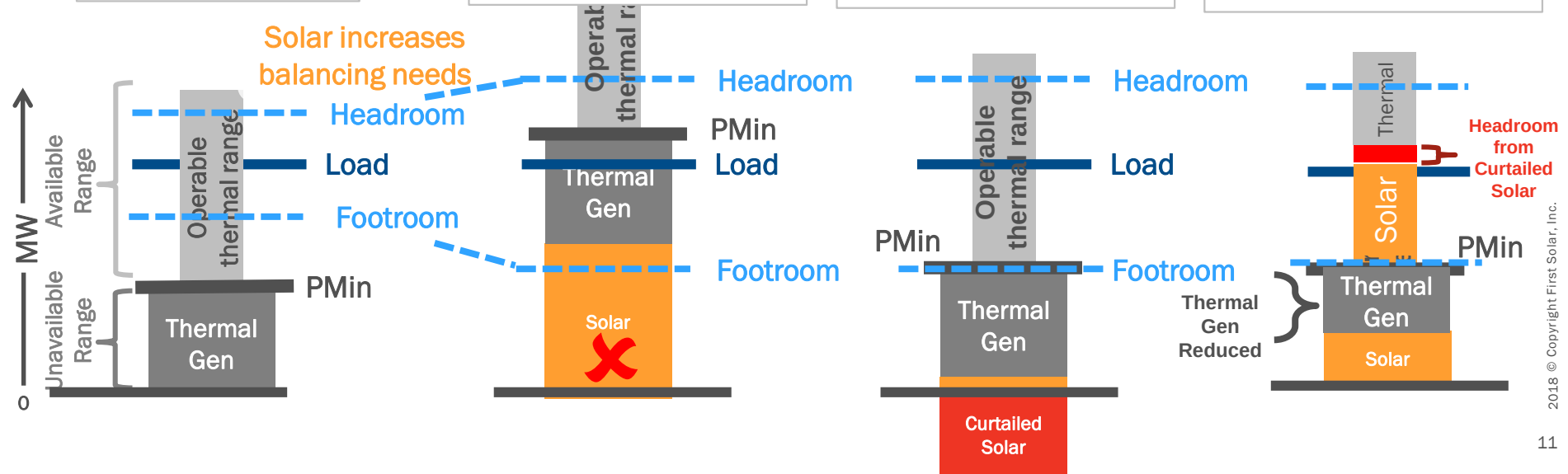
Required Headroom and Footroom fit within generation fleet available range

High Solar Penetration

Must-Run Solar Infeasible:
Minimum thermal dispatch (PMin) *above* footroom -- no feasible range available

Non-Dispatchable Solar Feasible:
Solar does not contribute to headroom and footroom range

Dispatchable Solar Optimal:
Solar contributes to footroom to headroom range



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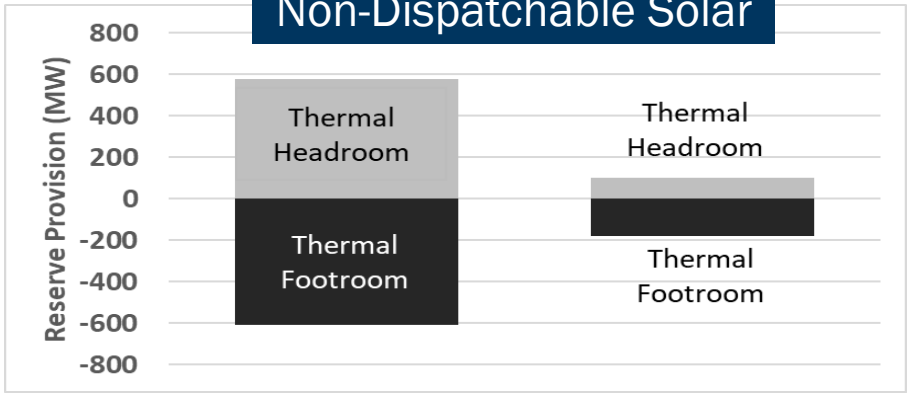
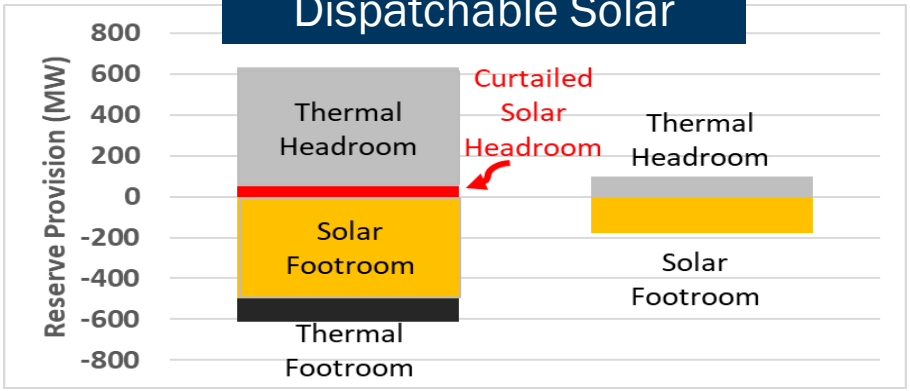
Example of Reserves & Resource Commitments on A Spring Daytime Hour

Non-Dispatchable Solar



Hours Ahead → **5 Min/Real Time**

Dispatchable Solar



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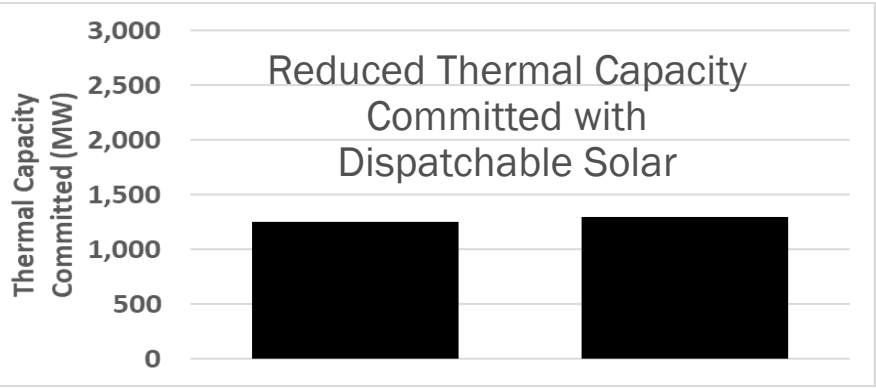

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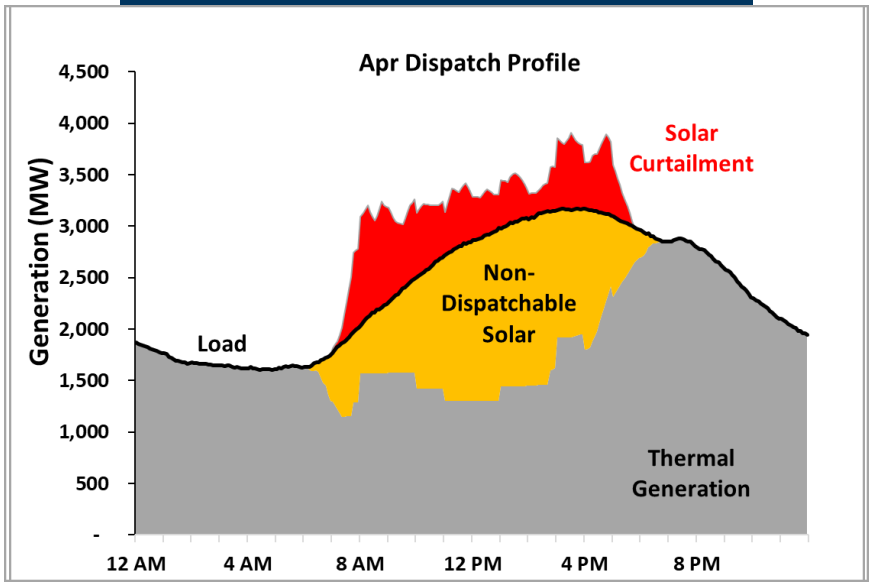
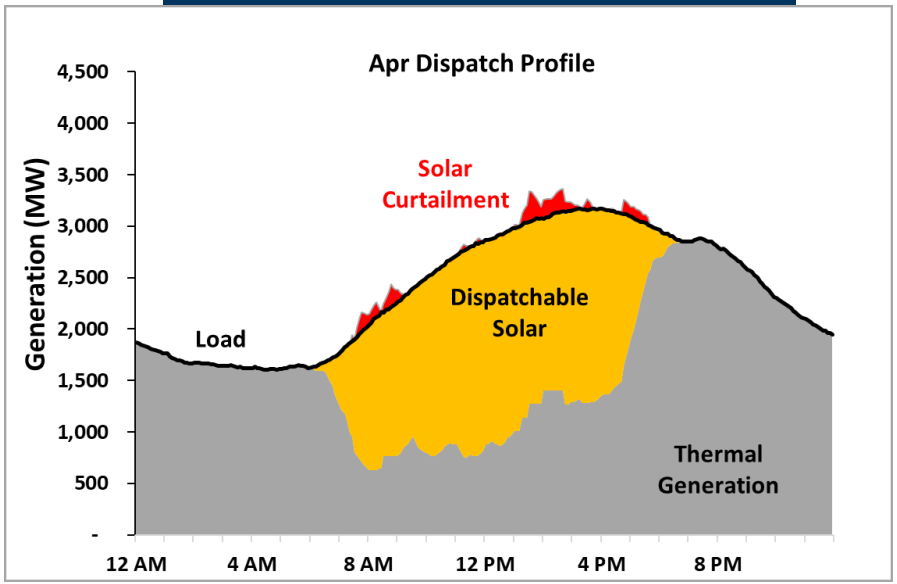
Comparison of Dispatch Profiles Over The Year (Animated)

Non-Dispatchable Solar



Grid Flexible Solar



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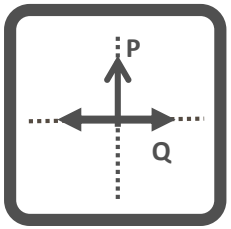
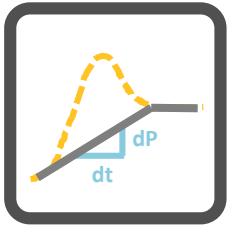
Role of Storage? … Further Enhances Grid Capability of PV Plant

Voltage Support



Ramp Control



Power Regulation

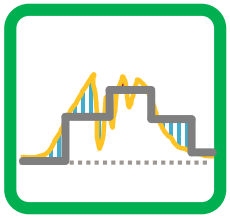
- AGC
- Up-Regulation
- Down-Regulation
- Frequency Regulation

Base Capability

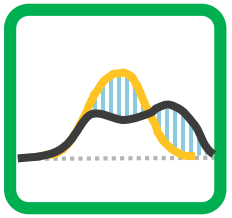
Grid Reliability Services

\+

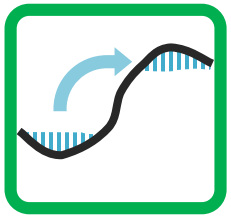
Capacity Firming



Energy Shifting



Flexibility



Grid Capabilities Enhanced with Storage

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Better Integration And Scale Through Flexibility

Solar Energy

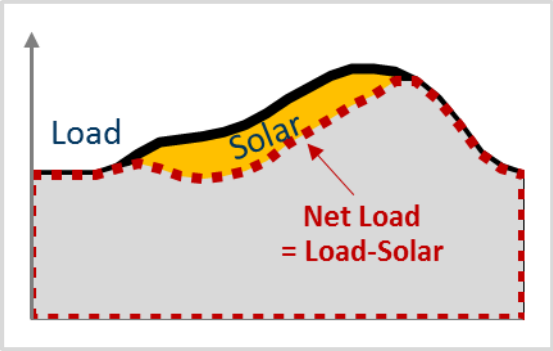
- Solar is part of mid-day load offsets peak or near-peak demand
- Energy-Only Value

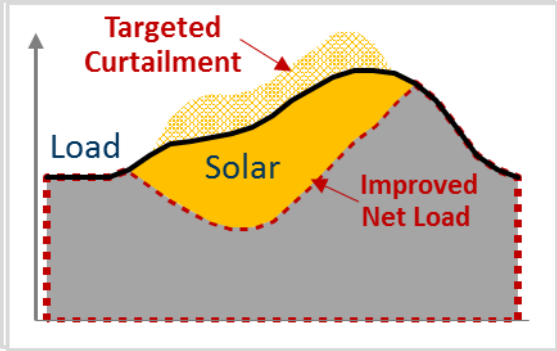
Grid Flexible Solar

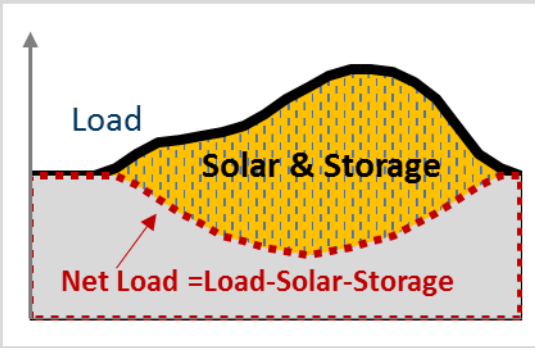
- Adds Grid Reliability Services & Flexibility Value

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 Takeaways – A Solar Industry Perspective on *Beyond LCOE*

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