The Role of Solar in Clean Energy Transition

Mahesh Morjaria, Ph.D.
VP, PV Systems Development

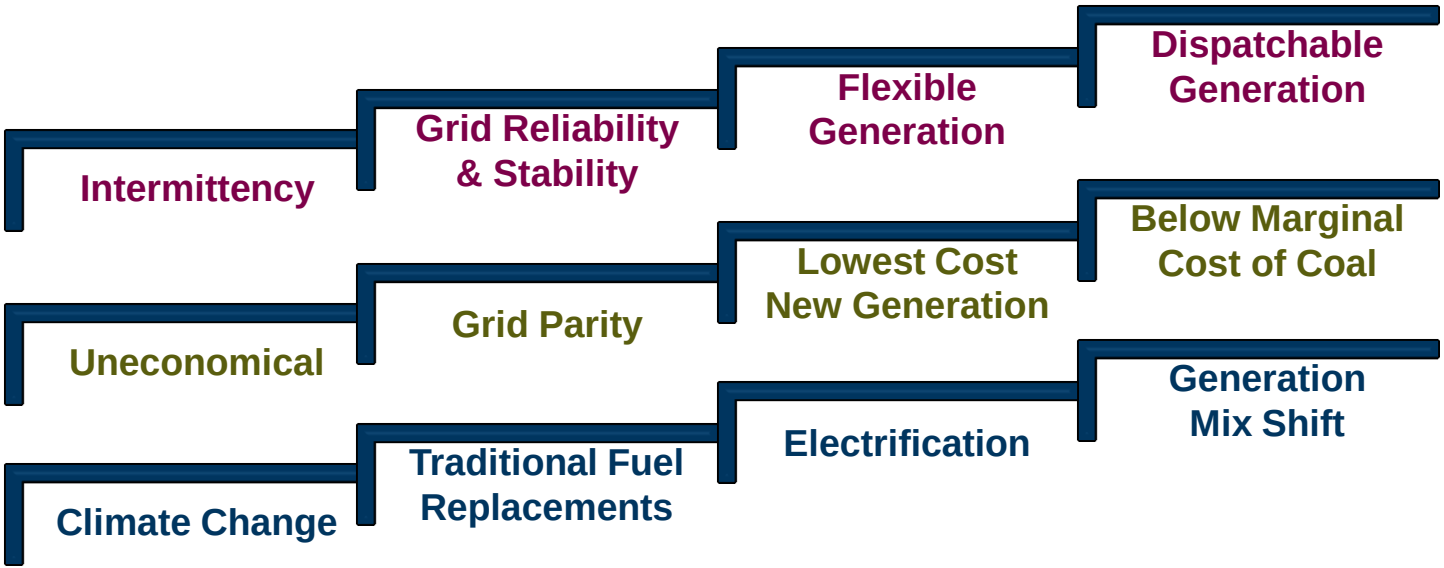
Amit Mehata,
Country Manager, India
July 29, 2019

First Solar®

LEADING THE WORLD'S SUSTAINABLE ENERGY FUTURE

Solar as a Strategic Resource

Progress Towards Making Solar a Strategic Resource



SOLAR Resource
23,000 TWy
per year

Source: R. Perez et al, "Renewable Energy Our Solar Future"

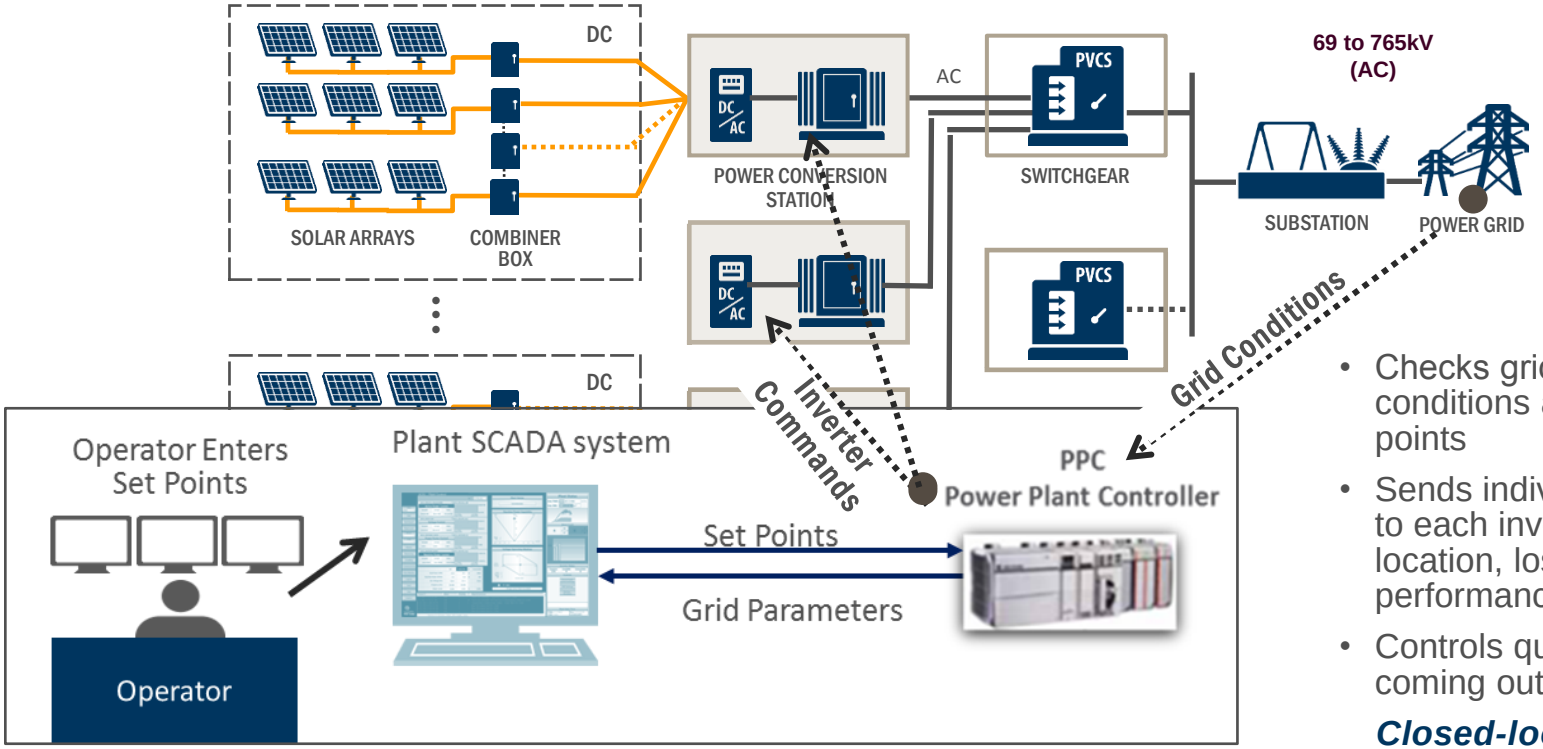
Solar Power Provides Energy, Flexibility and Capacity

- Utility-scale PV Solar **contributes to Grid Stability & Reliability**
- Utility-scale PV Plants provides **Essential Reliability Services** & **Grid Flexibility**
- Combined with **Storage**, Solar provides Clean & Competitive **Firm Capacity**

Can Solar Contribute to Grid Stability & Reliability?

Plant Control System Enables Grid Friendly Features

Sunlight to DC Power → DC Power to AC Power → AC Power to Grid



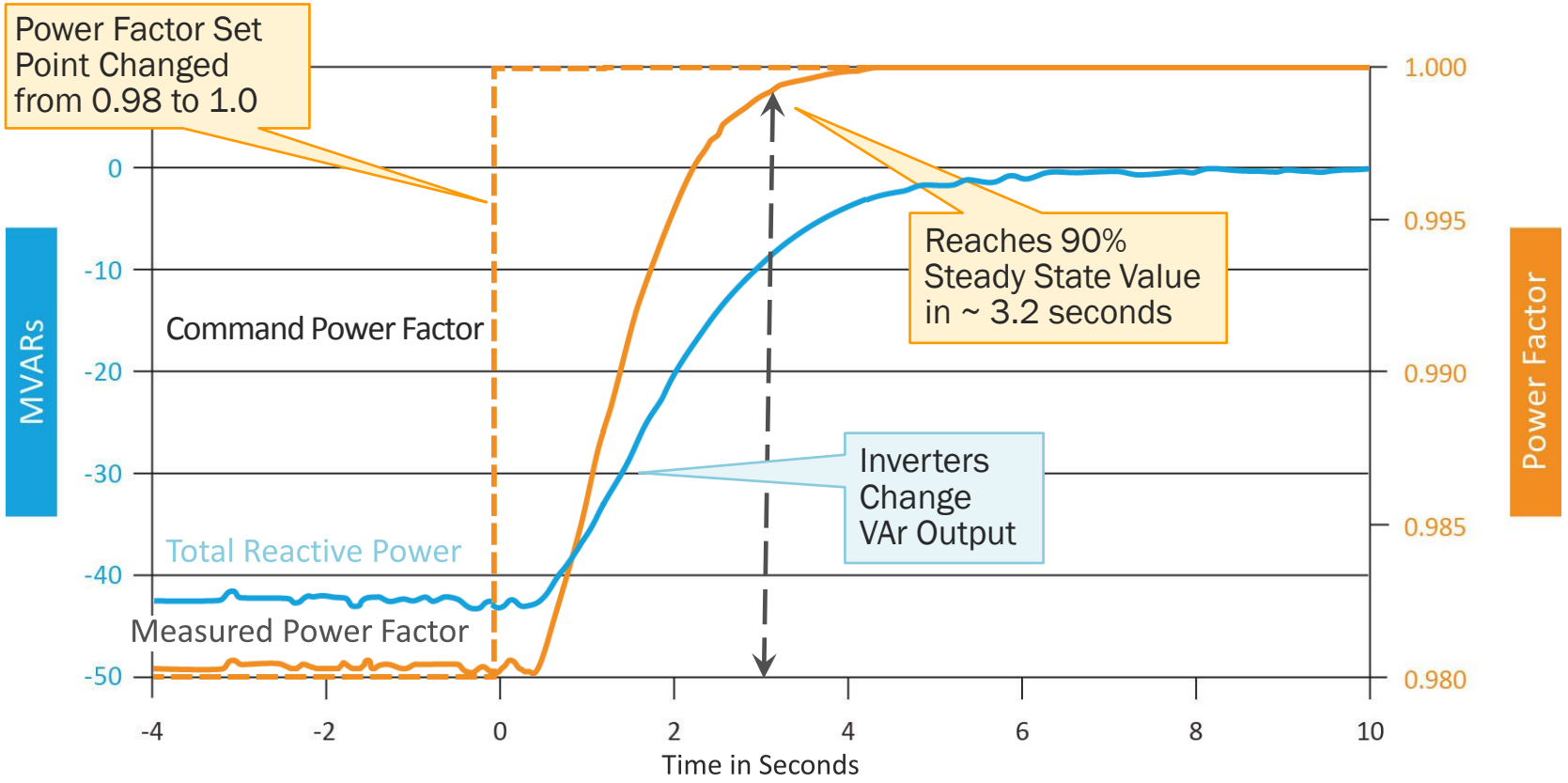
- Checks grid's actual conditions and required set points
- Sends individual instructions to each inverter based on location, losses, and performance
- Controls quality of power coming out of the PV plant

Closed-loop controls at 100 milliseconds!

Patent No. 8,774,974. Real-time photovoltaic power plant control system

Dynamic Power Factor Regulation

Excellent Reactive Power Dynamic Control

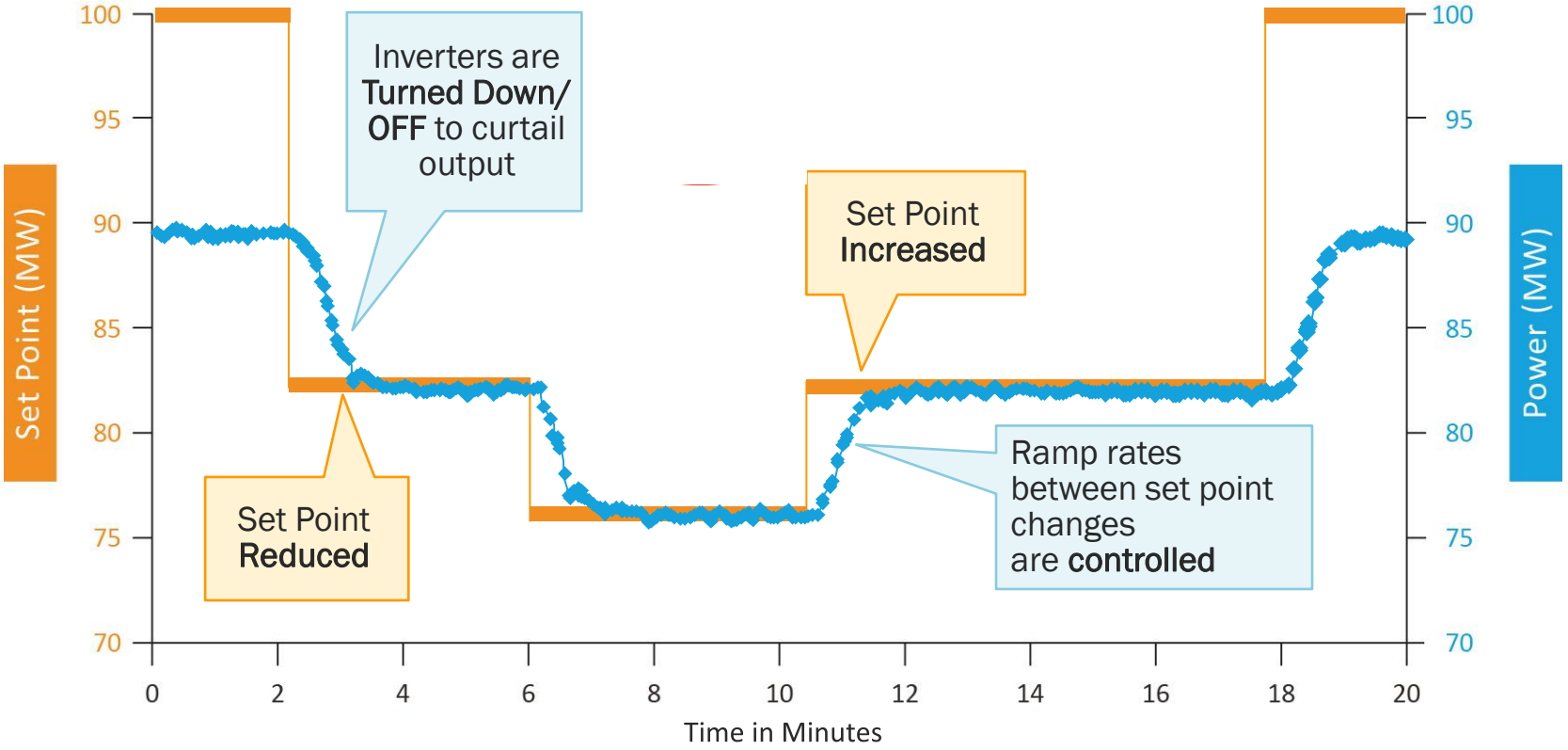


- Source: Agua Caliente PV Plant in Yuma, Arizona, USA May 23, 2012. ~212MW on-line.

Plant Curtailment Test

Excellent Control over Active Power

- Power Curtailment at Different Levels

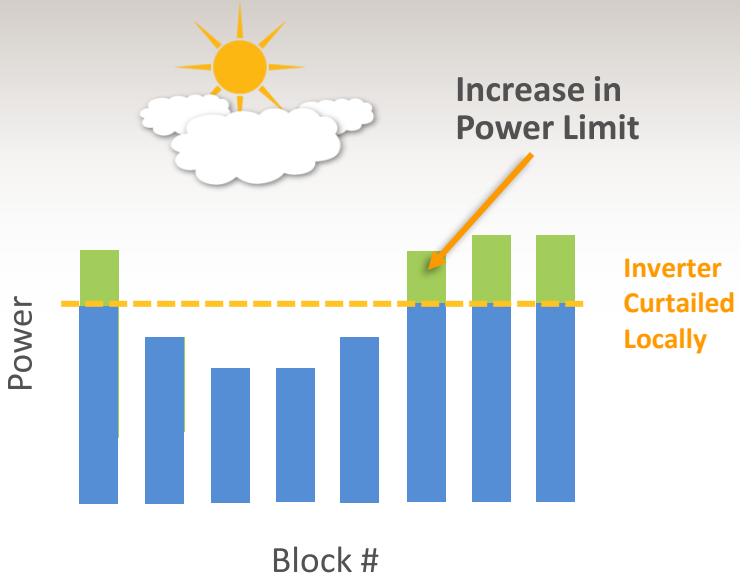


- Source: Agua Caliente PV Plant in Yuma, Arizona, USA March 13, 2012. ~90MW on-line.

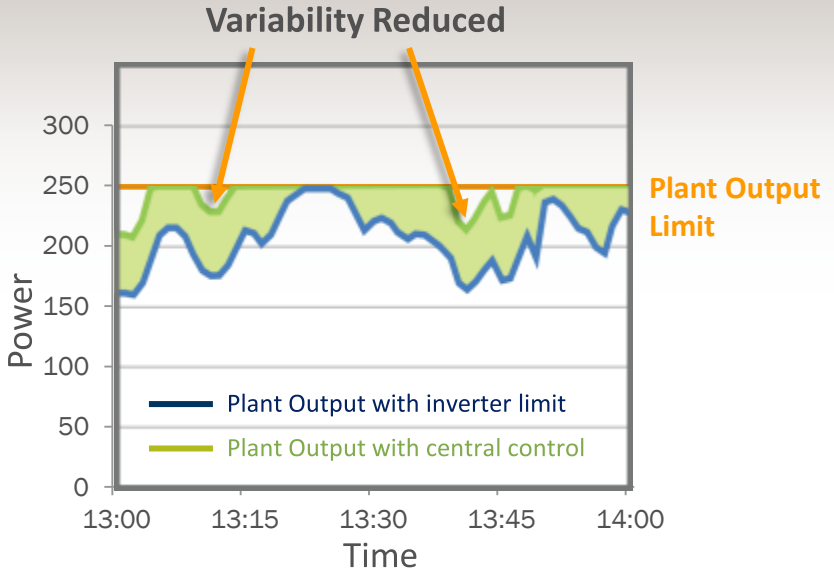
Benefit of Plant Level Control System

With a central control system, inverters are individually controlled when needed to meet the plant limit …

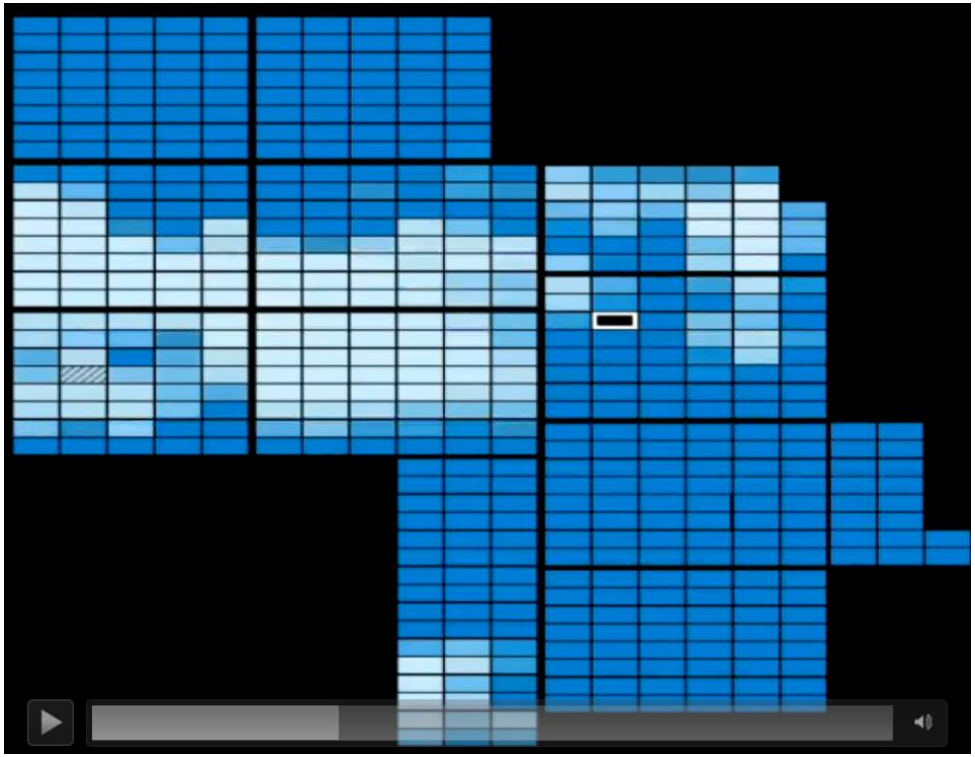
Output of Each Block

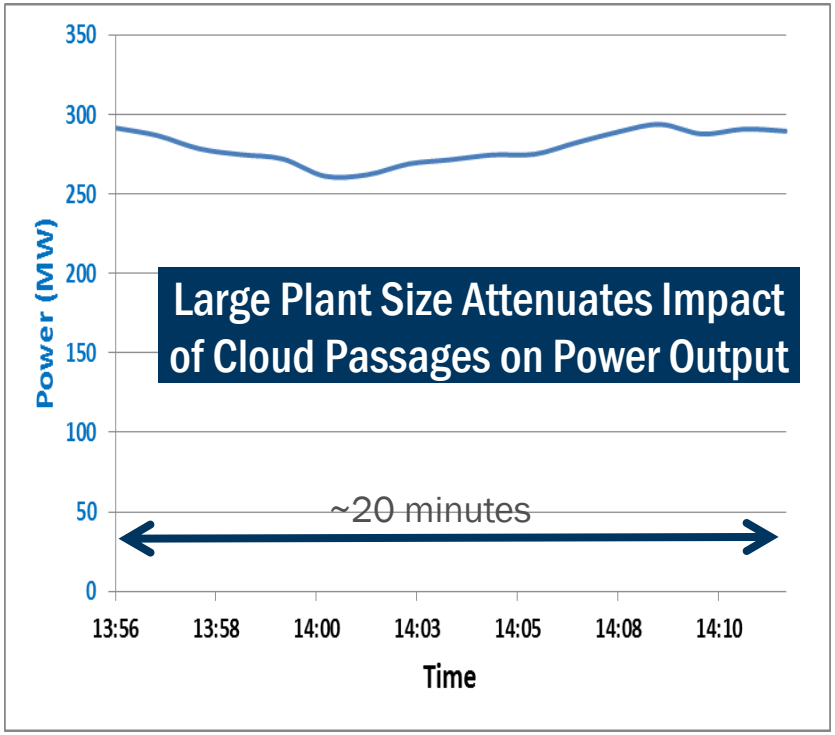


Plant Output Power



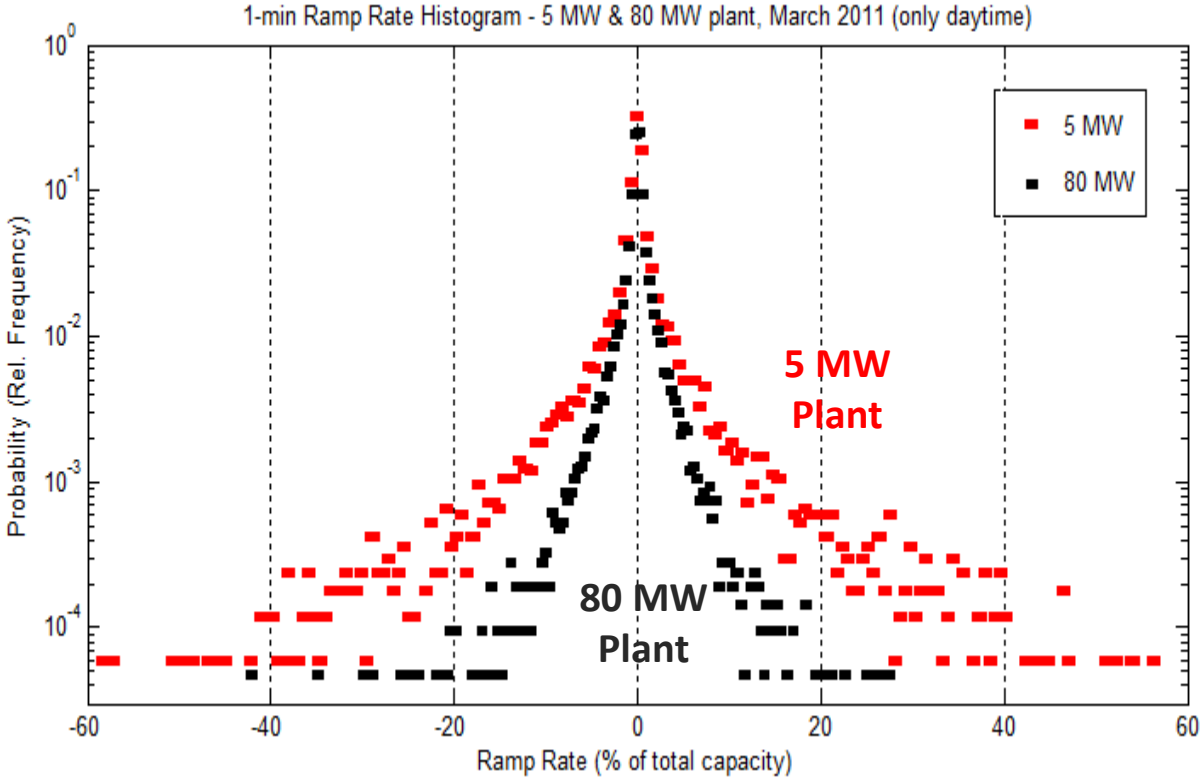
Geographic Dispersion Attenuates Short-Term Intermittency





Intermittency

One-Minute Ramps for 5 and 80 MW Plants



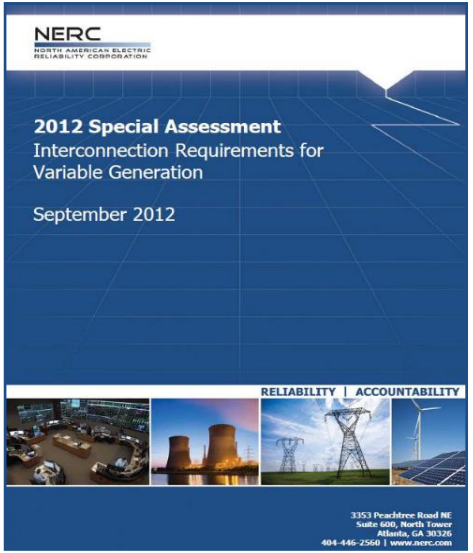
Source: Empirical Assessment of Short-term Variability from Utility Scale Solar-PV Plants
Rob van Haaren, Mahesh Morjaria and Vasilis Fthenakis, 2014

As plants become larger… ramp rates due to passing cloud are attenuated

Utility-Scale Solar Supports Grid Reliability & Stability

Utility-Scale PV Plants Provide Grid Friendly Features Required by NERC:

- ✓ Voltage regulation
- ✓ Real power control, ramping, and curtailment
- ✓ Primary frequency regulation
- ✓ Frequency droop response
- ✓ Short circuit duty control
- ✓ Fault ride through



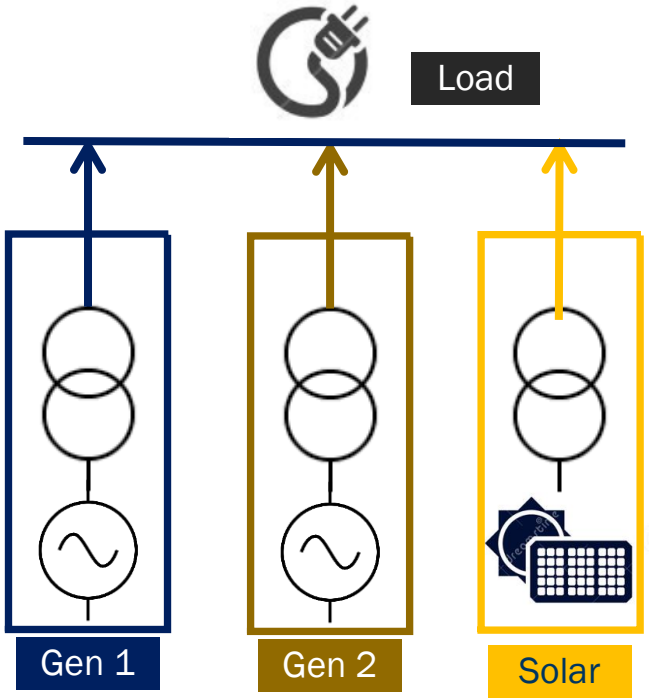
Intermittency

Grid Reliability & Stability

Sources: (1) NERC: 2012 Special Assessment Interconnection Requirements for Variable Generation
(2) M. Morjaria, D. Anichkov, V. Chadliev, and S. Soni. "A Grid-Friendly Plant." *IEEE Power and Energy Magazine* May/June (2014)

Can Solar Contribute to System Flexibility?

Simple Example Illustrating Use of Flexible Solar



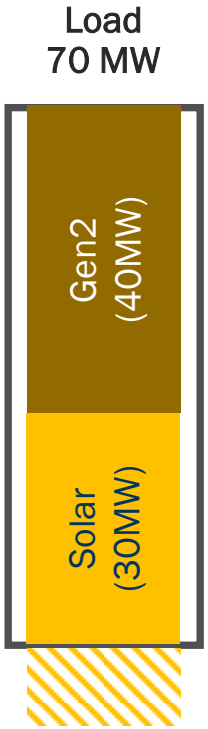
P_{min} = 10MW
P_{max} = 50 MW
Cost = $50/MWh

P_{min} = 40MW
P_{max} = 100 MW
Cost = $30/MWh

P_{max} = 40MW

Thermal Cost
$1,500

More Expensive Generator Has To Be Used Because of Pmin



With Solar Curtailed Less Expensive Generator Can Be Used

10 MW Solar Curtailed

Thermal Cost
$1,200

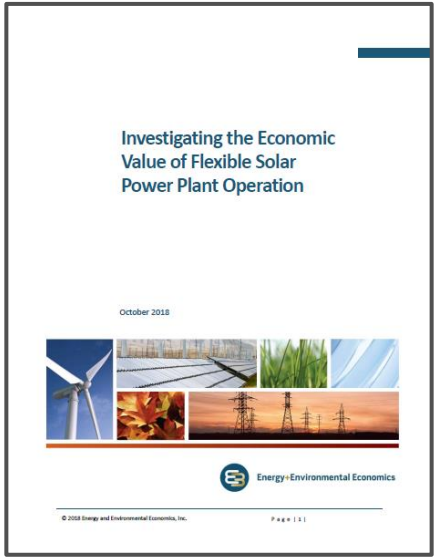
Source: Adapted from "The Hidden Cost of Priority Dispatch for Wind Power", Georgios Patsakis & Shmuel Oren, Being Published in 2019

Can Solar Contribute to System Flexibility?

TECO ENERGY
AN EMERA COMPANY

Energy+Environmental Economics

First Solar®



Source: E3,TECO, First Solar Report “Investigating the Economic Value of Flexible Solar Power Plant Operation”, https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf

.

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

Energy+Environmental Economics

TECO ENERGY AN EMERA COMPANY

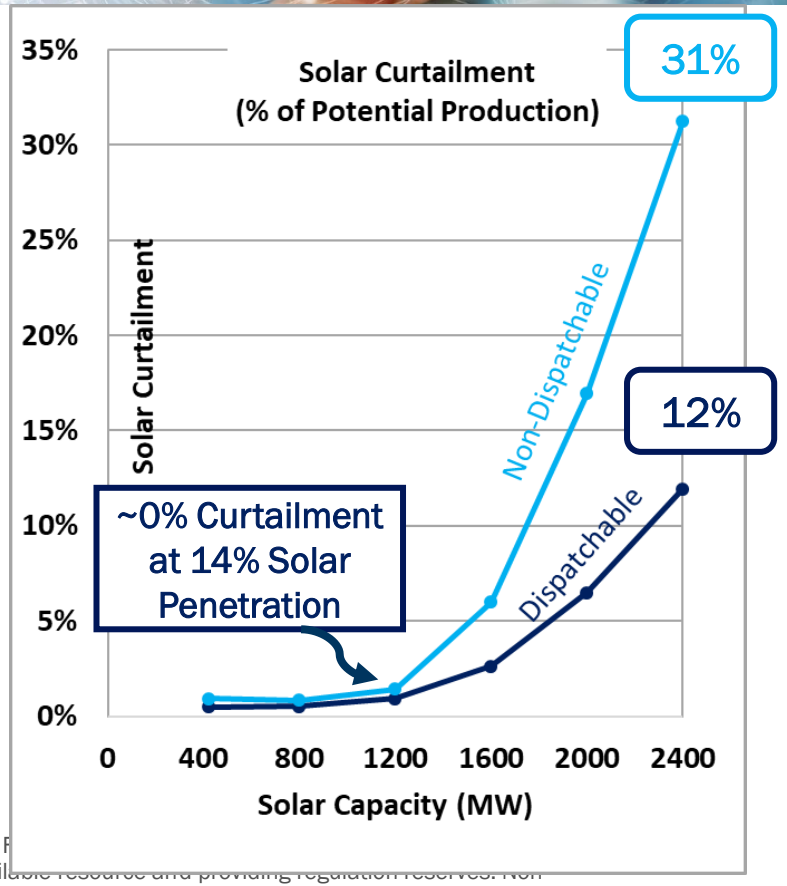
First Solar

E3/TECO/FS Study Goal

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

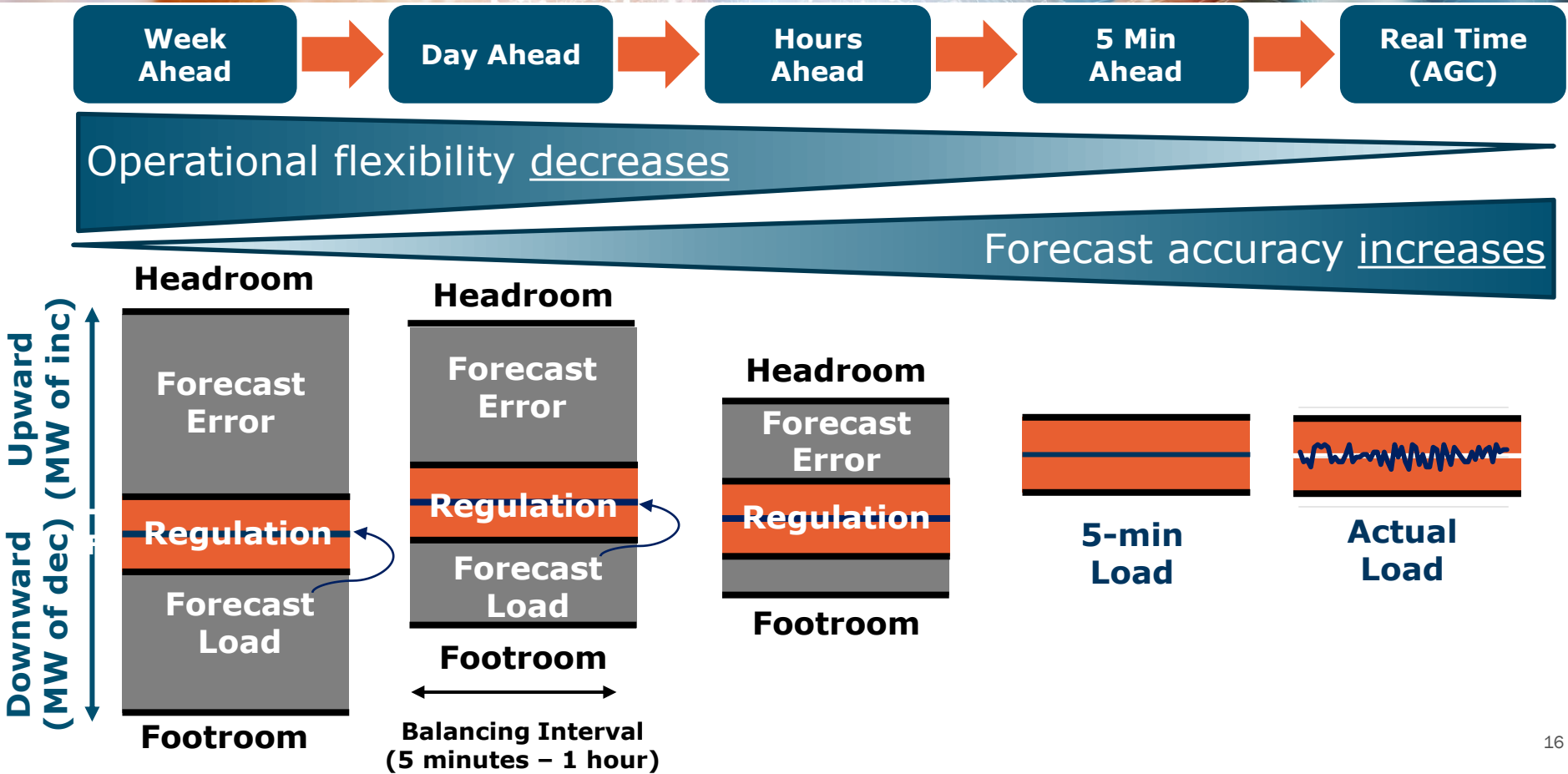
Key Study Results

- 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 at 28% potential penetration)



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

Head and Foot Room are Needed to Ensure Operational Control



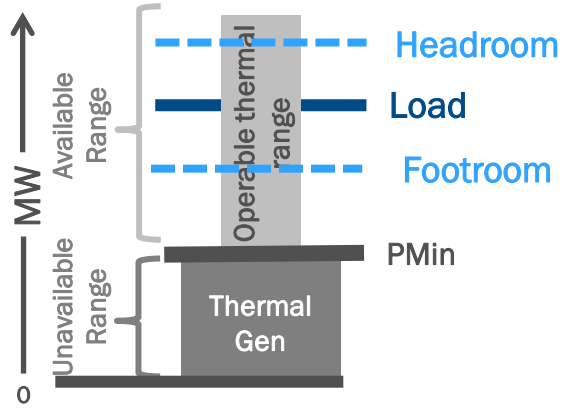
Solar Power Plant Operating Modes

Solar Operating Mode	Solar can be curtailed	Solar can contribute to footroom requirements	Solar can contribute to headroom requirements
Must-take	✗	✗	✗
Curtailable	✓	✗	✗
Downward Dispatch	✓	✓	✗
Full Flexibility	✓	✓	✓

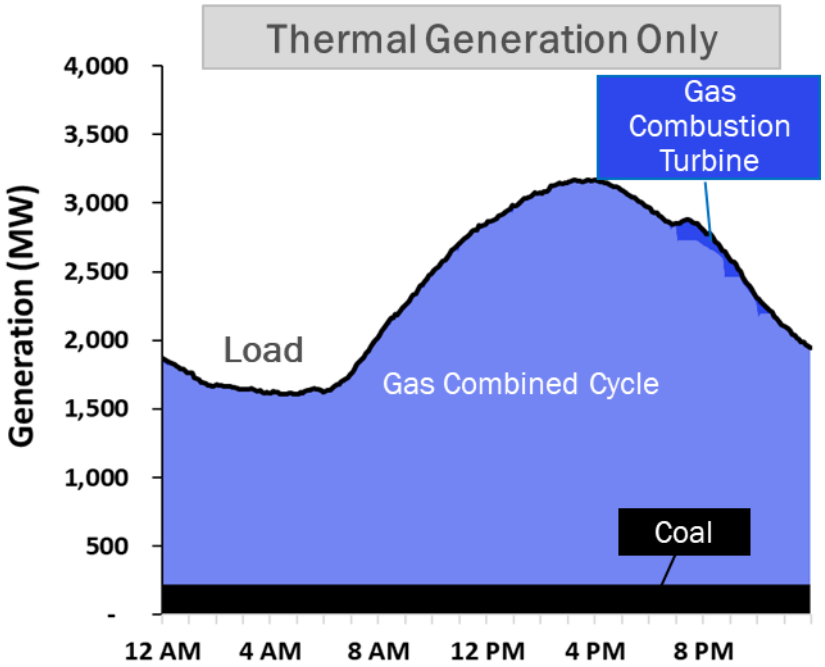
Generation Dispatch For Thermal Generation Only

A:Thermal Generation Only

Required headroom & footroom fit within generation fleet available range

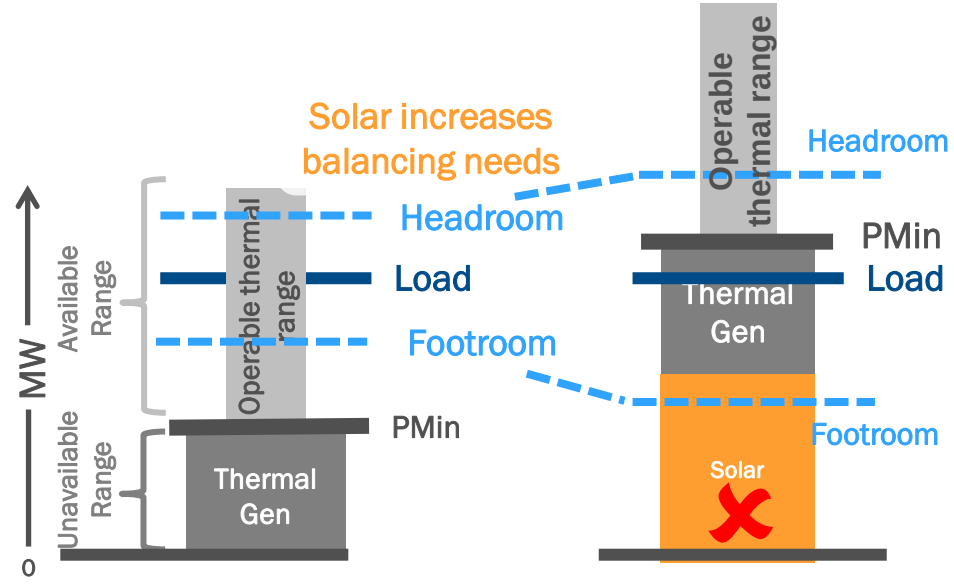


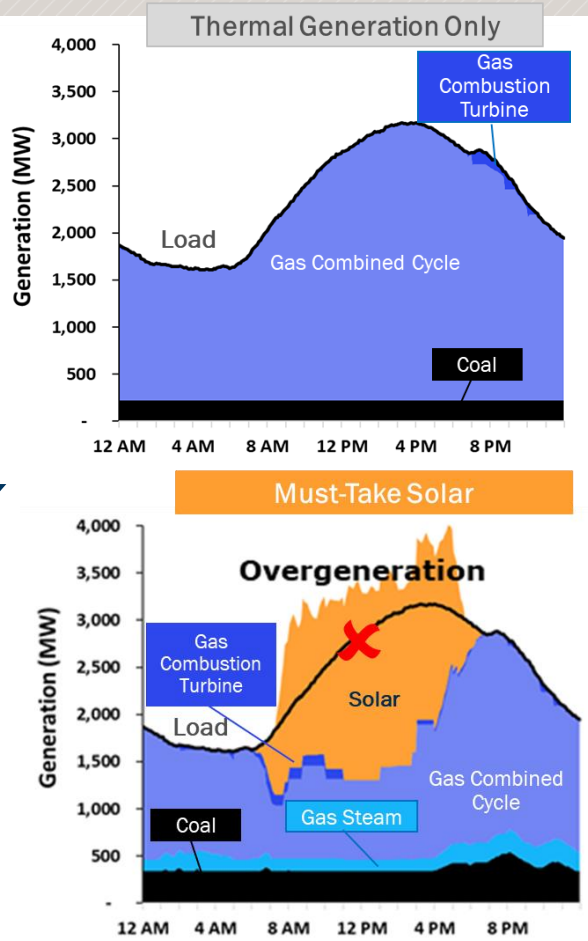
Generation Dispatch on A Spring Day



Generation Dispatch with Must-Take Solar – *Infeasible Under Higher Penetration*

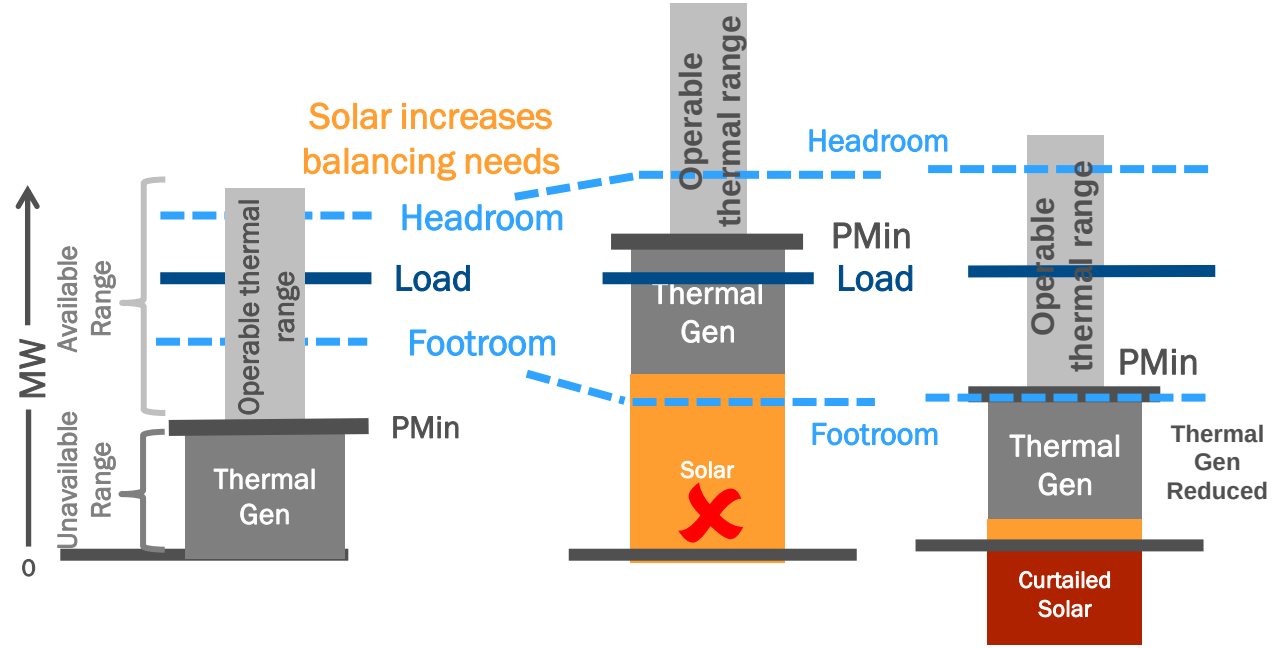
Thermal Generation Only	Must -Take Solar
Required headroom & footroom fit within generation fleet available range	Infeasible: Minimum thermal dispatch (PMin) *above* footroom -- no feasible range available

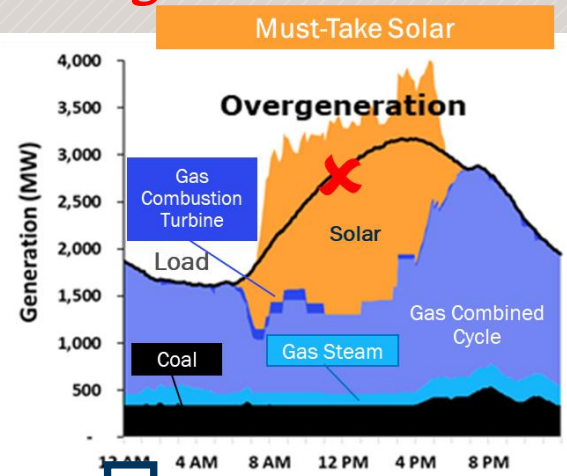


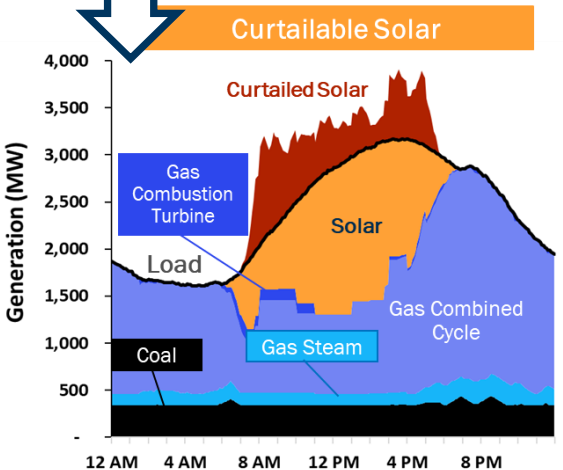


Generation Dispatch with Curtailable Solar – *Feasible but High Curtailment*

Thermal Generation Only	Must -Take Solar	Curtailable Solar
Required headroom & footroom fit within generation fleet available range	Infeasible: Minimum thermal dispatch (PMin) *above* footroom -- no feasible range available	Feasible: Solar is curtailed until thermal dispatch is within operable range







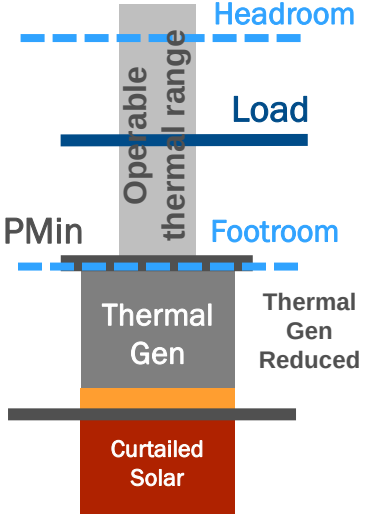
Generation Dispatch with Downward Dispatch Solar – *Increases Value*

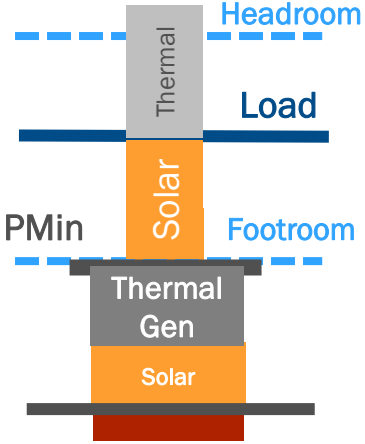
Curtailable Solar

Feasible:
Solar is curtailed until thermal dispatch is within operable range

Downward Dispatch Solar

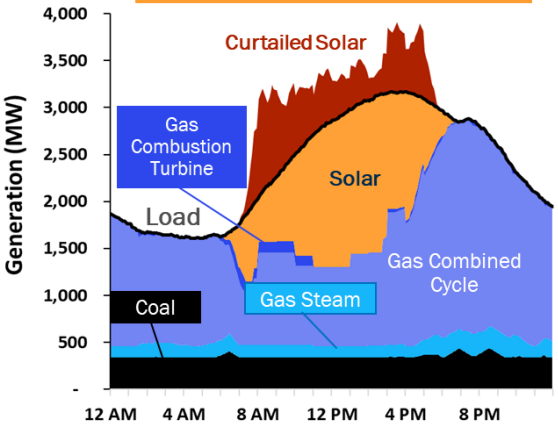
Increased Value:
Curtailment reduced because solar contributes to footroom



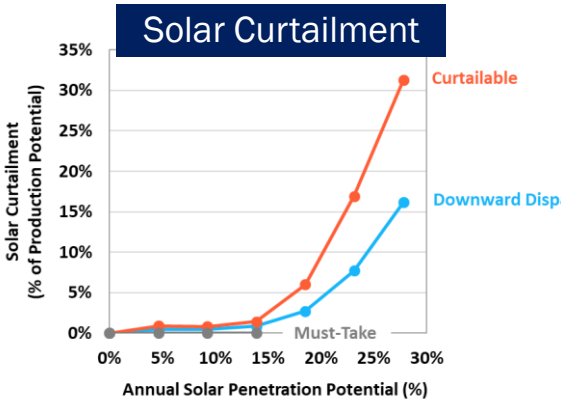


Solar Contributes to Footroom

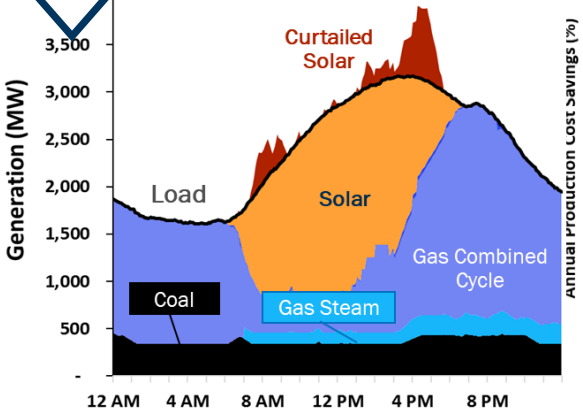
Curtailable Solar



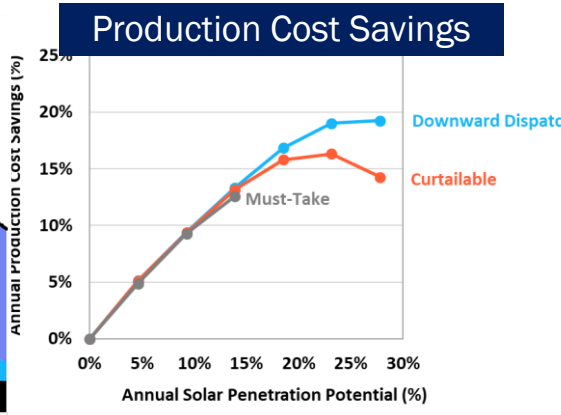
Solar Curtailment



Downward Dispatch Solar



Production Cost Savings



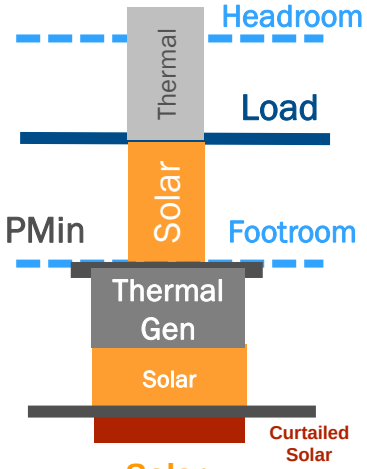
Full Flexibility Dispatch Solar – *Optimizes Value*

Downward Dispatch Solar

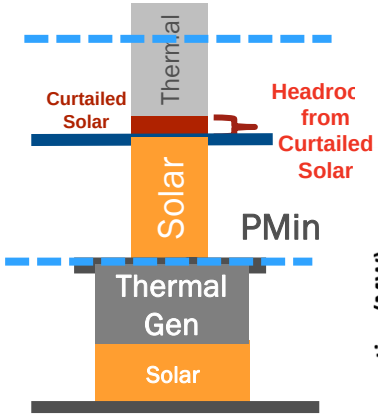
Increased Value:
Curtailment reduced because solar contributes to footroom

Full Flexibility Solar

Optimal Value:
Solar contributes to both footroom & headroom

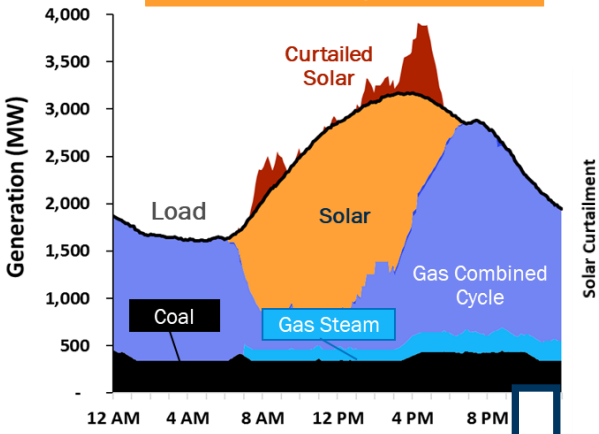


Solar Contributes to Footroom

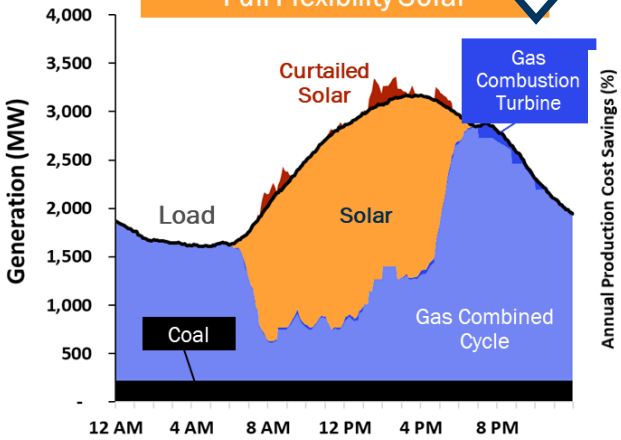


Solar Contributes to Footroom & Headroom

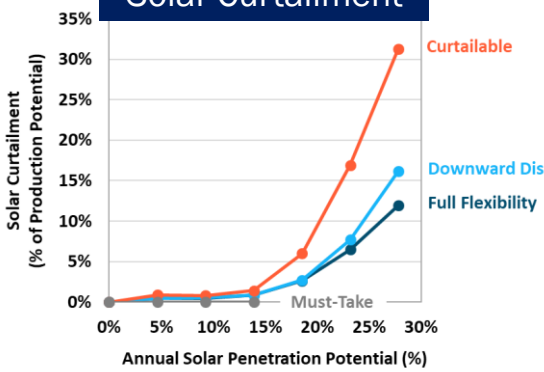
Downward Dispatch Solar



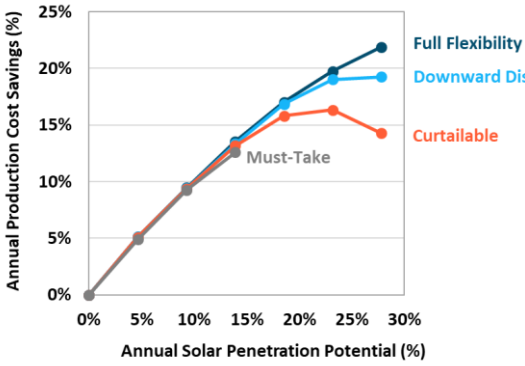
Full Flexibility Solar



Solar Curtailment



Production Cost Savings



“Dispatchable or Grid Flexible” Solar Contributes to Reserves

A:Thermal Generation Only

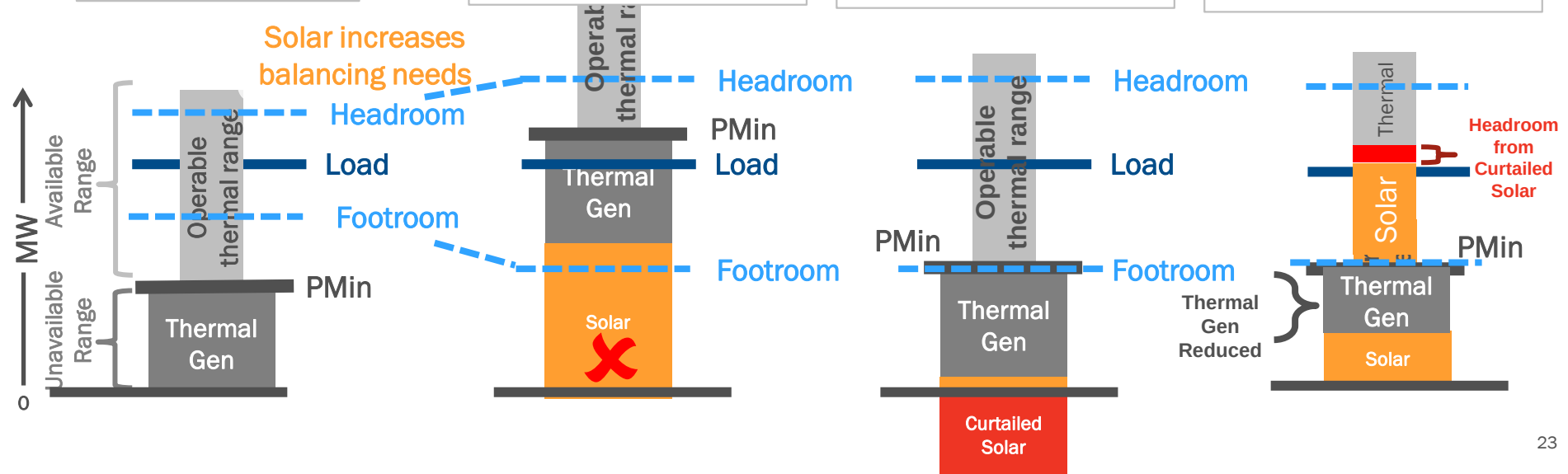
Required Headroom and Footroom fit within generation fleet available range

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

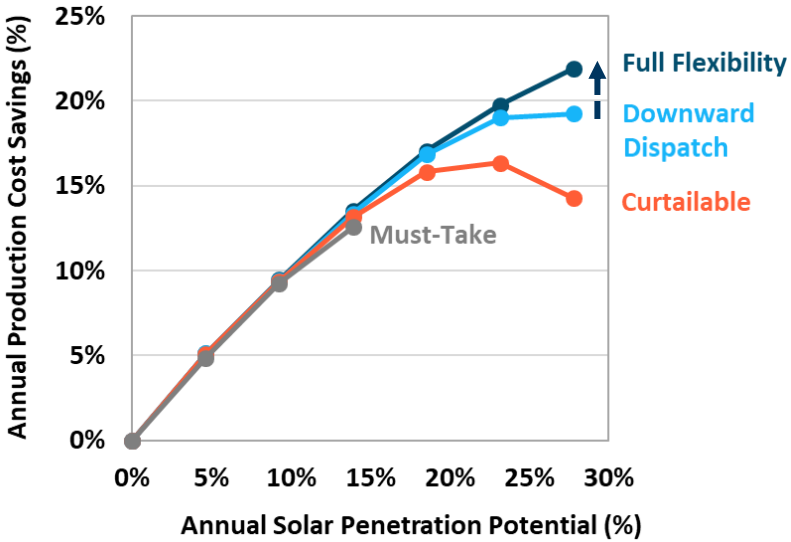
Dispatchable Solar
Optimal:
Solar contributes to footroom to headroom range

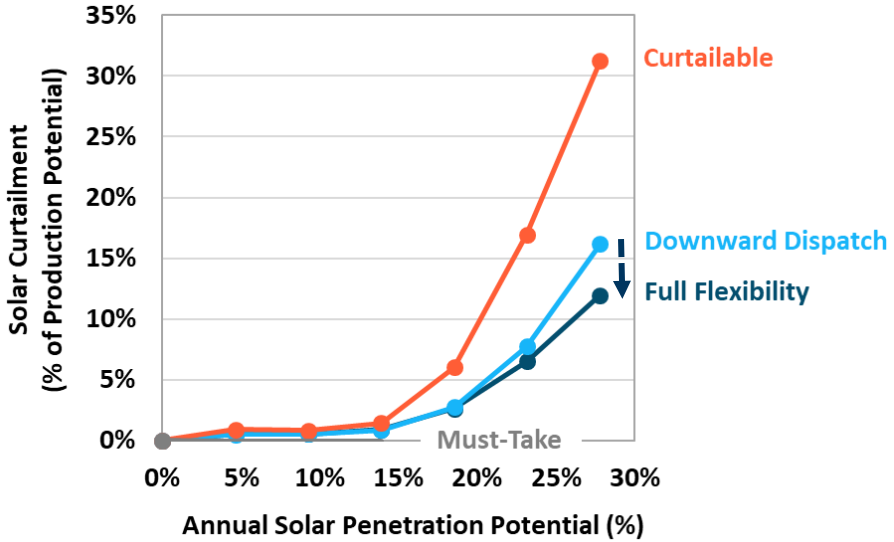


“Full Flexibility” Operating Mode: Additional solar value

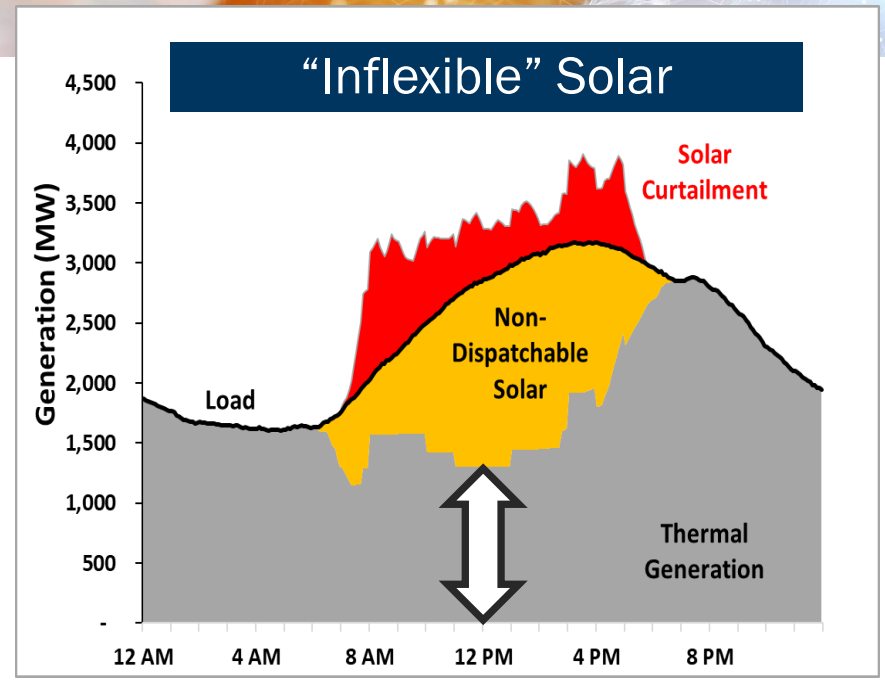
With headroom held on solar, thermal generators operate more efficiently in real time – and in some cases turn off ahead of real time – resulting in less fuel consumption and lower costs

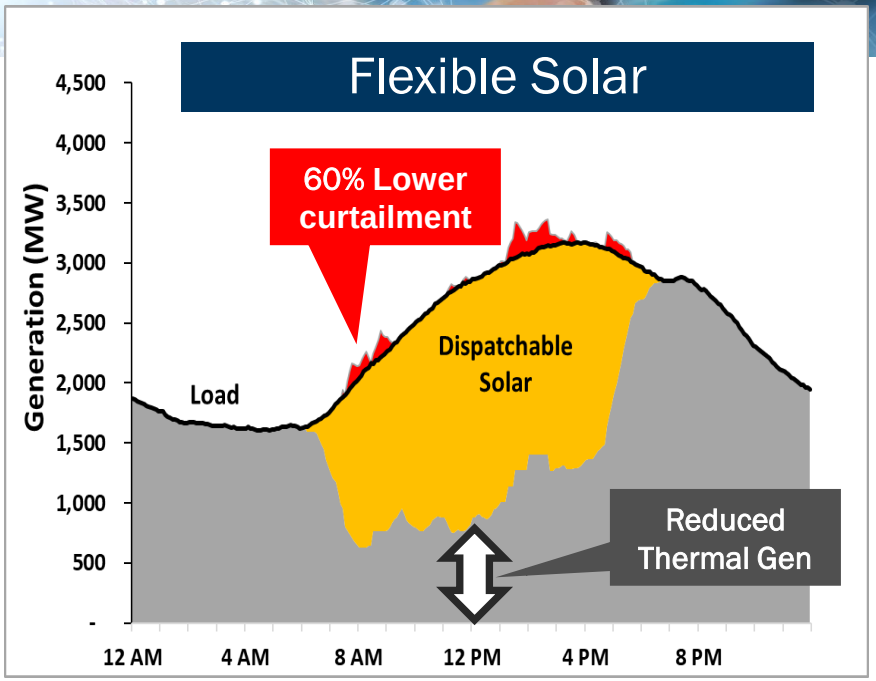
Curtailment is reduced because less thermal generation is necessary to balance the system





Flexible Solar Reduces Curtailment – An Illustration (2,400 MW Solar)





Solar Provides No Regulation Reserves

Flexible Solar: Provides regulation reserves.

Intermittency

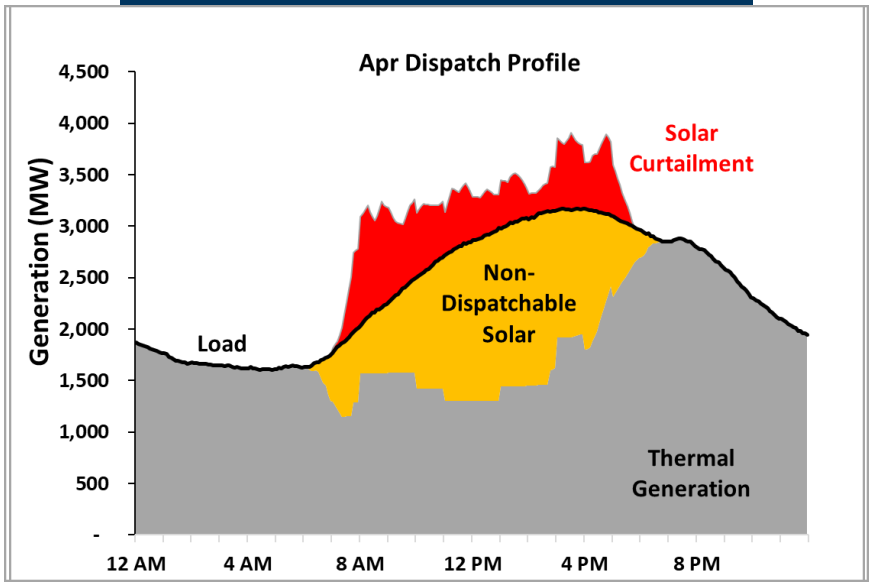
Grid Reliability & Stability

Flexible Generation

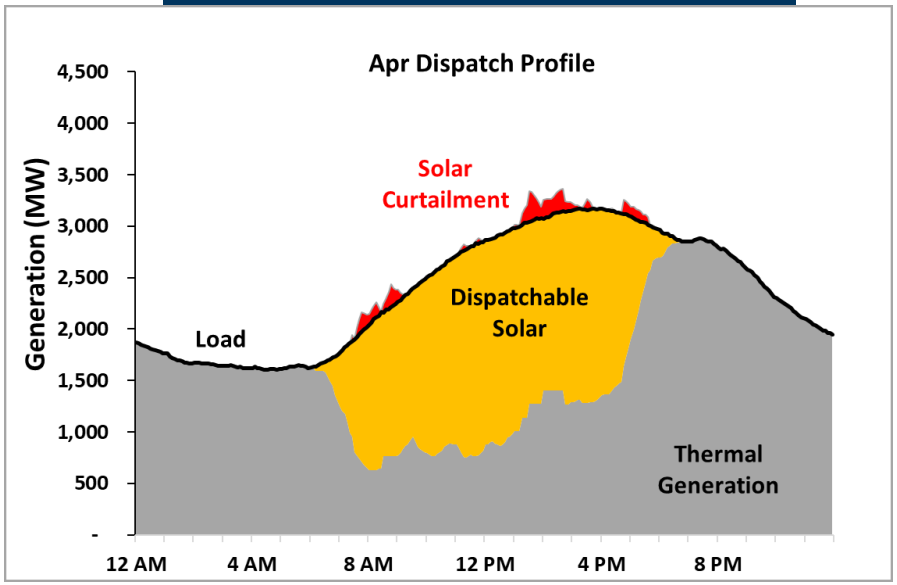
Source: E3,TECO, First Solar Report "Investigating the Economic Value of Flexible Solar Power Plant Operation", https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf

Comparison of Dispatch Profiles Over The Year (Animated)

Non-Dispatchable Solar



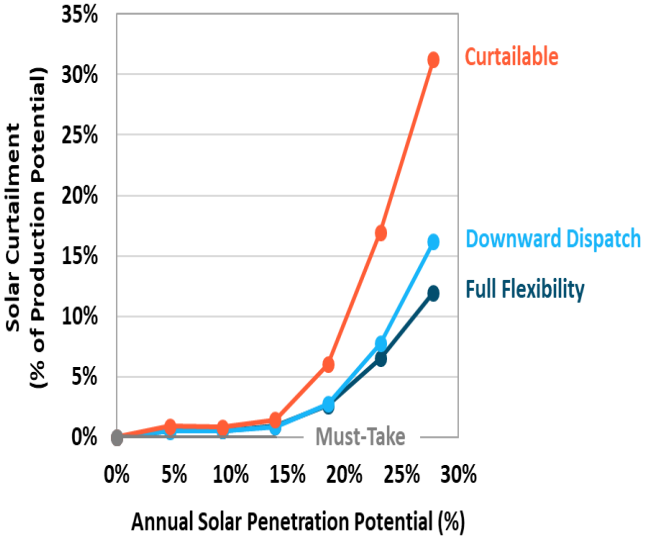
Fully Flexible Solar



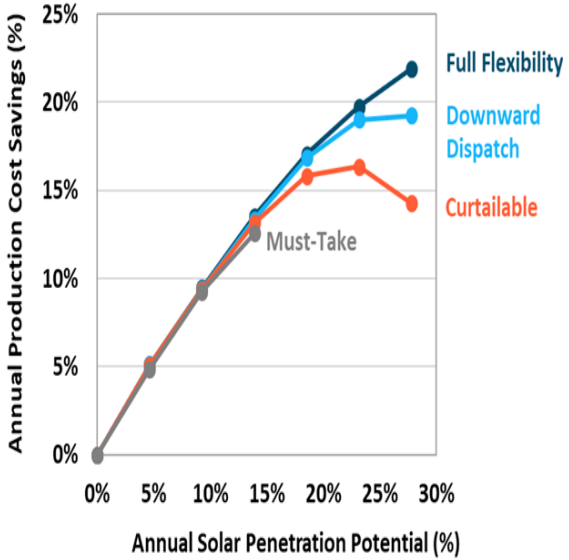
Source: E3,TECO, First Solar Report "Dispatchable Solar: The Key to Unlocking the Clean Energy Grid of the Future", under review.
Dispatchable or Grid Flexible Solar: operating solar plants at an optimal point which may be lower than available resource and providing regulation reserves. Non-dispatacbable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

Dispatchable Solar Saves System Costs

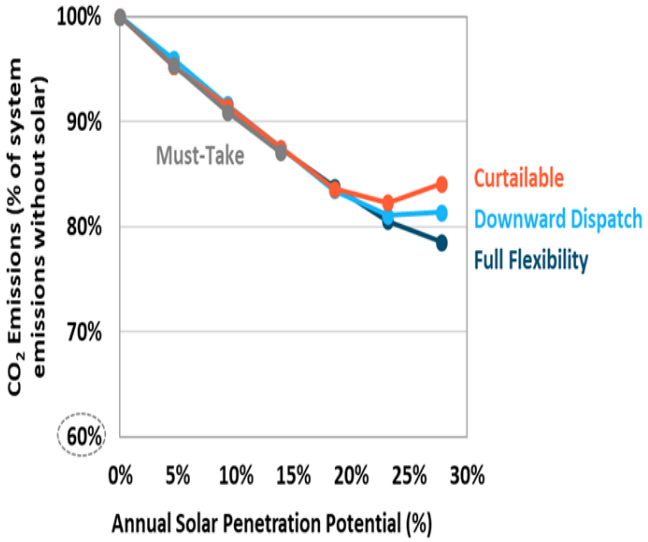
Reduces Curtailment



Increases Production Cost Savings



Reduces Emissions



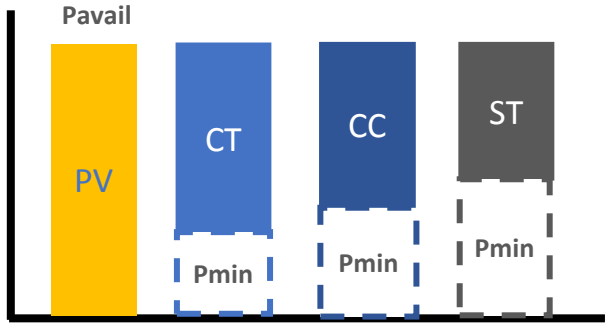
Flexible dispatch for utility-scale solar resources reduces solar curtailment, fuel consumption & emissions

Flexibility = Key Resource Attribute of the Future Grid

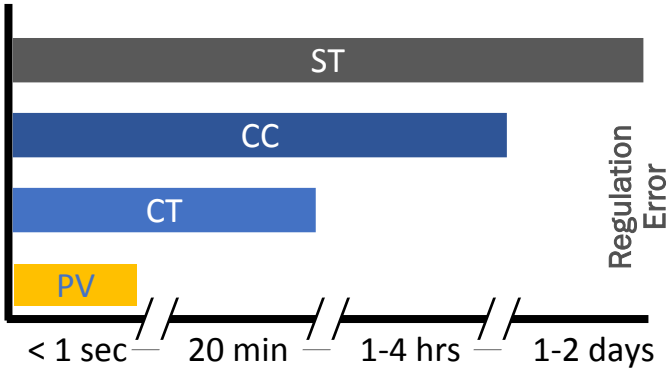
Utility-scale PV is more flexible and responsive than today's fossil fleet:

- Operates flexibly from 0 to Available Power (*no Pmin*)
- Can start up in seconds (*when solar resource is available*)
- Accurately follows dispatch (AGC – 4 second) signals

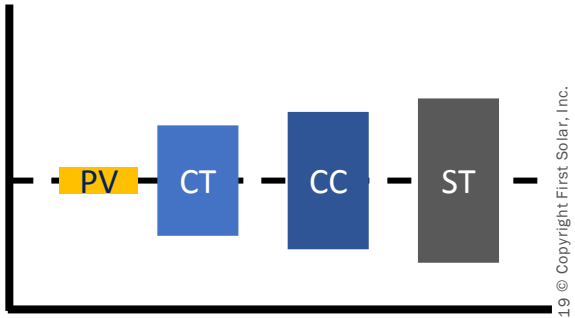
PV can operate flexibly from 0 to available power (P_{avail})



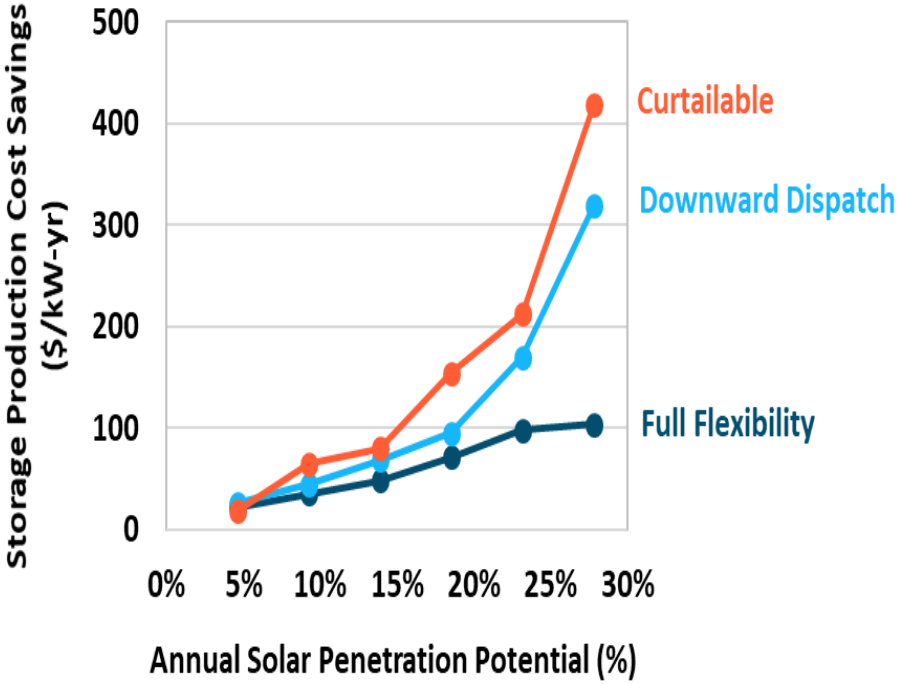
PV starts up in seconds

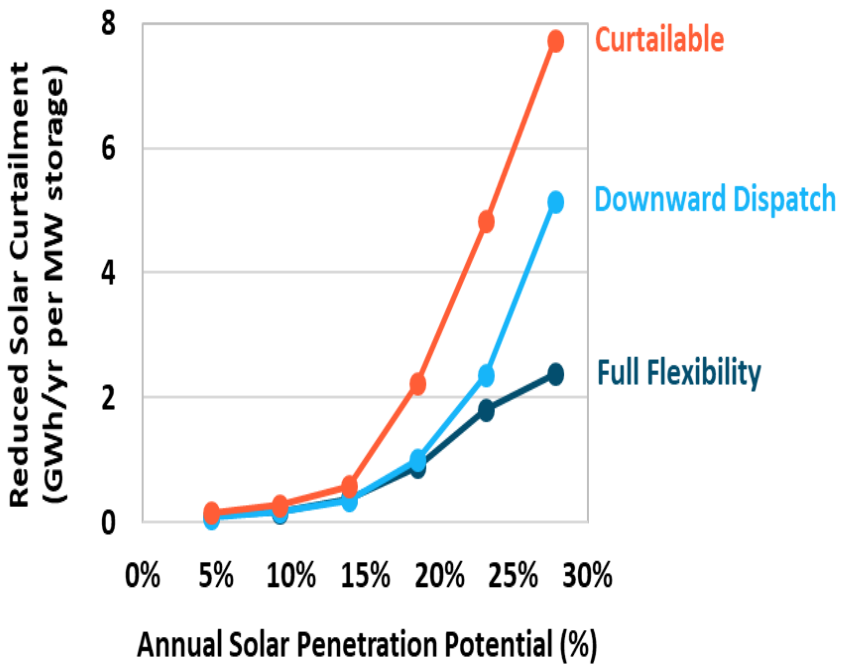


PV follows AGC signal with high accuracy



Impact of Storage Reduced W Flexible Solar … *due to reduced curtailment*





Storage Size: 50 MW, 200 MWh

Can Solar Provide Firm Capacity?

Solar + Storage Provide Clean Dispatchable Generation

Can Solar Provide Firm Capacity Required by Utility?

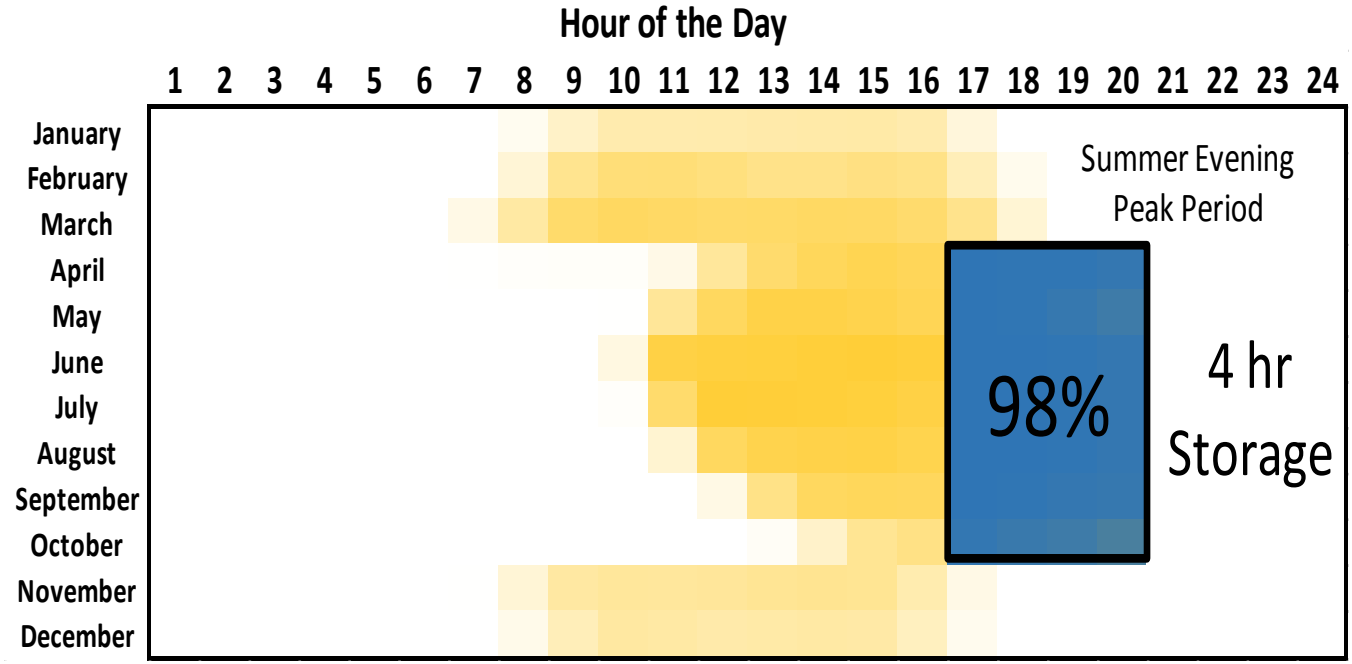
aps

APS to install 50 MW, 135 MWh solar-shifting battery

First Solar®

Solar and Storage Provide Firm Capacity

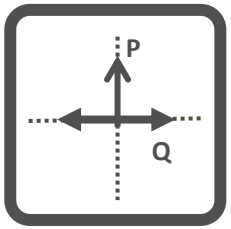
+



Game Changer: Clean Energy Plant
More Cost-effective Than Conventional Generation

Storage Enhances Grid Capability of PV Plant

Voltage Support



Ramp Control

Power Regulation

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

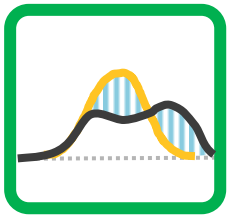
Base Capability

Grid Reliability Services

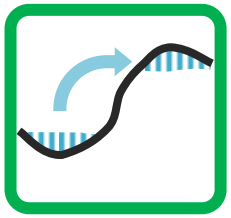
\+

Capacity Firming

Energy Shifting



Flexibility



Grid Capabilities Enhanced with Storage

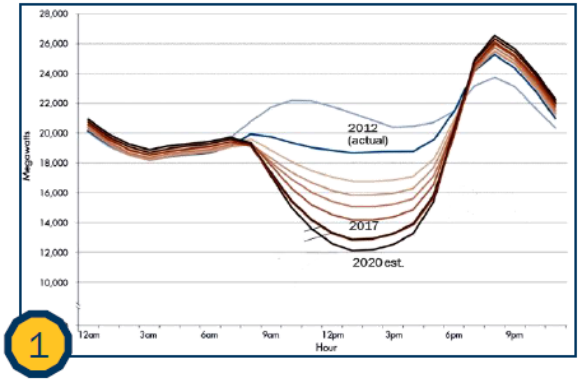
Enabling Flexibility in Procurement and Contracting

IMPACTS TO PROCUREMENT

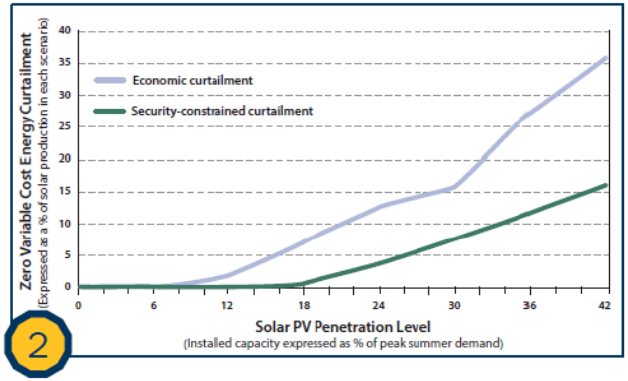
Inflexible solar can challenge grid operations and **reduce system efficiency**

Flexible solar allows grid to be balanced **through curtailment** of flexible solar output

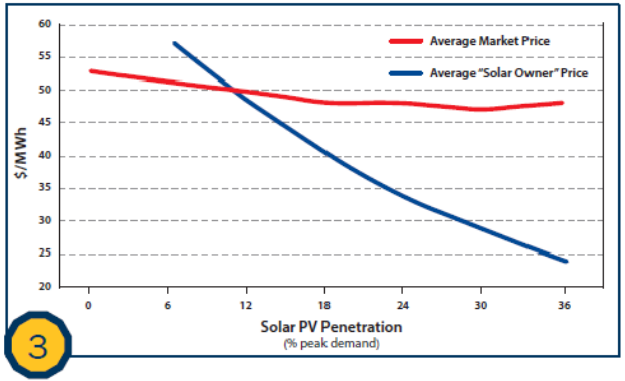
Without market corrections, **increased curtailment** and **reduced peak value** could eventually **erode PV value**



1



2



3

Current market, procurement, & contracting approaches need revamping to recognize the availability benefits solar provides

Flexible Solar Requires Evolution In Procurement & Operations

Key Considerations

- Create a PPA that enables off-taker/system operational flexibility and secures owner revenue visibility
- Reconcile reduced production with the value of flexibility

- With Merit Order Dispatch utilities can dispatch assets for the best benefit to consumers
- Utilities procuring solar resources through PPAs historically prioritized production over dispatchability;
- Solar resources are competing against conventional units on cost alone
- Procurement processes need to evolve to value flexibility (move away from Must-Run)

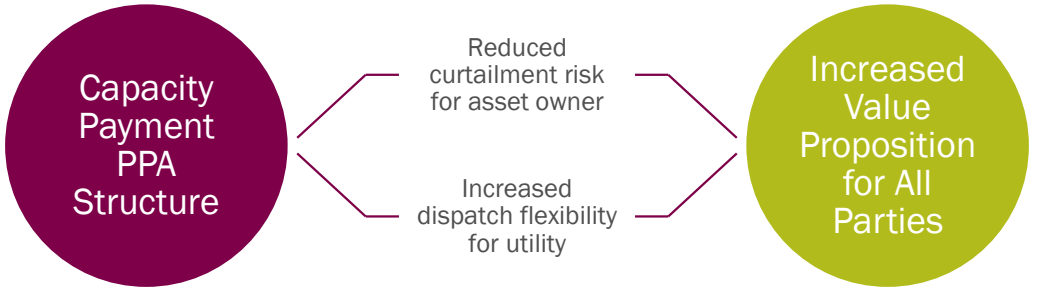
Potential Avenues to Pursue

- Incorporation into economic dispatch stack
- Capacity and energy payments that contemplate a target % of system dispatch
- Tolling agreement that allows full dispatchability thru the inverter
- Discrete ancillary services revenue stream

Capacity-Based PPA Structure - Benefits & Considerations

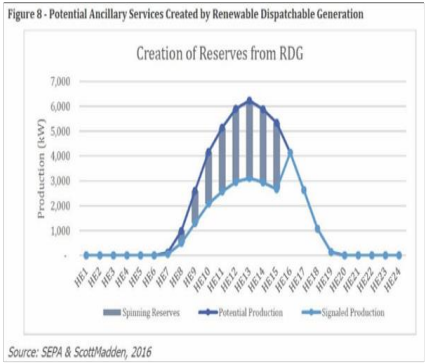
- Capacity payments <> take-or-pay agreements
  - Focus is on dispatch rather than curtailment
  - Dispatch creates incremental value streams
  - Revenue certainty results in more attractive financing

- Moving towards a capacity payment PPA structure requires the incorporation of additional metrics and associated performance guarantees
  - System dispatchability performance
    - MW/min
    - PV and storage availability
    - Accuracy
  - PV degradation
  - Storage degradation



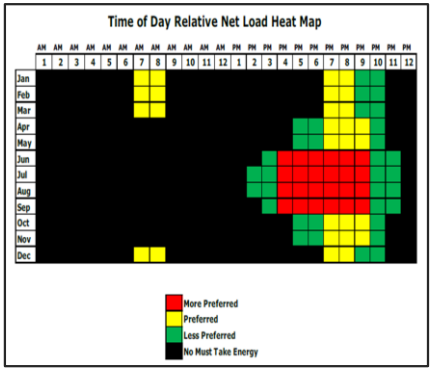
Early Movers on Dispatchable Renewable Procurement

Hawaiian Electric



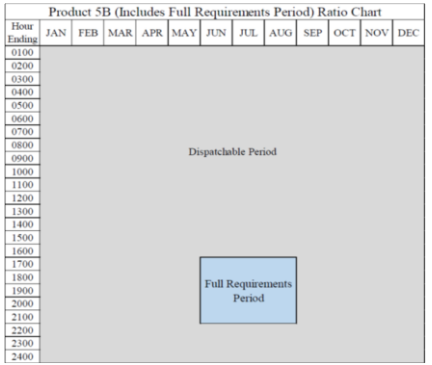
- New PPA balances curtailment risk, creates the opportunity for essential grid services, and results in financeable projects
- Lump sum payment structure
- In Dec 2018, the Companies filed 7 PPAs totaling 262 MW of solar with 4 hours of storage

APS



- RFP designed to meet evening peak needs
- First Solar won the RFP, competing on economics alone against conventional generation, with a 65 MW solar project coupled with a 50 MW / 135 MWh battery system

NV Energy



- NV Energy RFP required dispatchable renewable resources
- Project must respond to AGC signals every four seconds and dynamically operate at or below the instantaneous maximum output of the resource

Next Steps

Policymakers

- Ensure proper value is placed on solar's capacity, energy, and grid flexibility
- Collaborate on new PPA constructs that contemplate the provision of (and payment for) flexible dispatch
- Variable renewable energy resources should be modeled as having dispatch flexibility in IRP processes

Grid Operators

- Value flexibility in all resources
- Prioritize units that are the most efficient in meeting dispatch signals
- Increase reliance on variable renewable energy resources to provide capacity and essential grid services

Summary

Solar Integration And Scale

Solar Energy

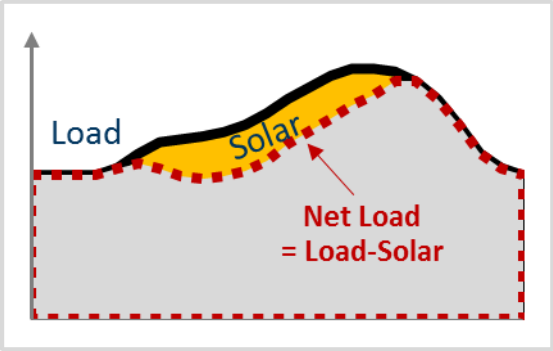
- Solar is part of mid-day load offsets peak or near-peak demand
- Energy-Only Value

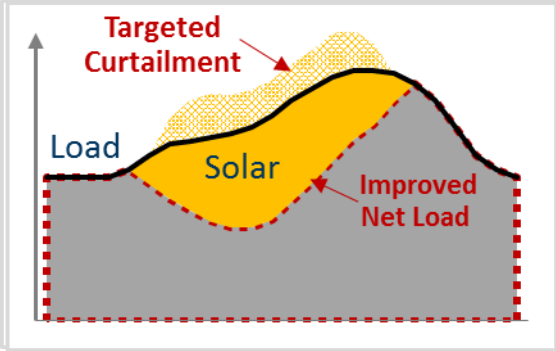
Grid Flexible Solar

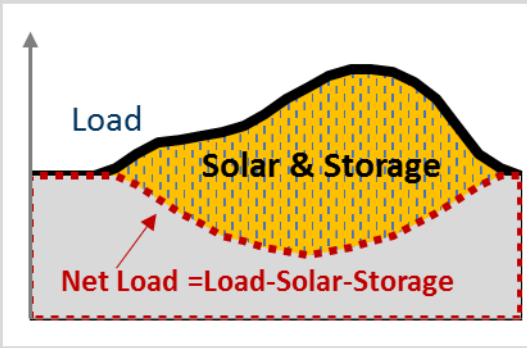
- Adds Grid Reliability Services & Flexibility Value

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

Solar Power Provides Energy, Flexibility and Capacity

- Grid Code should be mandated so that the PV plants supports **Grid Stability** and **Reliability** like a conventional plant
  - Energy (real power), Voltage control etc
- Leverage **Grid Flexibility of Solar Plants vs *Must-run***
  - Increases solar penetration (which is the least cost generation)
  - Reduces coal consumption (production costs) and emissions
  - Reduces the need for storage capacity on the grid
- Procurement (PPAs) to be modified for **valuing Flexibility**
  - Provide for system flexibility to operator and assured revenue to the generator
  - Model RE as **Flexible resource** in the IRP process
- Combined with **Storage**, Solar provides Clean & **Firm Capacity**
  - High cost of storage limits wide scale adoption

Backup Material

Can Solar Provide Essential Reliability Services?

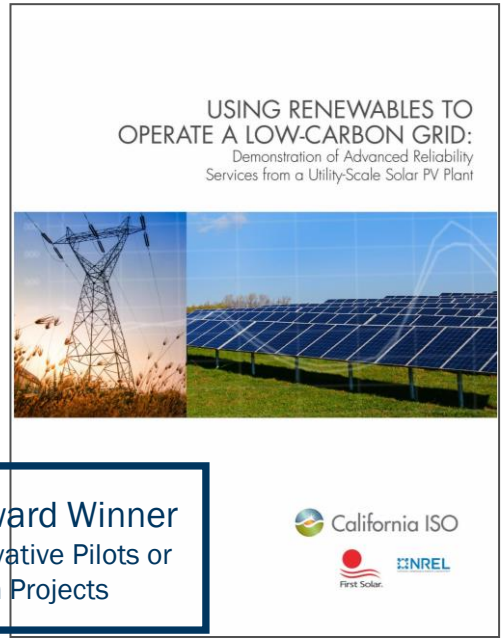
Solar Can Provide Reliability Services

NERC identified essential reliability services to integrate higher levels of renewable resources, including:

- Frequency Control
- Ramping capability or flexible capacity

Reduces need for conventional generation

- Goes beyond simple PV energy value
- Enables additional solar
- Reduces need for expensive storage



2017 NARUC Award Winner
Utility Industry Innovative Pilots or Demonstration Projects

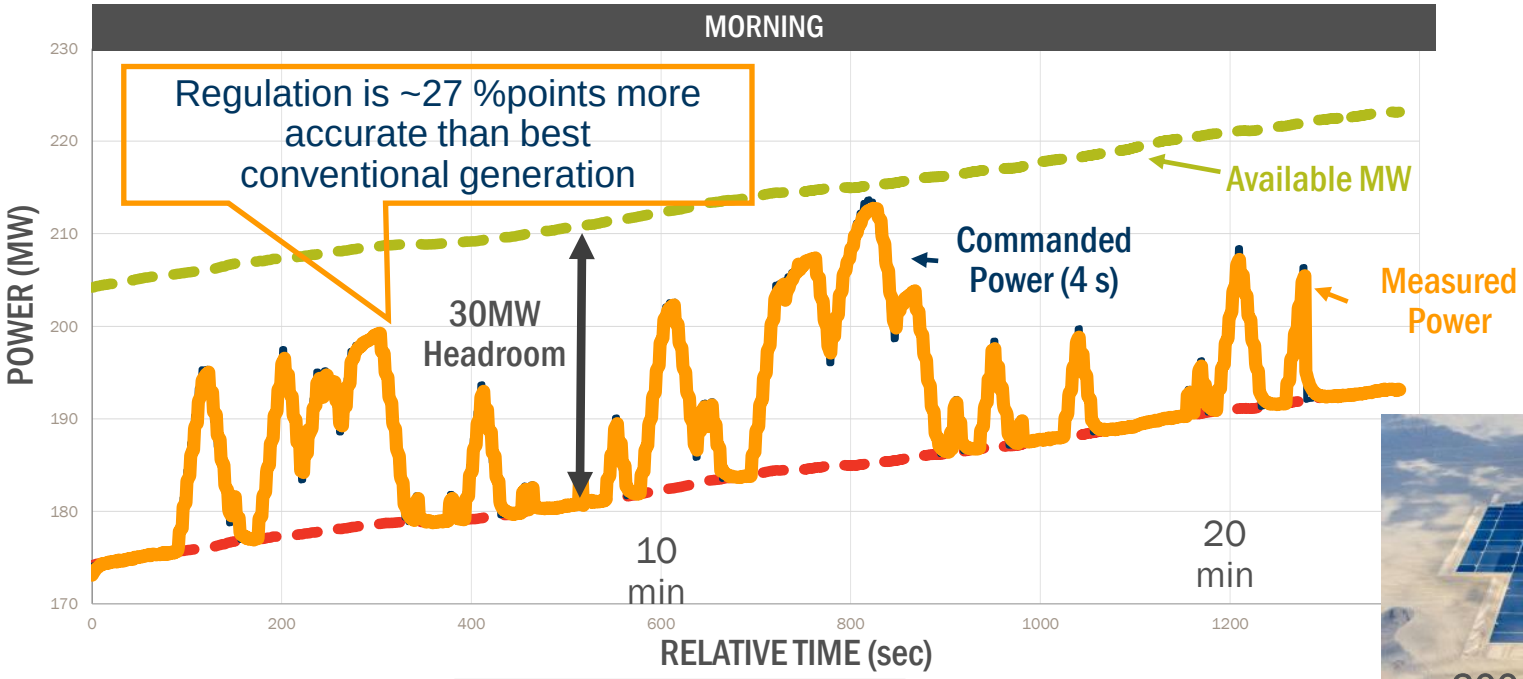
2018 Intersolar Outstanding Project Winner

Grid Reliability & Stability

Intermittency

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

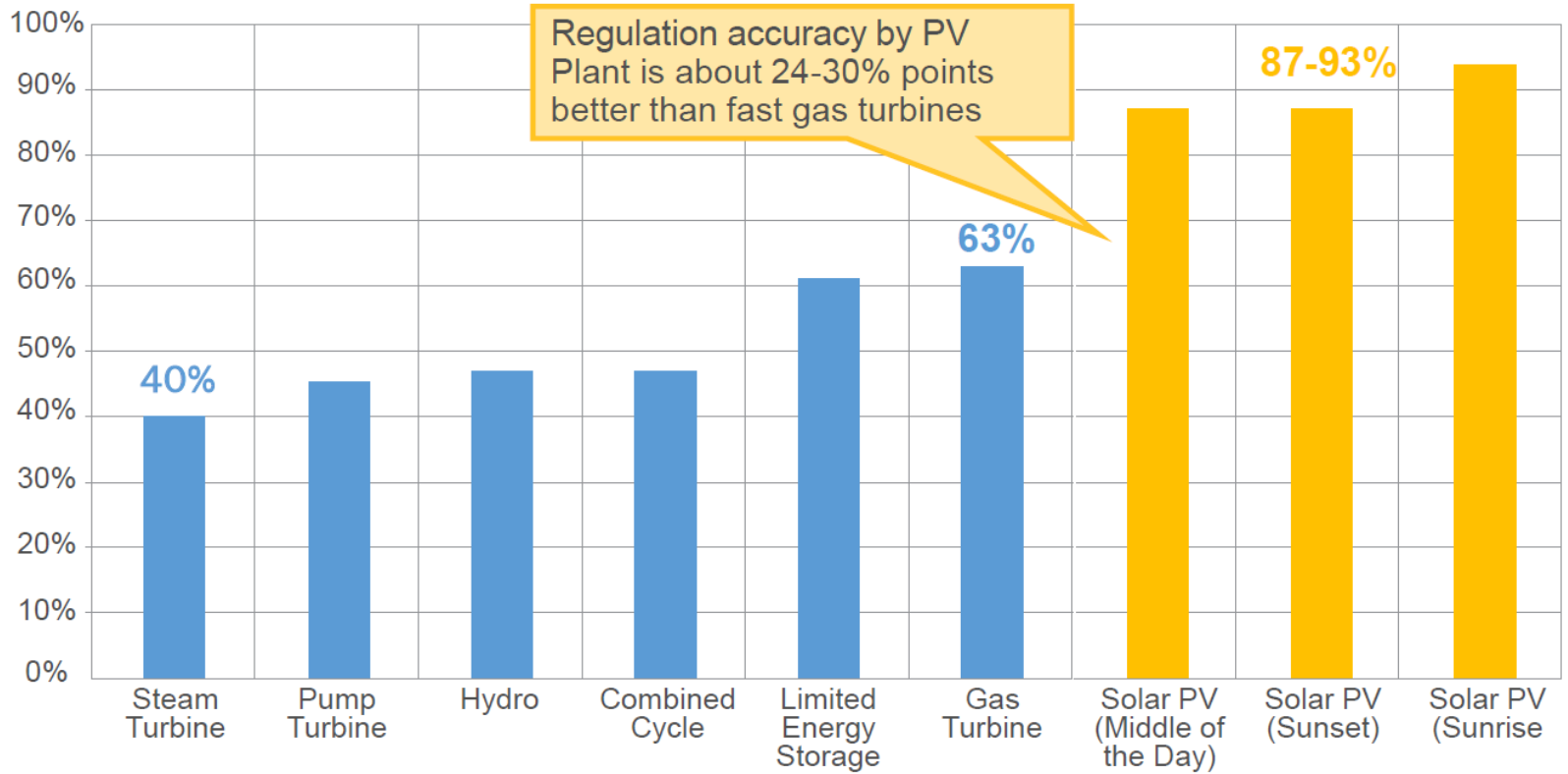
Solar Plant Follows Grid Operator Commands (AGC) Very Accurately



Intermittency → **Grid Reliability & Stability**

- Source: http://www.caiso.com/Documents/TestsShowRenewablePlantsCanBalanceLow-CarbonGrid.pdf.
  AGC: Automated Generator Control

PV Plants Outperform Conventional Plants in Frequency Regulation



California ISO

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

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

CASE STUDY : HAWAIIAN ELECTRIC LEADING THE WAY IN PPA REFORM

- High penetration of behind-the-meter solar, coupled with an old oil-fired fleet has lead to significant curtailment issues on some of the Hawaiian Islands (upwards of 20%)
  - Existing PPAs dictate a reverse chronological curtailment order, meaning newer, cheaper units are curtailed first
- Developers have desired “take-or-pay” contracts to mitigate their curtailment risk; however, this unduly shifts the burden to ratepayers
- HECO’s consultants identified a new contract structure to better balance curtailment risk going forward, and create the opportunity for essential grid services to be provided from utility-scale renewables
  - Renewable Dispatchable Generation (RDG) Model
  - Capacity-based payment structure ($/MW-mo) allows for surety in financing projects for developers, while creating ability to dispatch resources to meet grid needs
- In early 2018, HECO formally issued RFPs totaling over 300 MW leveraging the RDG model and new PPA

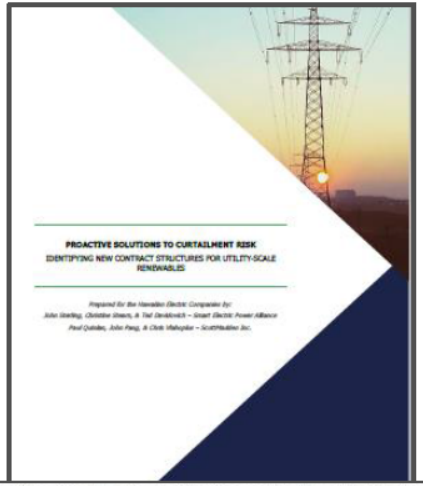
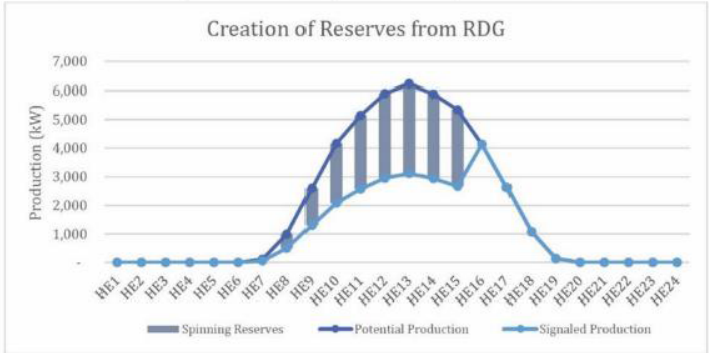


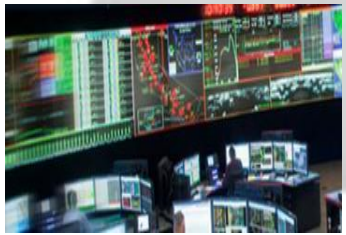
Figure 8 - Potential Ancillary Services Created by Renewable Dispatchable Generation



Source: SEPA & ScottMadden, 2016

System Flexibility Sources

Increasing Cost



Markets & Operations

Demand Response

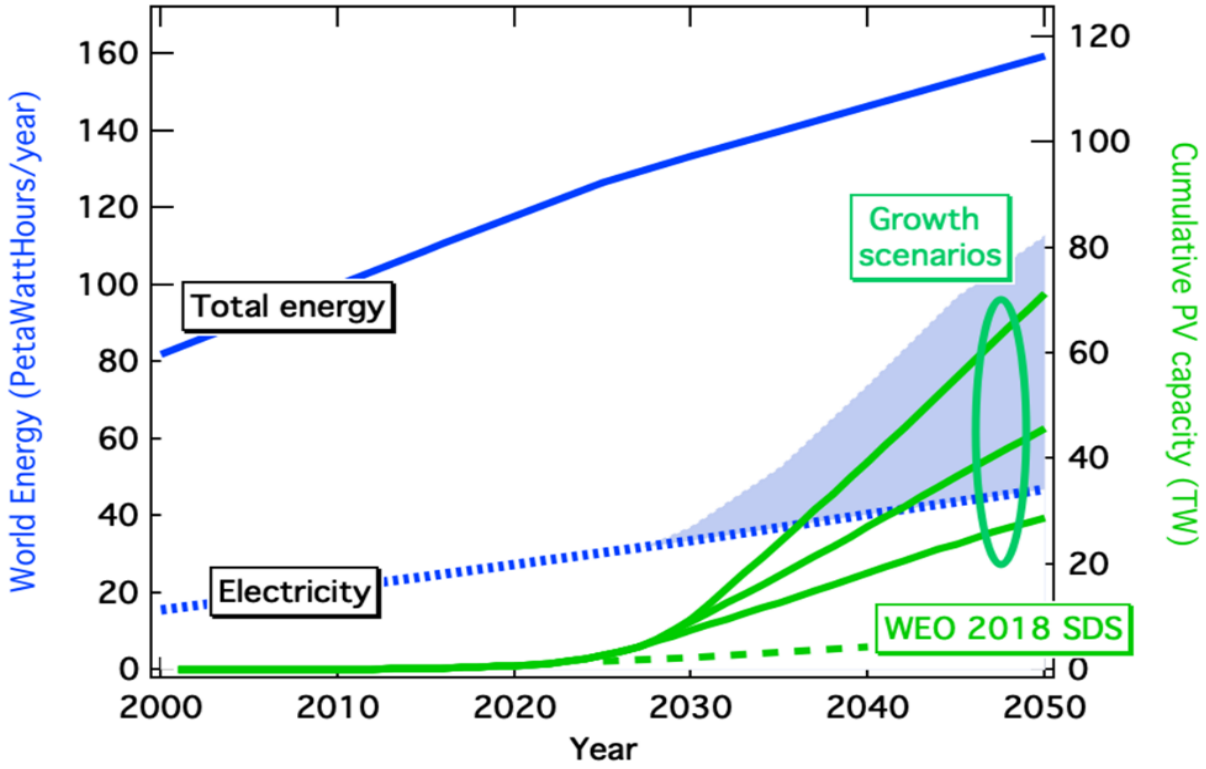
Grid Expansion

Flexible Generation

Energy Storage

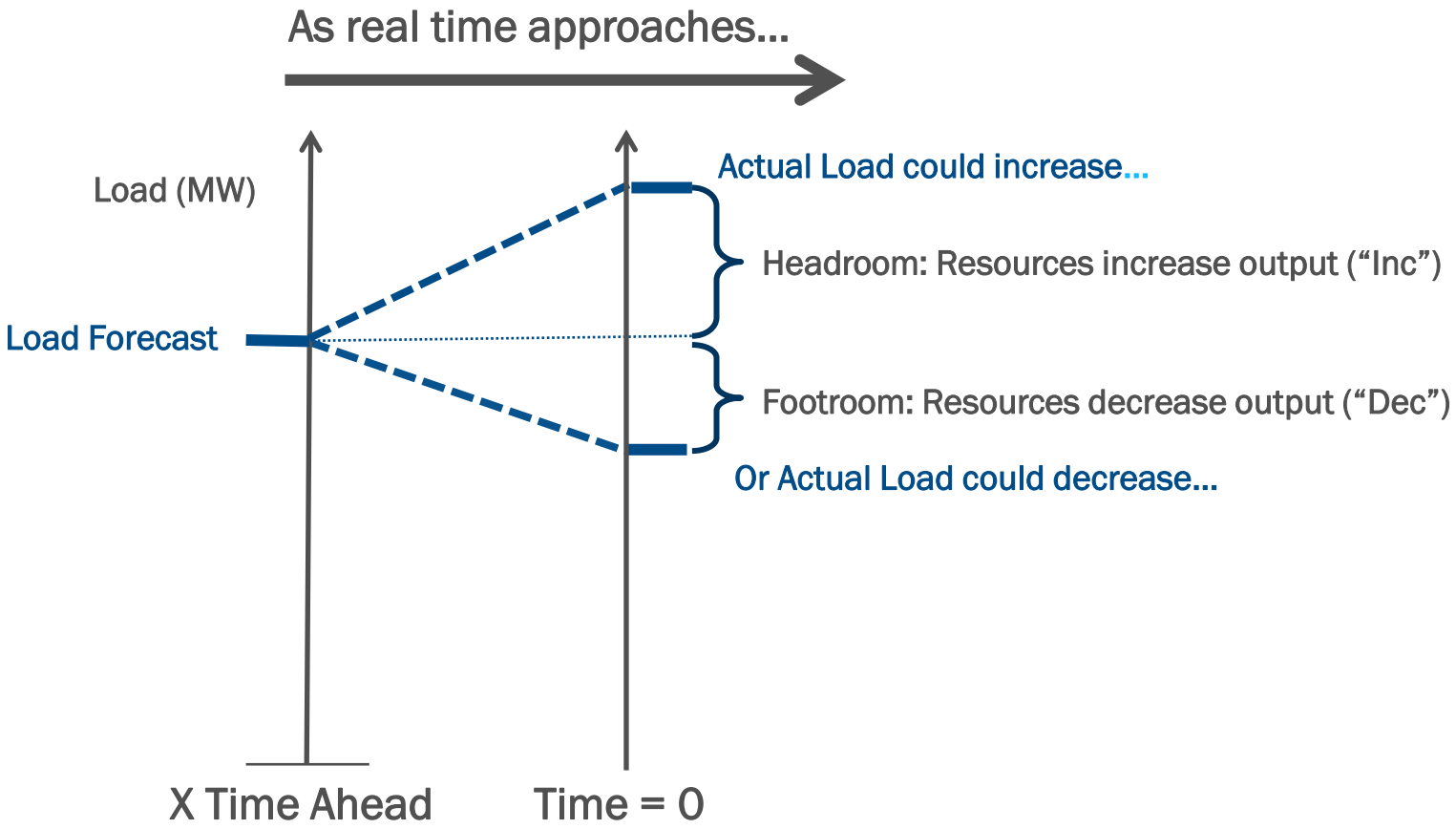
Increasing Flexibility

Terawatt-scale PV: Transforming the global energy system

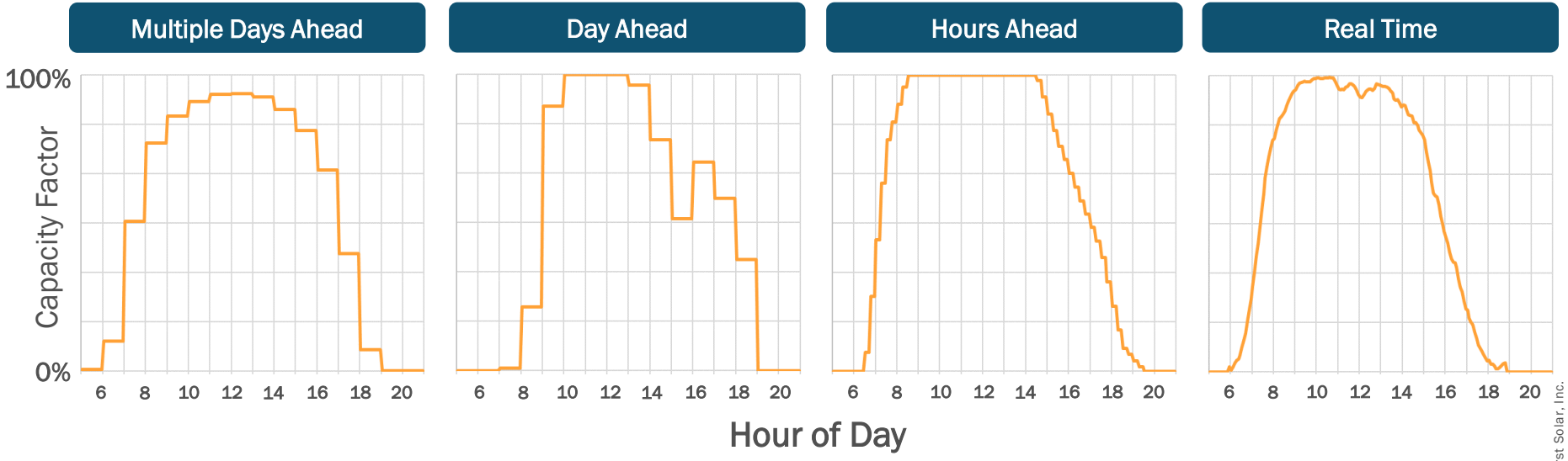


Source: Terrawatt Workshop Modeling and Breyer et al … assumes major electrification in heating , transportation, desalination and industrial sectors

System Balancing and Uncertainty

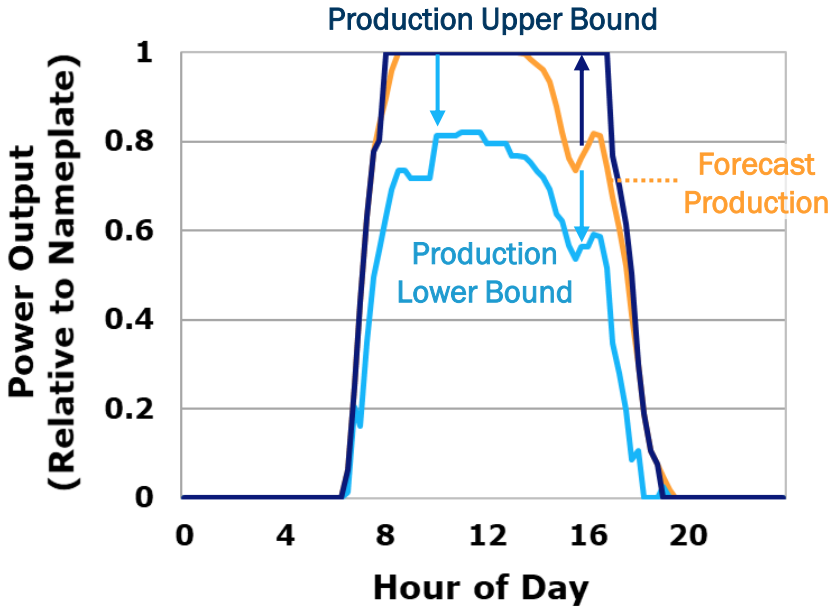


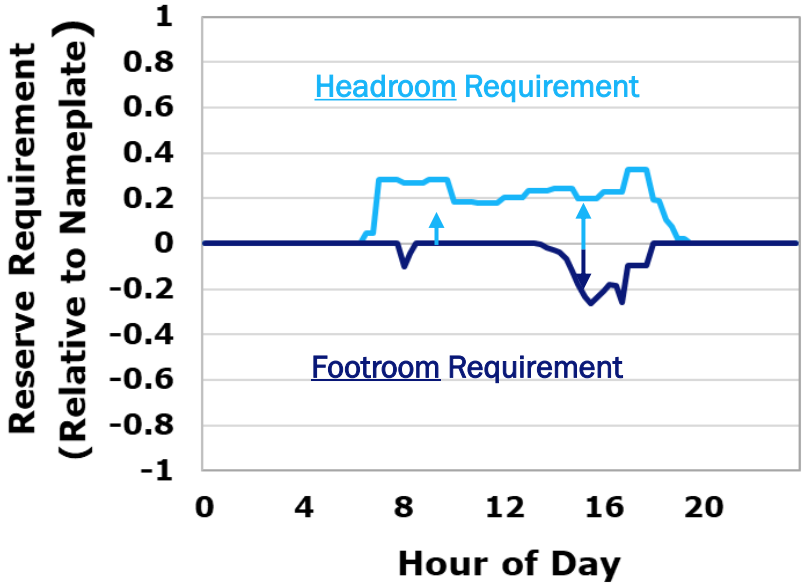
Solar Adds Variability & Uncertainty



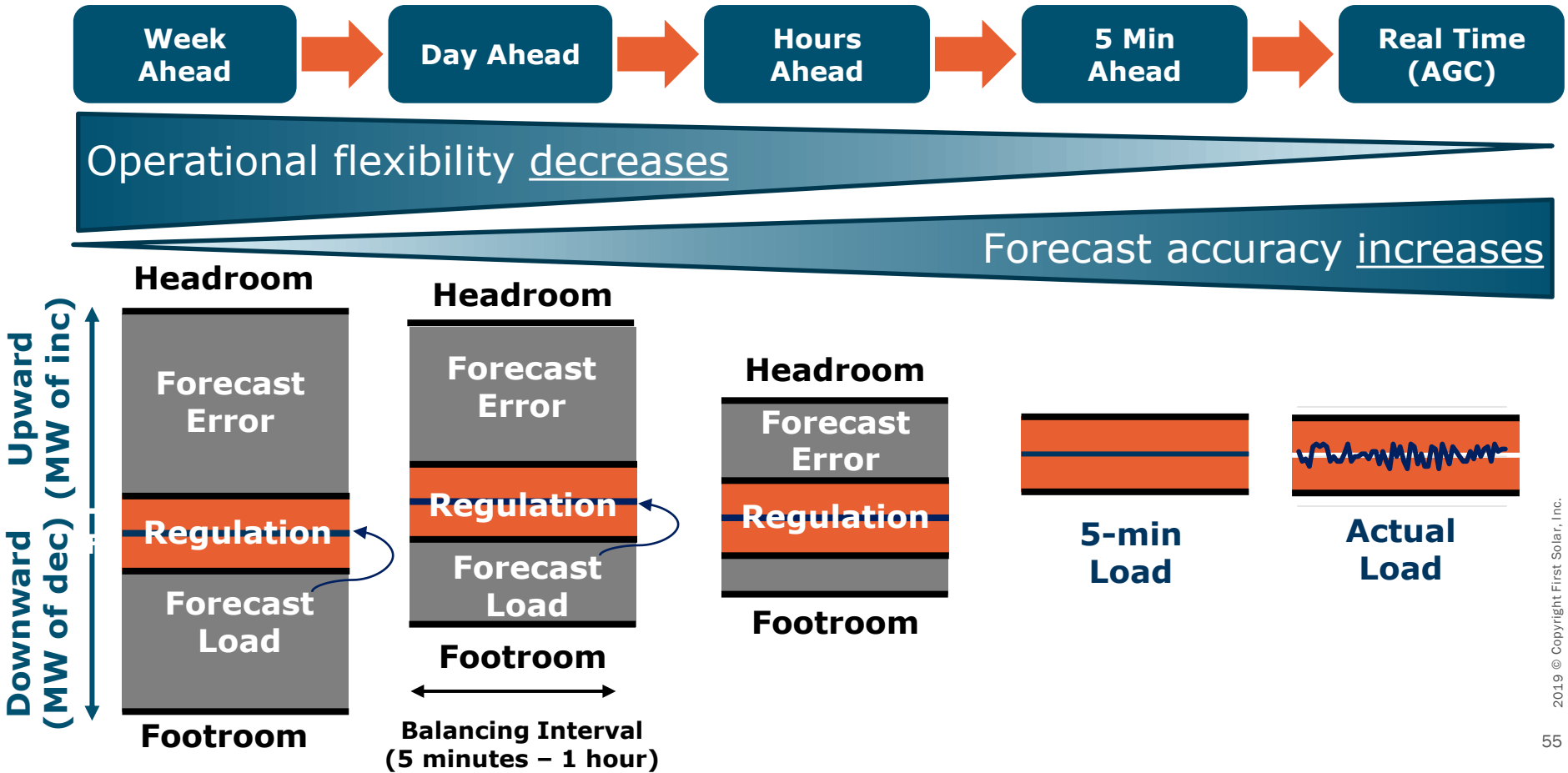
Forecast Error Sets Bounds On Possible Solar Production

Sunny Day, Hours ahead of real-time





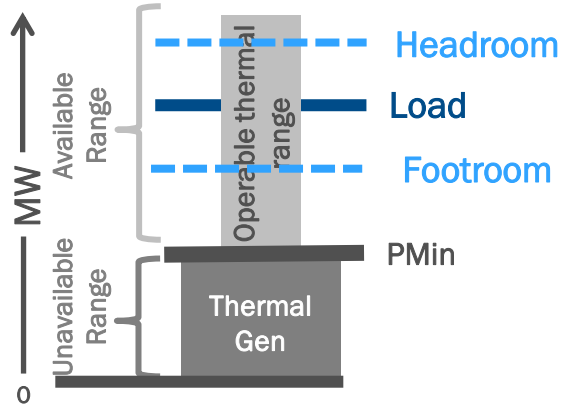
Head and Foot Room are Needed to Ensure Operational Control



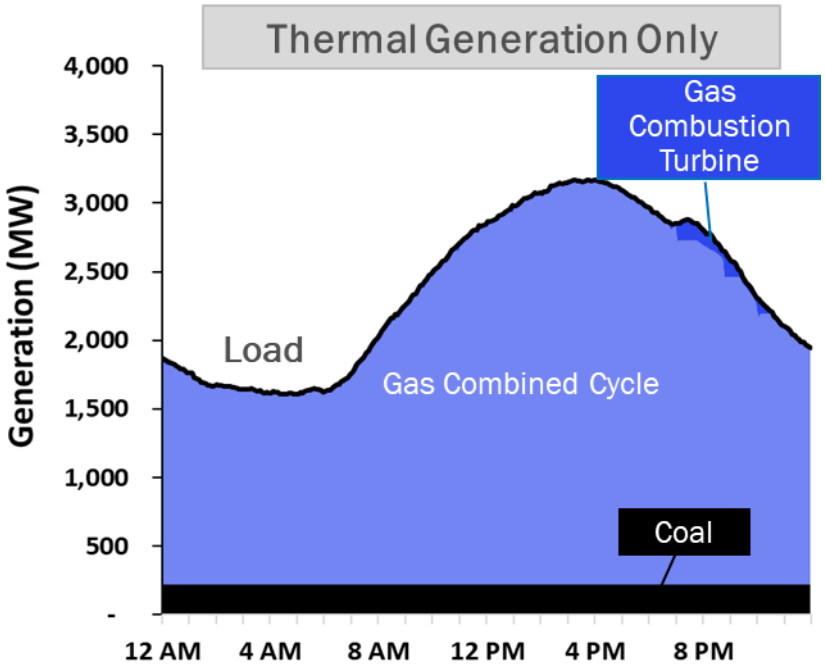
Generation Dispatch For Thermal Generation Only

A:Thermal Generation Only

Required headroom & footroom fit within generation fleet available range

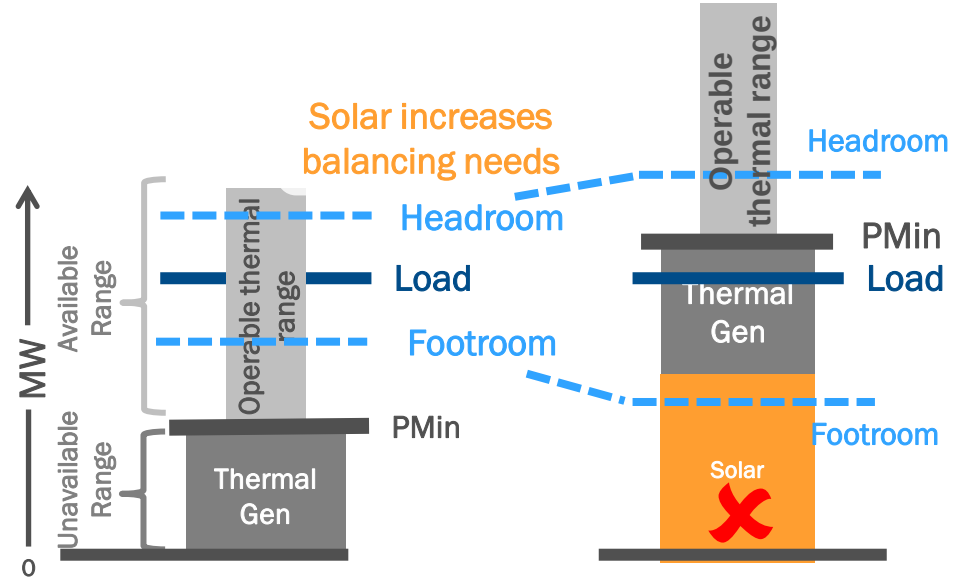


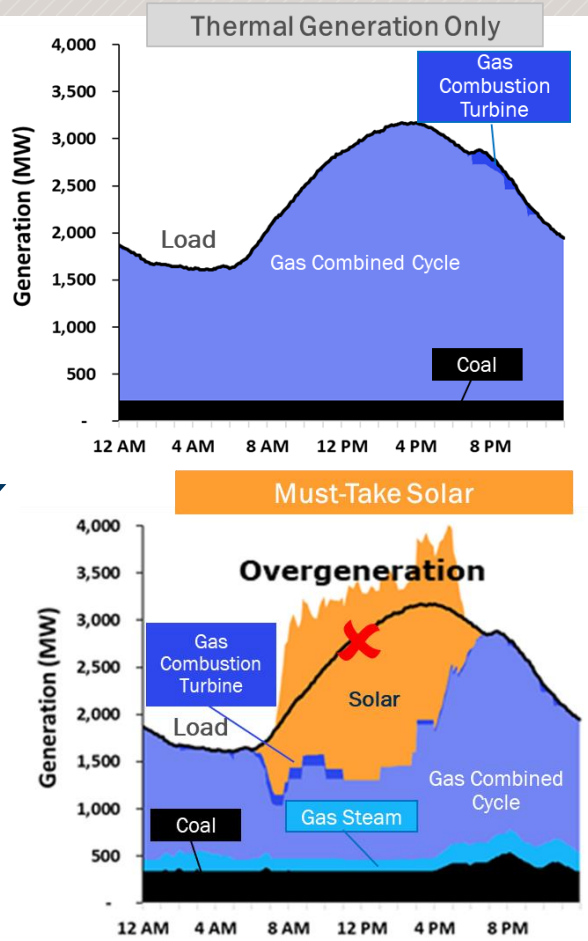
Generation Dispatch on A Spring Day



Generation Dispatch with Must-Take Solar – *Infeasible Under Higher Penetration*

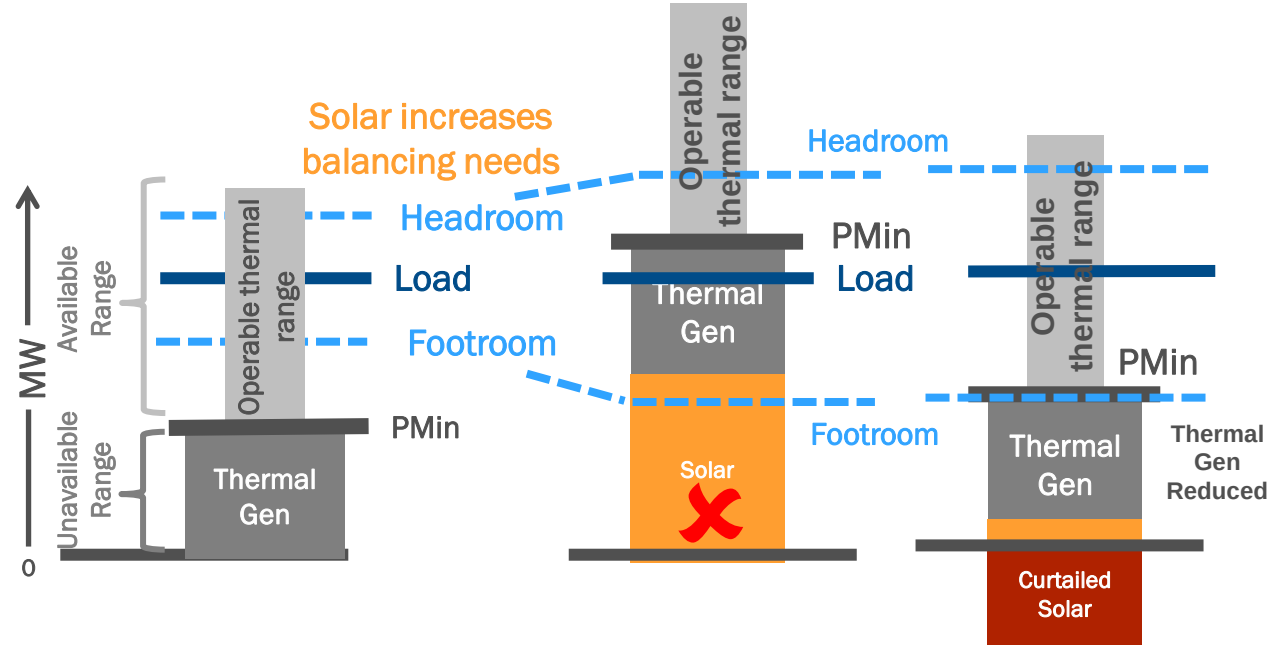
Thermal Generation Only	Must -Take Solar
Required headroom & footroom fit within generation fleet available range	Infeasible: Minimum thermal dispatch (PMin) *above* footroom -- no feasible range available

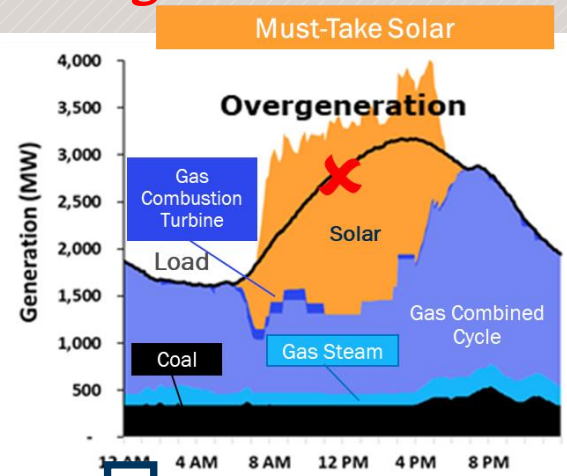


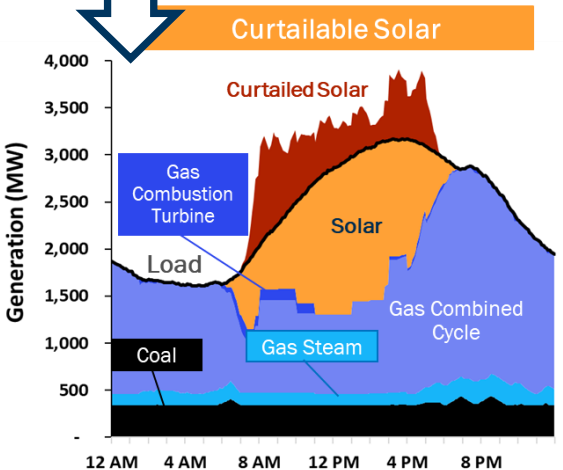


Generation Dispatch with Curtailable Solar – *Feasible but High Curtailment*

Thermal Generation Only	Must -Take Solar	Curtailable Solar
Required headroom & footroom fit within generation fleet available range	Infeasible: Minimum thermal dispatch (PMin) *above* footroom -- no feasible range available	Feasible: Solar is curtailed until thermal dispatch is within operable range







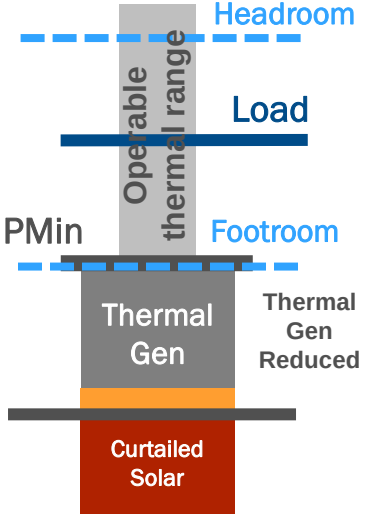
Generation Dispatch with Downward Dispatch Solar – *Increases Value*

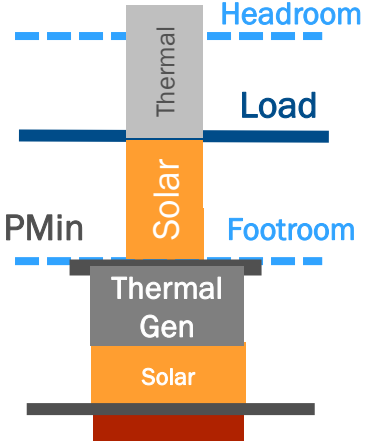
Curtailable Solar

Feasible:
Solar is curtailed until thermal dispatch is within operable range

Downward Dispatch Solar

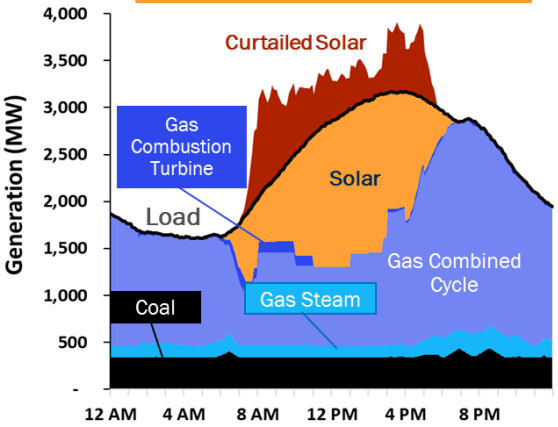
Increased Value:
Curtailment reduced because solar contributes to footroom



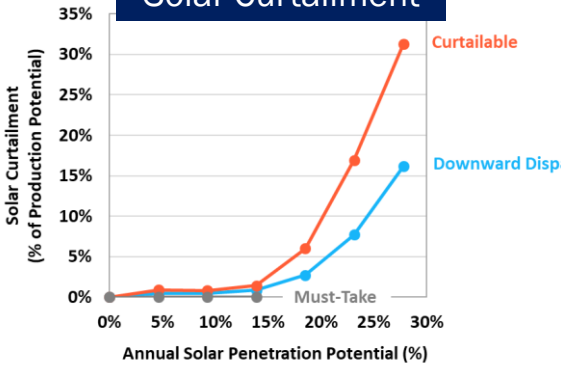


Solar Contributes to Footroom

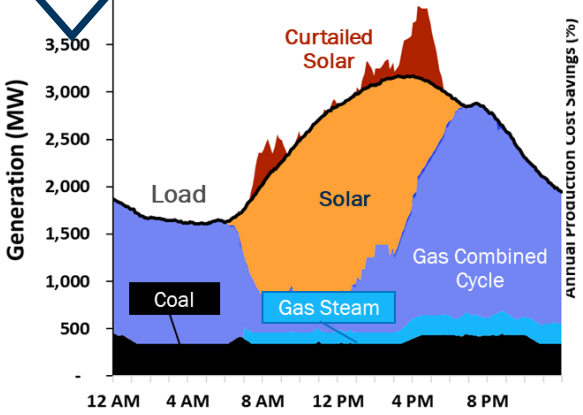
Curtailable Solar



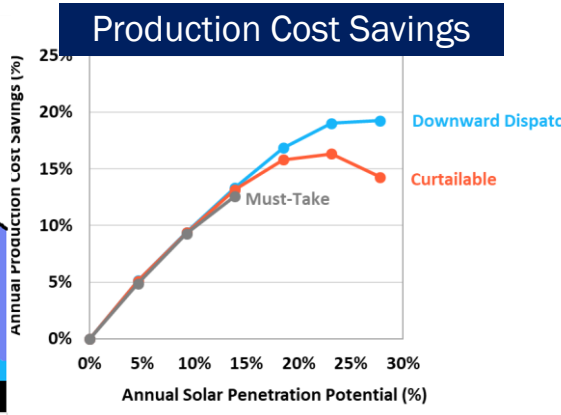
Solar Curtailment



Downward Dispatch Solar



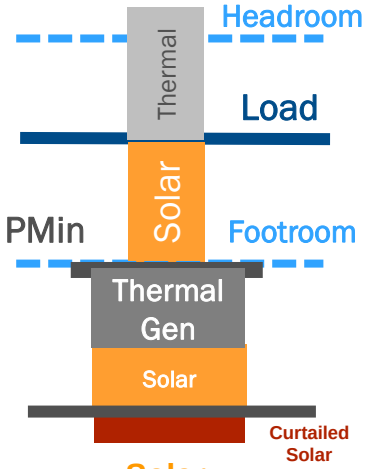
Production Cost Savings



Full Flexibility Dispatch Solar – *Optimizes Value*

Downward Dispatch Solar

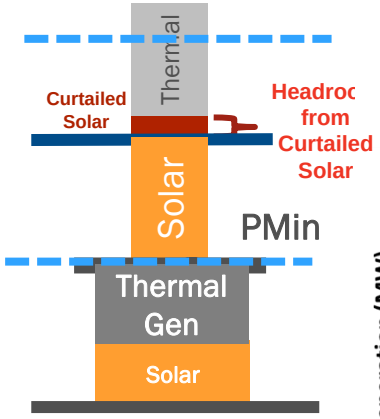
Increased Value:
Curtailment reduced because solar contributes to footroom



Solar Contributes to Footroom

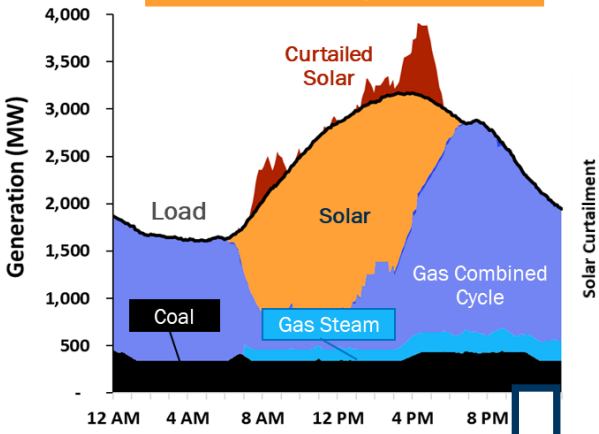
Full Flexibility Solar

Optimal Value:
Solar contributes to both footroom & headroom

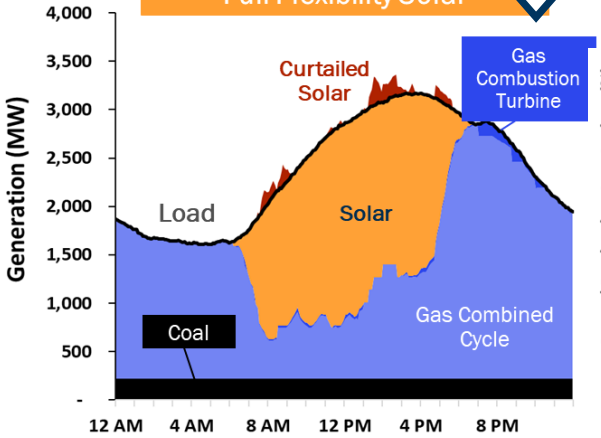


Solar Contributes to Footroom & Headroom

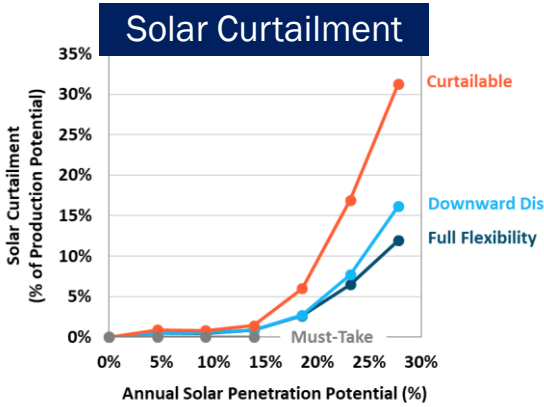
Downward Dispatch Solar



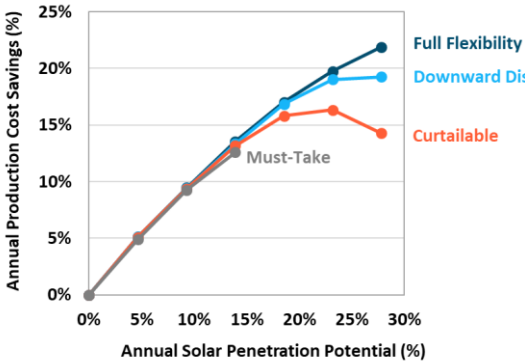
Full Flexibility Solar



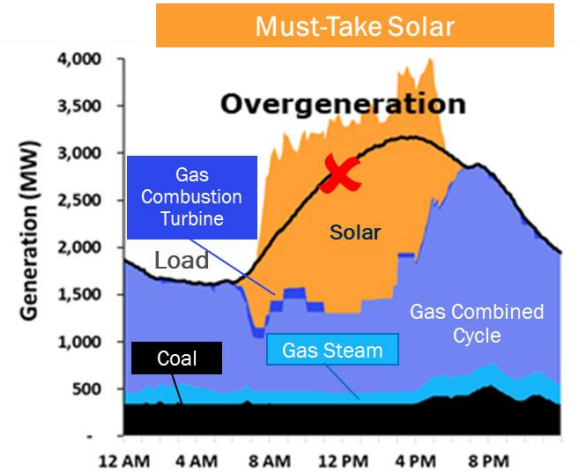
Solar Curtailment

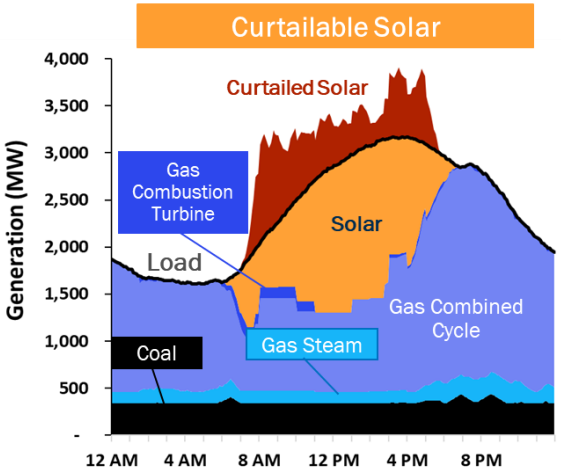


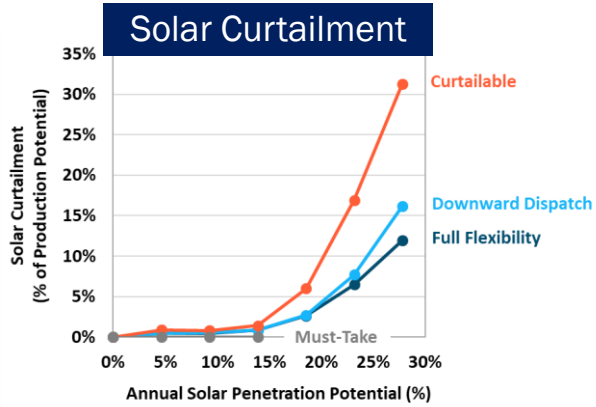
Production Cost Savings

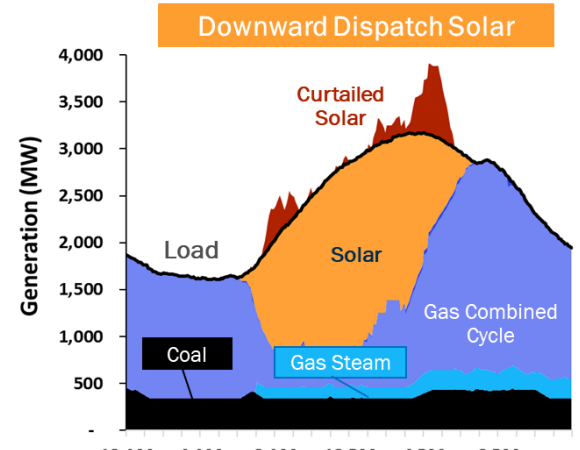


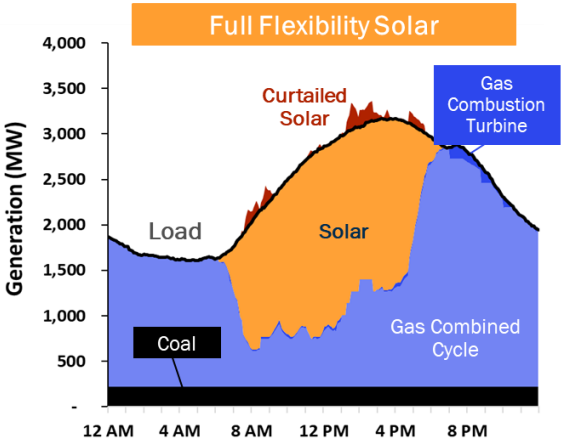
Dispatch Profile Details for Various Solar Modes at High Penetration

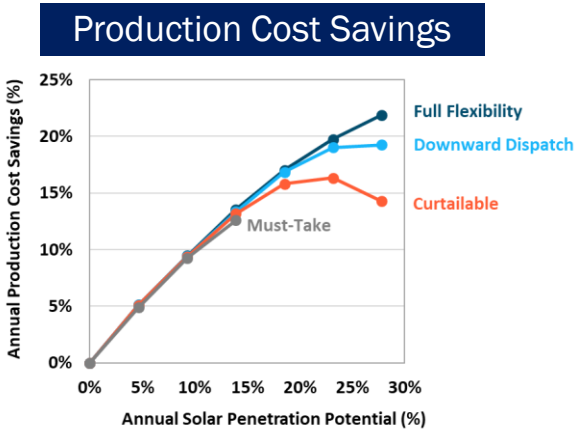




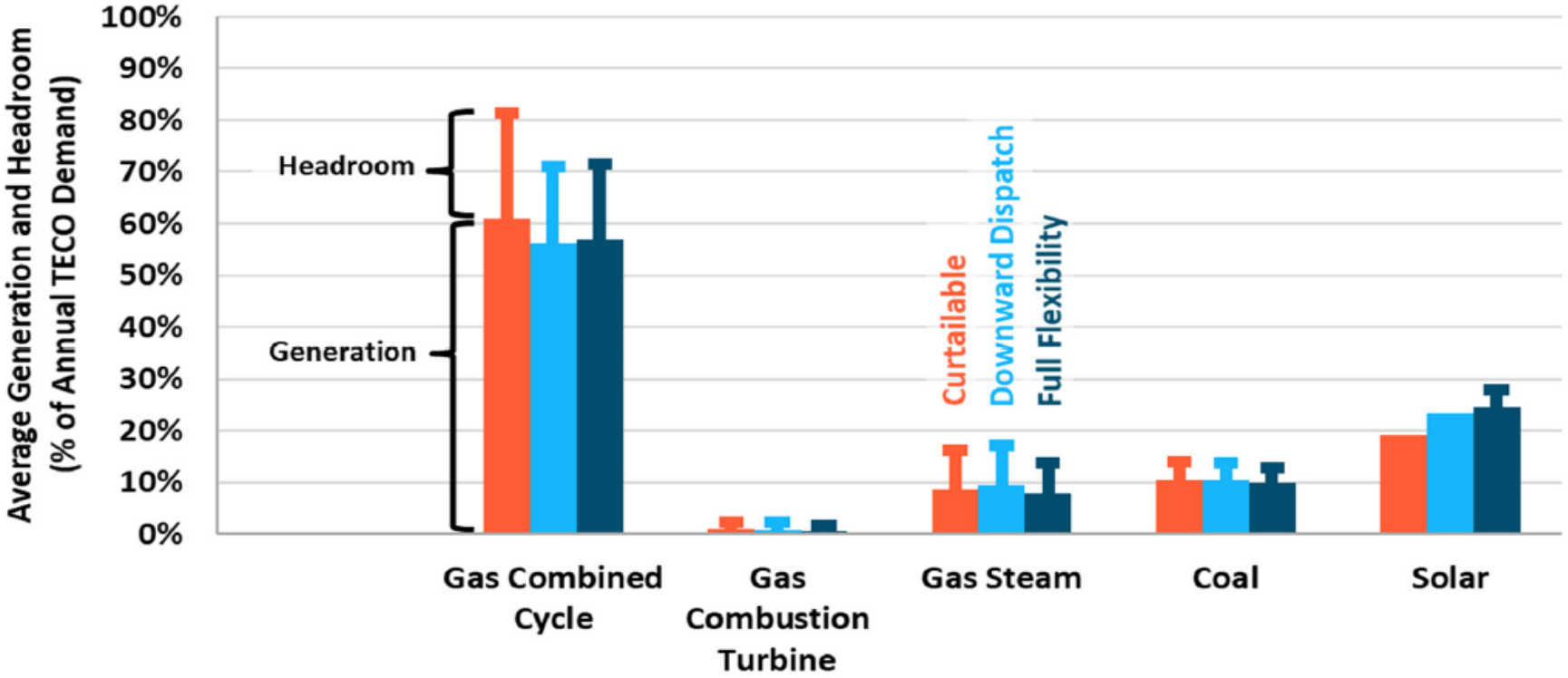




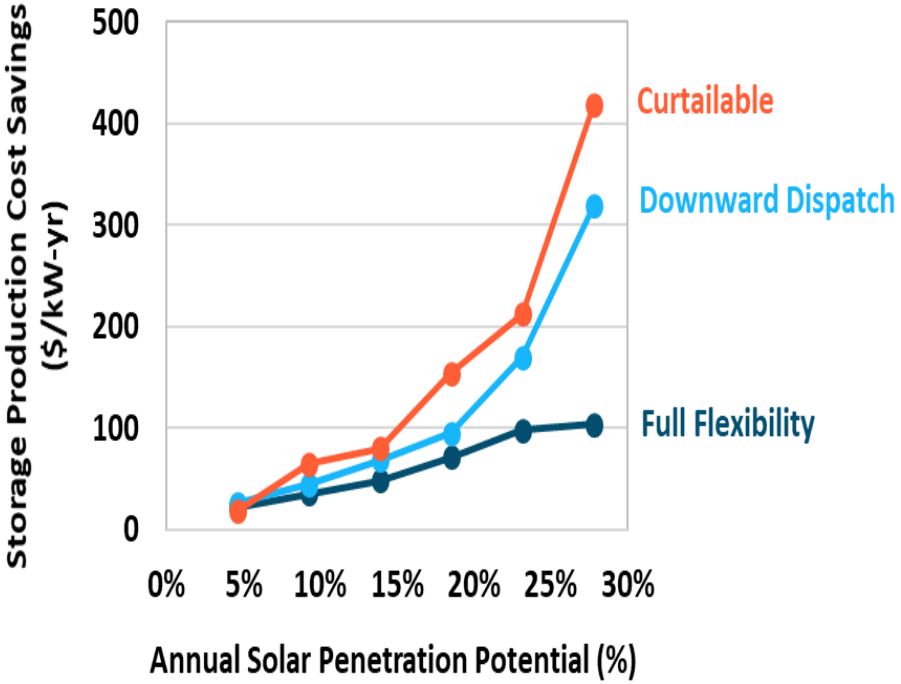


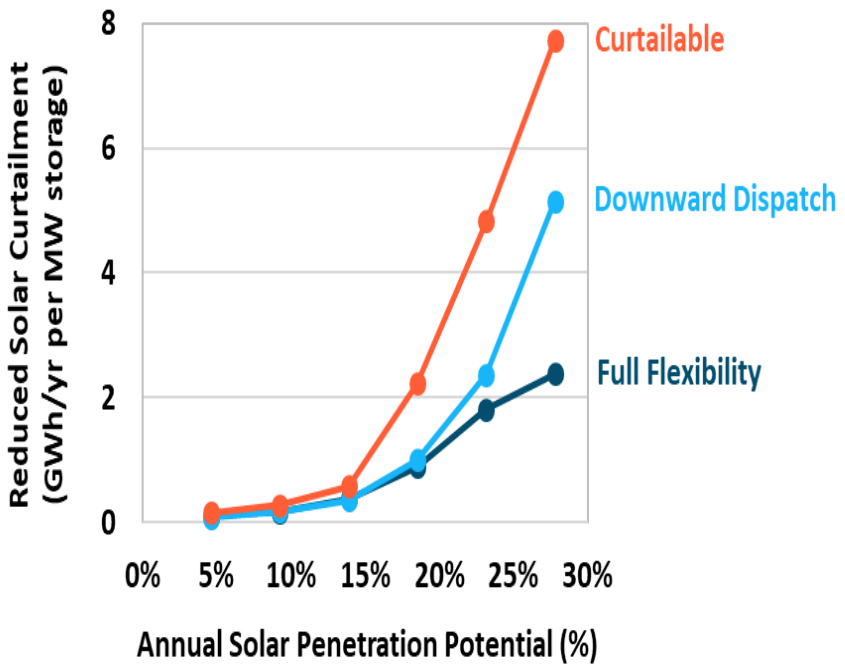


Annual Average Generation & Headroom At 28% Solar Energy Production Potential



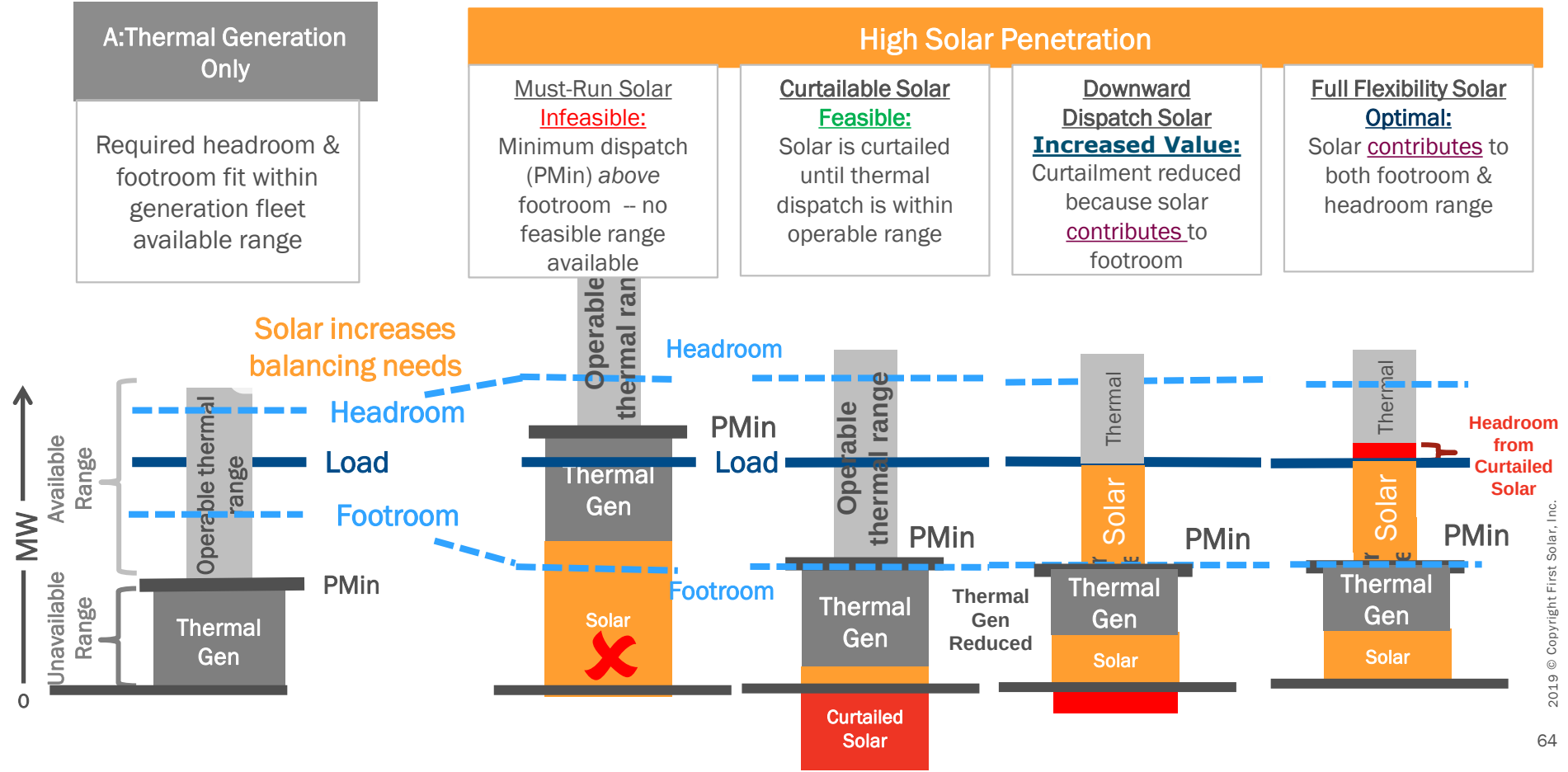
Impact of Storage Reduced W Flexible Solar … *due to reduced curtailment*





Storage Size: 50 MW, 200 MWh

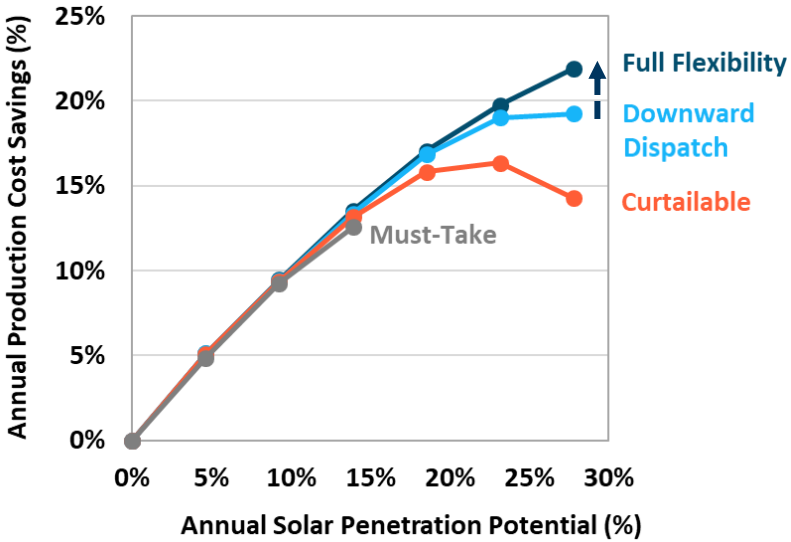
“Dispatchable or Grid Flexible” Solar Contributes to Reserves

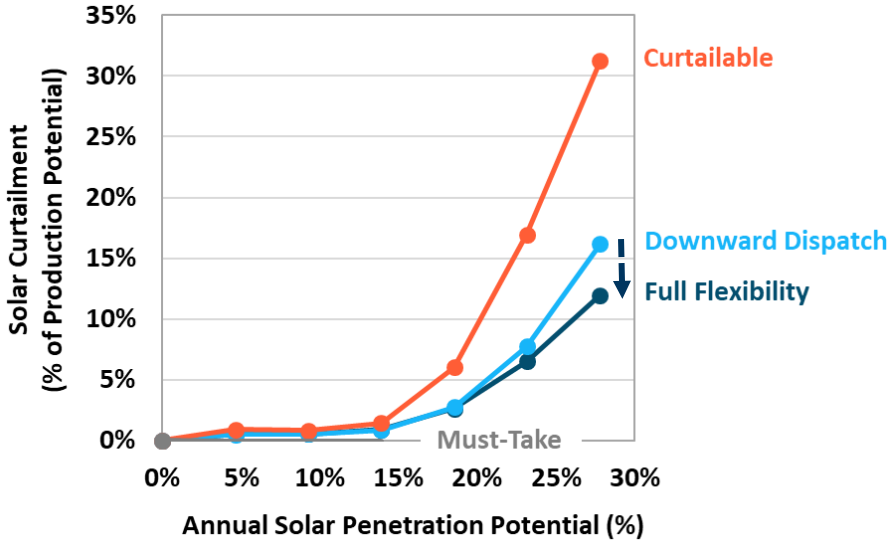


“Full Flexibility” Operating Mode: Additional solar value

With headroom held on solar, thermal generators operate more efficiently in real time – and in some cases turn off ahead of real time – resulting in less fuel consumption and lower costs

Curtailment is reduced because less thermal generation is necessary to balance the system





Solar + Storage Provides Firm Capacity

Can Solar Provide Firm Capacity?

aps

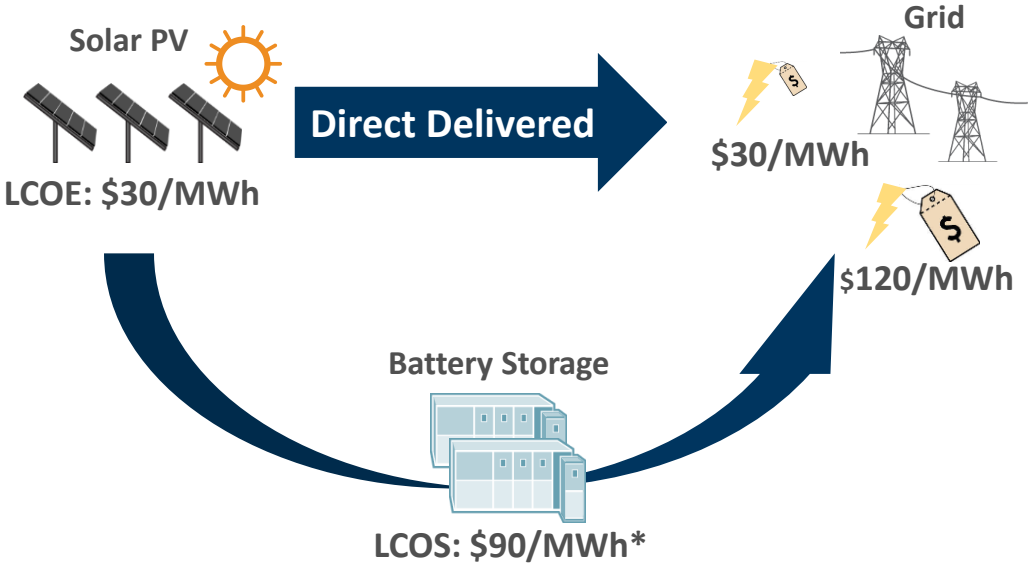
APS to install 50 MW, 135 MWh solar-shifting battery

First Solar®

PV + Storage LCOE (Levelized Cost of Electricity)

1. Cost of direct delivered energy from PV plant is equal to PV LCOE
2. Cost of shifted energy (delivered via storage) is: PV LCOE + Storage LCOS

Overall LCOE is weighted average of (1) and (2), depending on how much energy is delivered directly and how much is shifted



Example:

- 50% delivered directly
- 50% energy shifted

Overall PVS LCOE becomes:

0.5*$30 + 0.5*$120 =

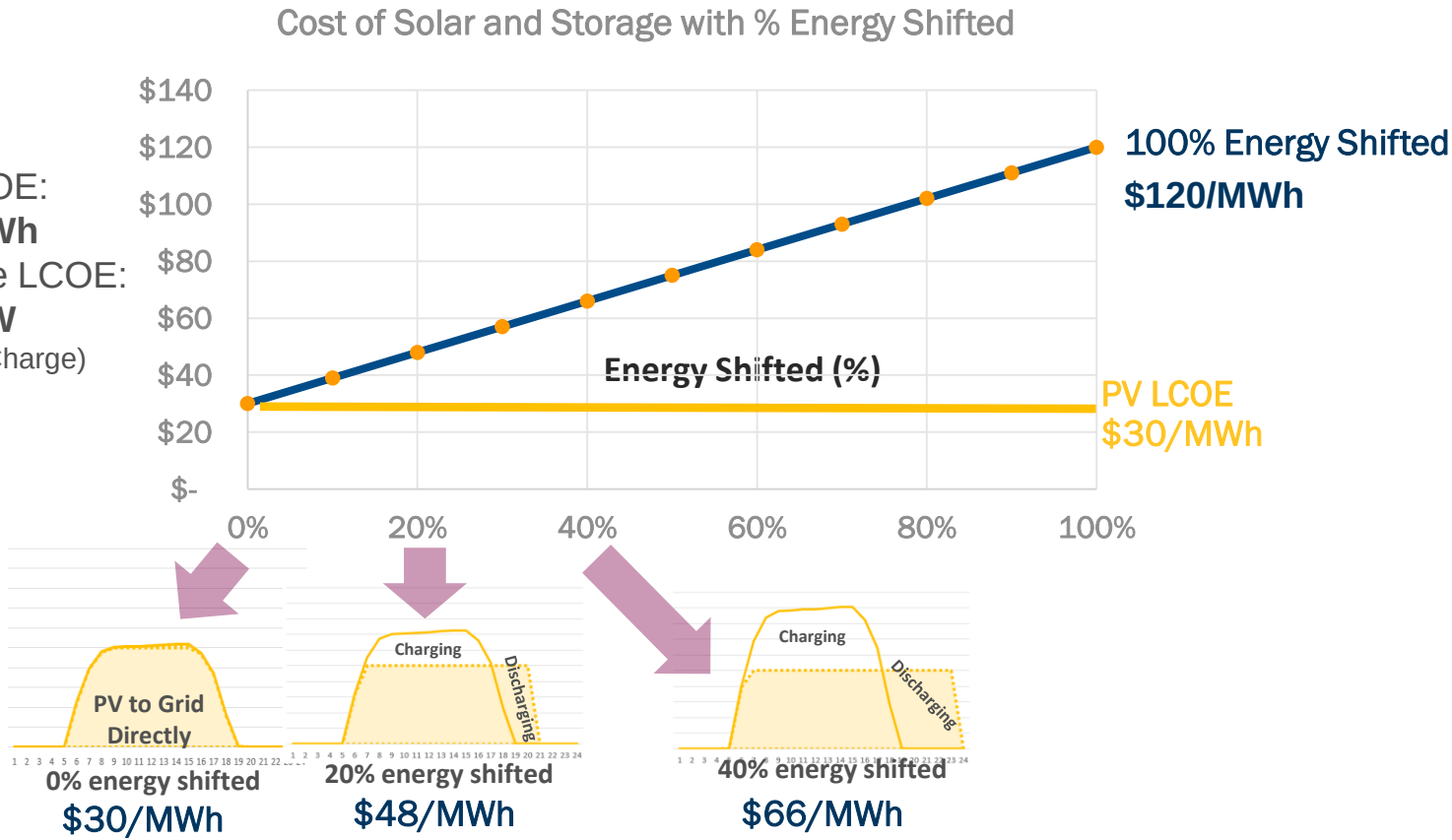
$75/MWh

(or $45/MWh increment)

**storage LCOS includes costs of energy losses, 1 cycle per day (about $200/kWh capacity)*

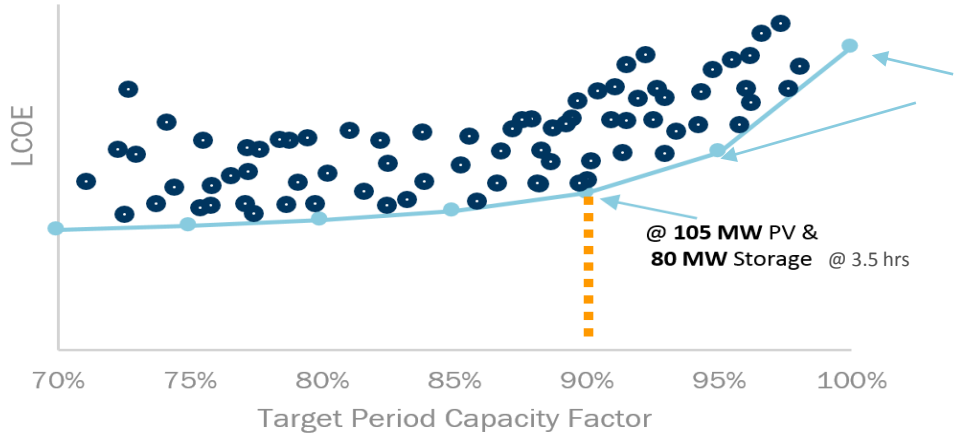
Desired Generation Profile drives PVS LCOE

- PV LCOE: **$30/MWh**
- Storage LCOE: **$90/MW** (Tolling Charge)



Bidder: Techno-Economic Sizing Optimization

- A developer can find the optimum mix of PV and Storage capacity that balances:
  1. Availability/Firmness during target period capacity factor (“TPCF”) window
  2. Cost of delivered energy (PVS LCOE or PPA price)
- TOD factors help guide the developer on determining charging hours
- Higher availability requirements by the customer result in higher PV and Storage capacity, and higher costs.



Each point on the line represents the optimum mix of PV and Storage capacity to achieve that availability (= TPCF) level

Target Period Capacity Factor: The Target Period Capacity Factor is a measurement of firmness/availability during a specific time window. It is the average power output during the target period over the course of a year, expressed as % of the project's power capacity (LGIA limit)

Storage Enhances Flexible Solar Value Propositions

Understanding the solution storage will solve drives sizing and cost

Increasing Amounts of Storage
(and Increasing LCOEs)

Regulation

- Smaller battery
- Designed for fast cycling

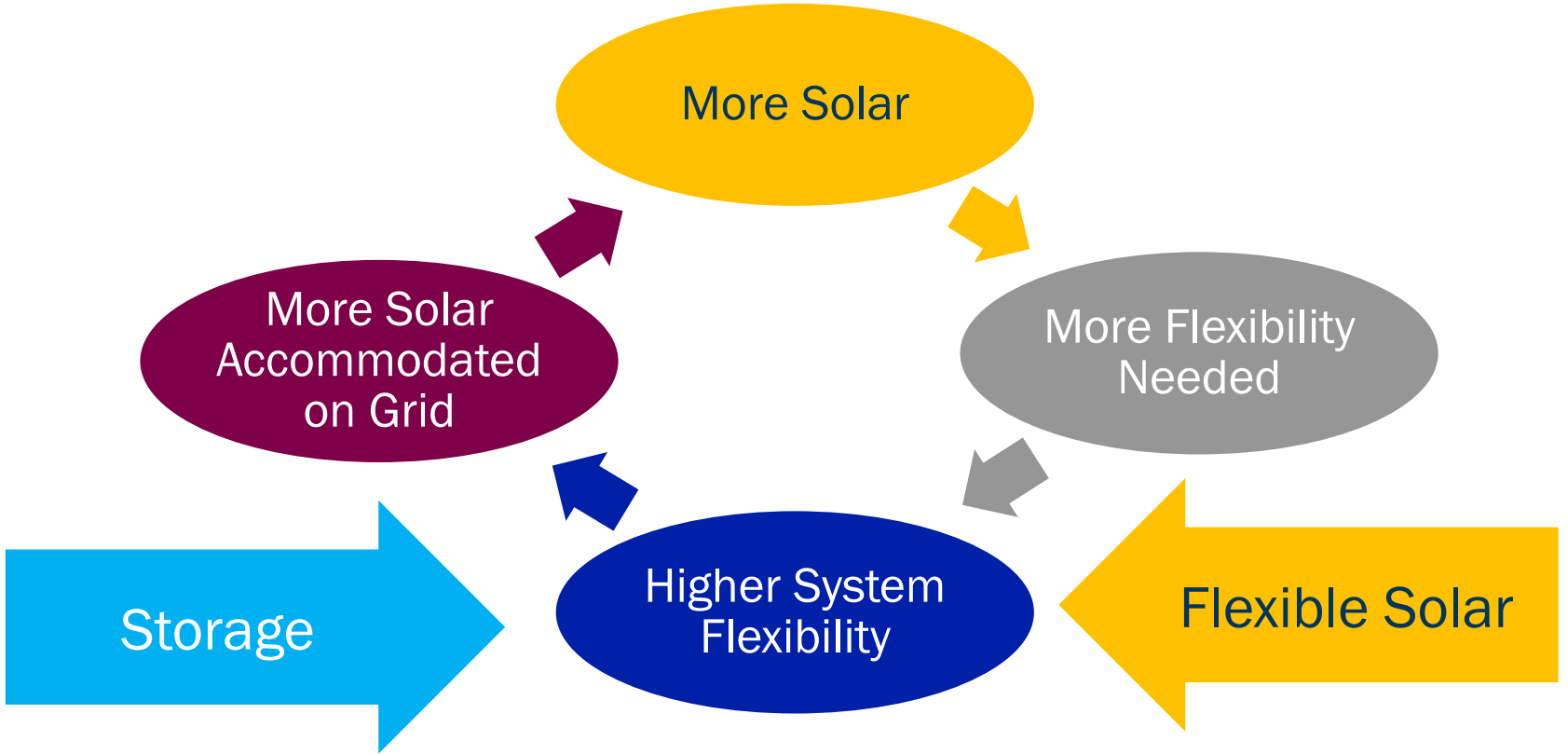
Target Period Dispatch

- Larger battery
- Fixed target dispatch period
- Typically firms output during periods partially covered by PV output

Firm Dispatch During any Hour

- Potential for largest battery
- Battery sized to supply all site output during period regardless of chosen hours that day
- PV sized to assure adequate charging even during low irradiance day

VRE Drive Need for Higher Flexibility



Solar Evolution

Better Integration And Scale Through Flexibility

Solar Energy

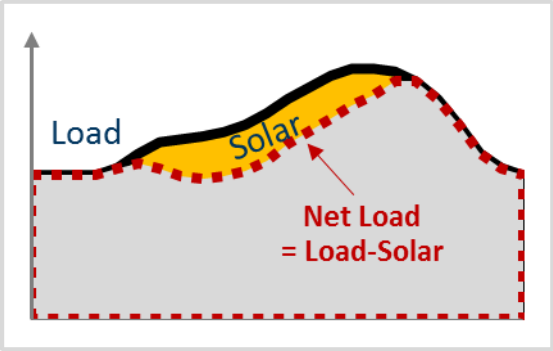
- Solar is part of mid-day load offsets peak or near-peak demand
- Energy-Only Value

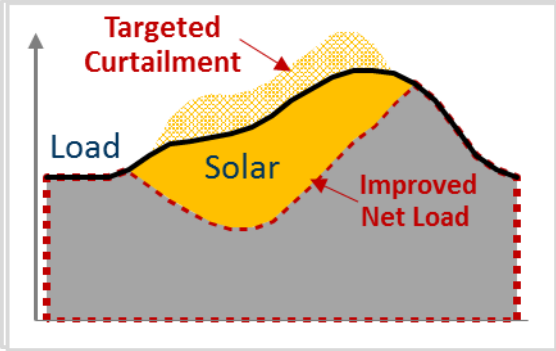
Grid Flexible Solar

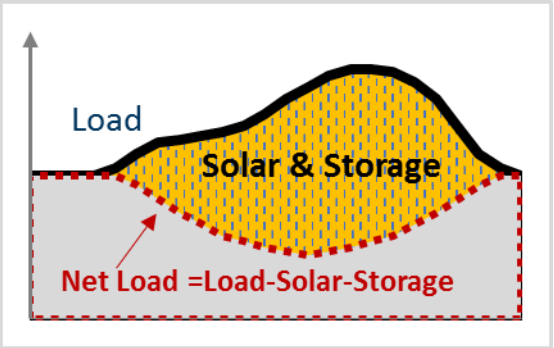
- Adds Grid Reliability Services & Flexibility Value

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

Solar Power Provides Energy, Flexibility and Capacity

- Utility-scale PV Solar **contributes to Grid Stability & Reliability**
- Utility-scale PV Plants provides **Essential Reliability Services** & **Grid Flexibility**
- Combined with **Storage**, Solar provides Clean & Competitive **Firm Capacity**

Enabling Flexibility in Procurement & Contracting

Flexible Solar Requires Evolution In Procurement & Operations

Key Considerations

- Create a PPA that enables off-taker/system operational flexibility and secures owner revenue visibility
- Reconcile reduced production and delivery of RECs with value of flexibility
- Balance the need for flexibility against firm dispatchability to understand storage requirements (if any)

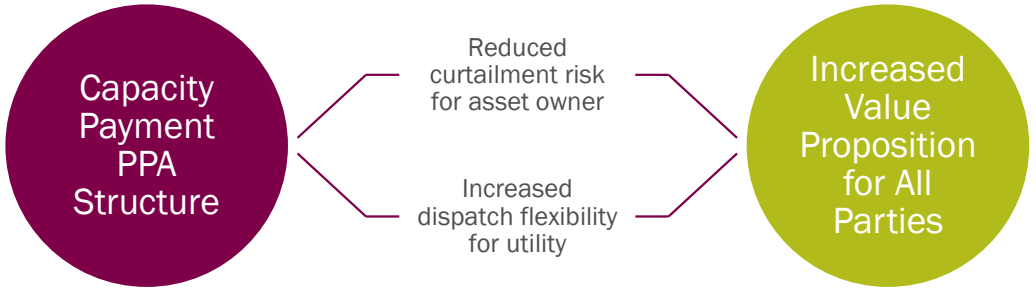
- Vertically-integrated utilities can dispatch owned assets for the best benefit to consumers
- Utilities procuring solar resources through PPAs historically prioritized production over dispatchability; however, these processes are evolving
- Solar resources are competing against conventional units on cost alone
- Integrating storage provides firm dispatchability, and the value proposition is readily apparent

Potential Avenues to Pursue

- Utility ownership and incorporation into economic dispatch stack
- Capacity and energy payments that contemplate a target % of system dispatch
- Tolling agreement that allows full dispatchability thru the inverter
- Discrete ancillary services revenue stream

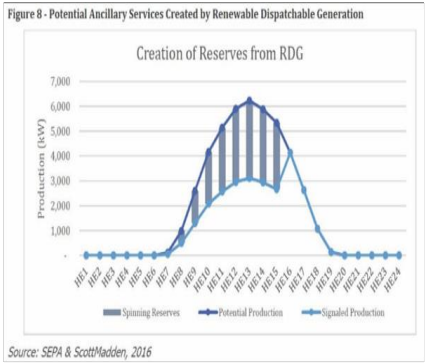
Capacity-Based PPA Structure - Benefits & Considerations

- Capacity payments <> take-or-pay agreements
  - Focus is on dispatch rather than curtailment
  - Dispatch creates incremental value streams
  - Revenue certainty results in more attractive financing
- Moving towards a capacity payment PPA structure requires the incorporation of additional metrics and associated performance guarantees
  - System dispatchability performance
    - MW/min
    - PV and storage availability
    - Accuracy
  - PV degradation
  - Storage degradation



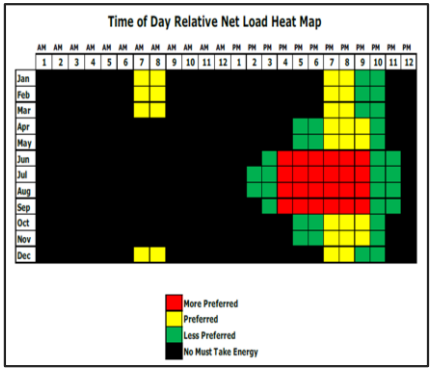
Early Movers on Dispatchable Renewable Procurement

Hawaiian Electric



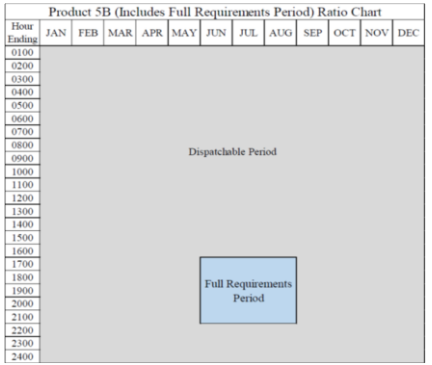
- New PPA balances curtailment risk, creates the opportunity for essential grid services, and results in financeable projects
- Lump sum payment structure
- In Dec 2018, the Companies filed 7 PPAs totaling 262 MW of solar with 4 hours of storage

APS



- RFP designed to meet evening peak needs
- First Solar won the RFP, competing on economics alone against conventional generation, with a 65 MW solar project coupled with a 50 MW / 135 MWh battery system

NV Energy



- NV Energy RFP required dispatchable renewable resources
- Project must respond to AGC signals every four seconds and dynamically operate at or below the instantaneous maximum output of the resource

Next Steps

Policymakers

- Ensure proper value is placed on solar's capacity, energy, and grid flexibility
- Collaborate on new PPA constructs that contemplate the provision of (and payment for) flexible dispatch
- Variable renewable energy resources should be modeled as having dispatch flexibility in IRP processes

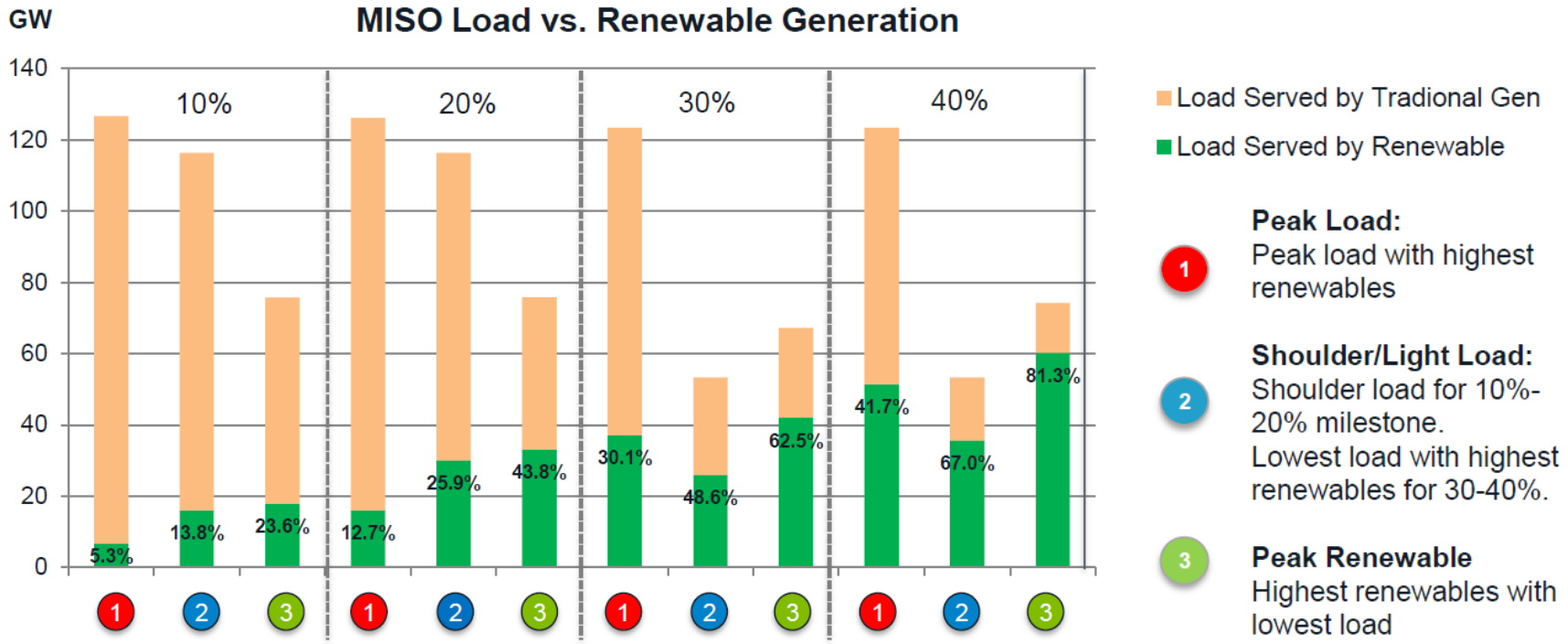
Grid Operators

- Value flexibility in all resources
- Prioritize units that are the most efficient in meeting dispatch signals
- Increase reliance on variable renewable energy resources to provide capacity and essential grid services

Backup

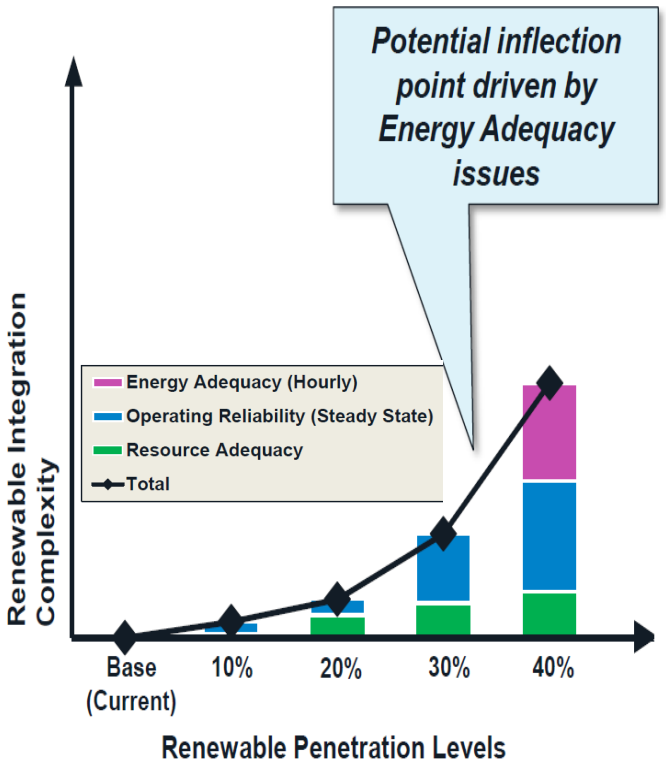
Industry Concerns

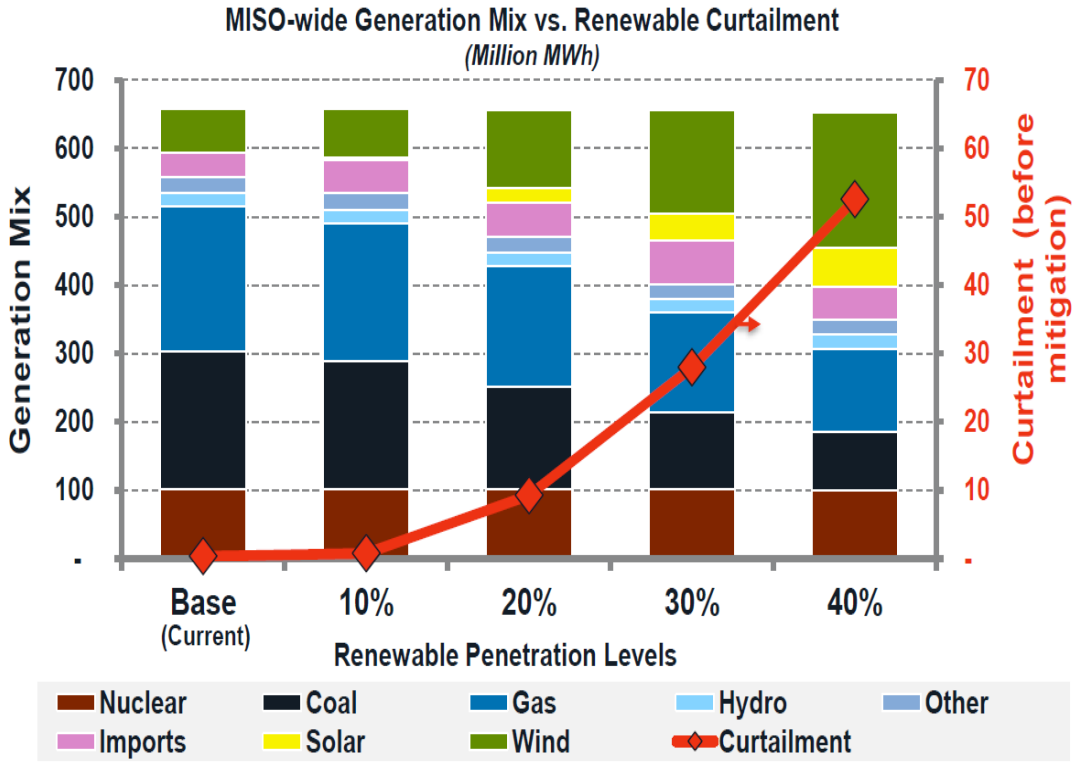
Integration Complexity Increases Sharply at 40%



Source: Jordan Bakke, MISO: Renewable Integration Impact Assessment, ESIG Presentation, March 2019

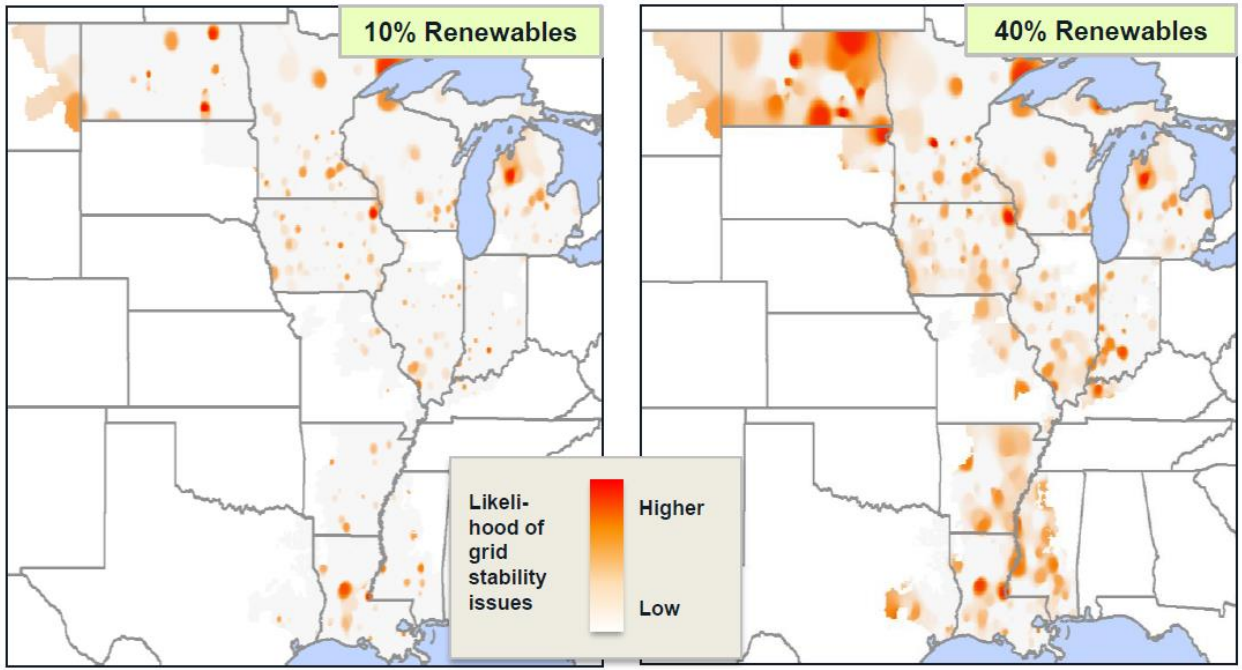
Increasing Curtailment of Renewables





Source: Jordan Bakke, MISO: Renewable Integration Impact Assessment, ESIG Presentation, March 2019

Power System Stability Concerns Increase



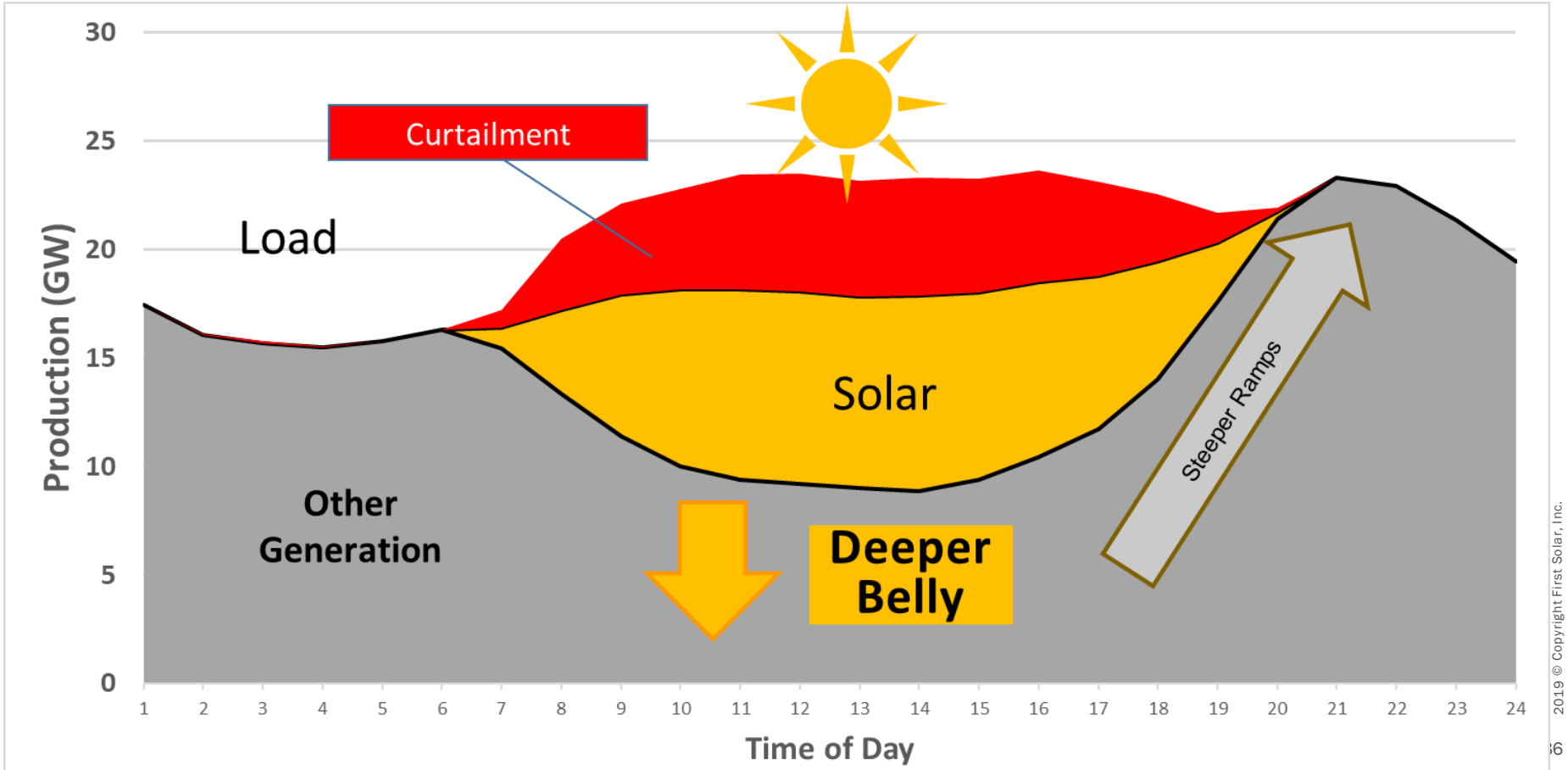
- Stability concerns are driven by the reduction in conventional generation and the increase in inverter based generation
- Additional system reinforcement is needed (e.g., more transmission, keeping more conventional generation online, grid forming inverters)

Weighted Short Circuit Ratio (WSCR) is used as an indicator of the system's strength to deal with disturbances at high renewable penetrations

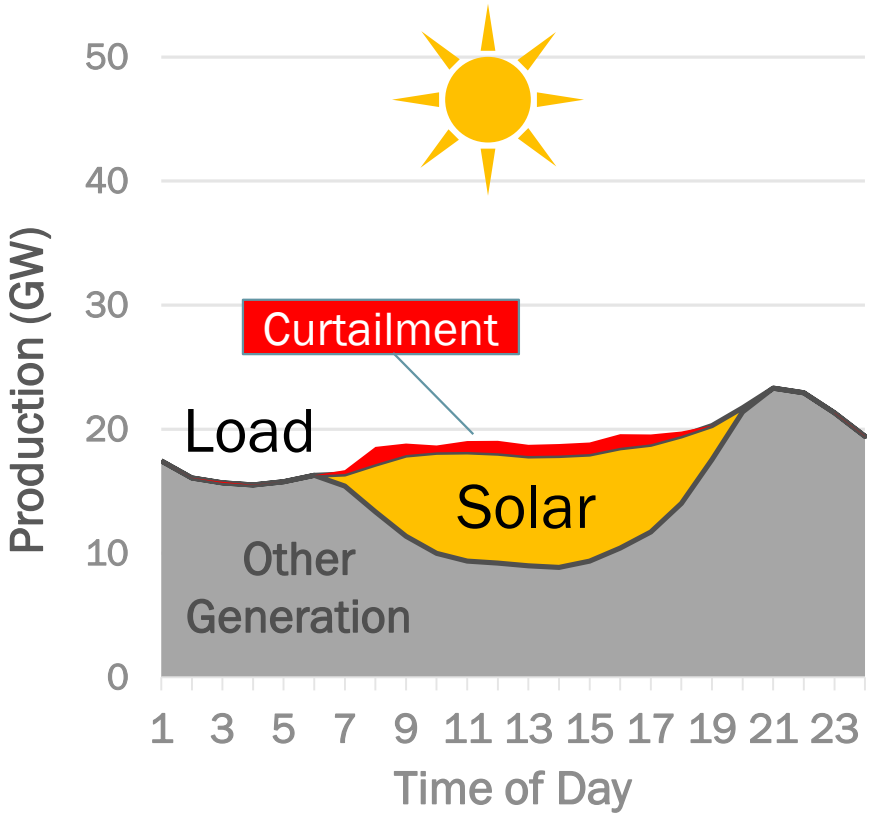
Source: Jordan Bakke, MISO: Renewable Integration Impact Assessment, ESIG Presentation, March 2019

System Integration is the Next Challenge

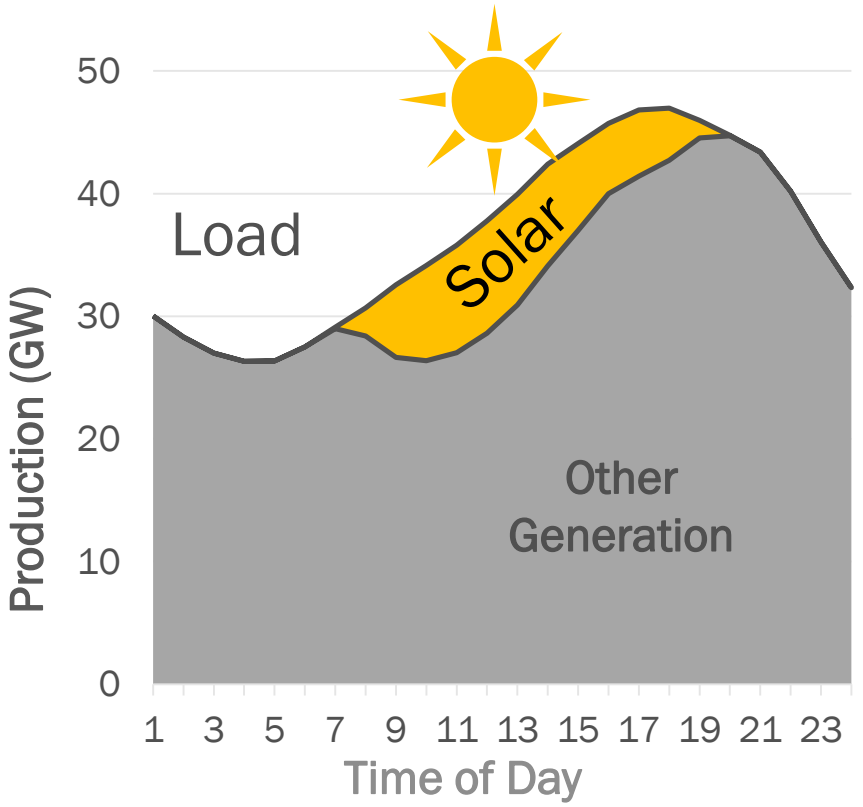
California “Duck Curve”



Low Load Day

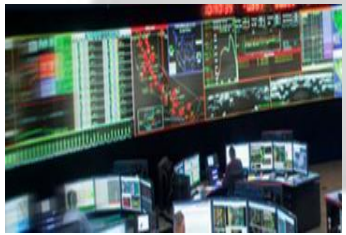


High Load Day



R&I Opportunities (Presented at EU SET Plan Nov '18)

Increasing Cost



Markets & Operations

Demand Response

Grid Expansion

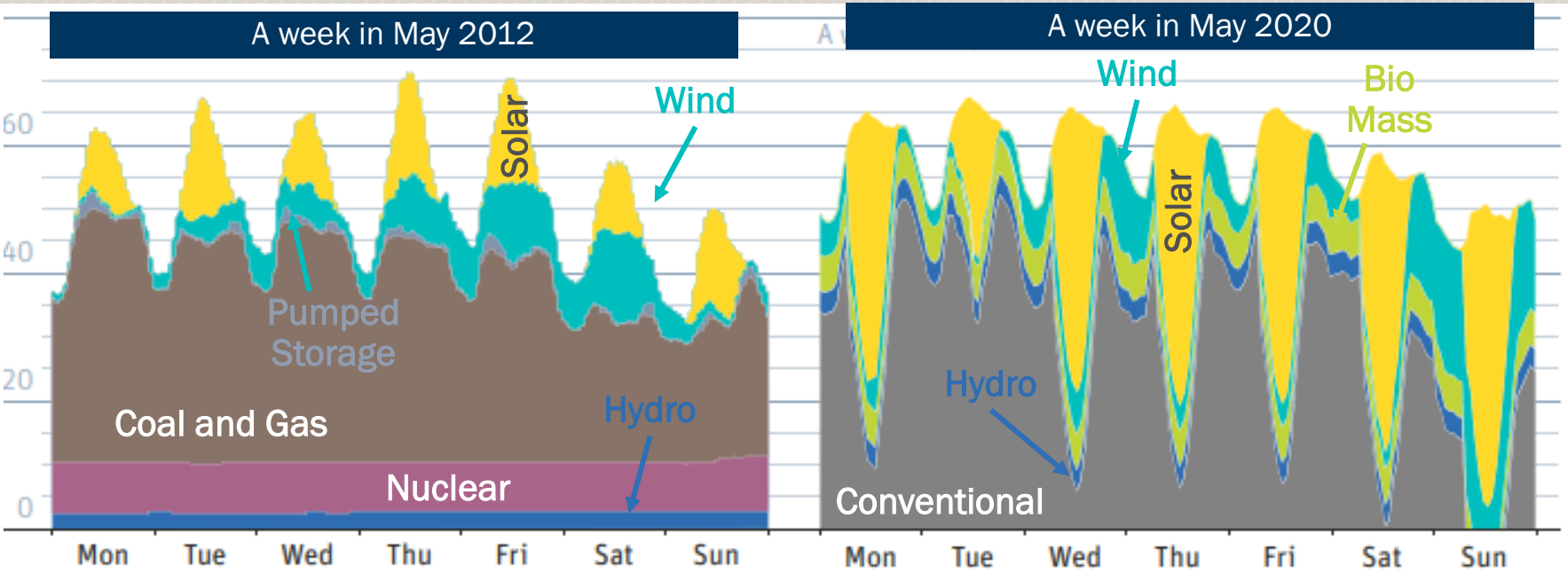
Flexible Generation

Energy Storage

Increasing Flexibility

Grid Integration Challenges

Renewables Driving Significant Change in Operations

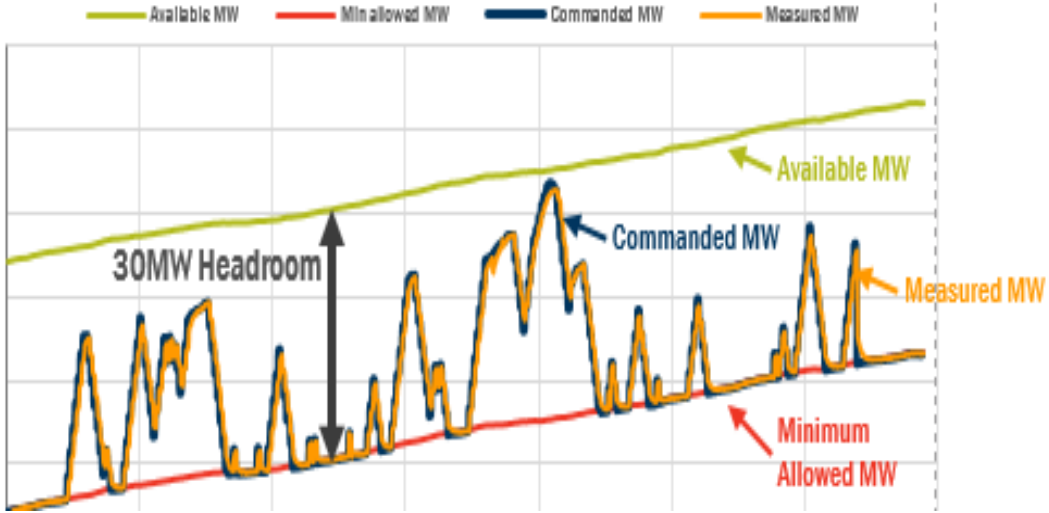


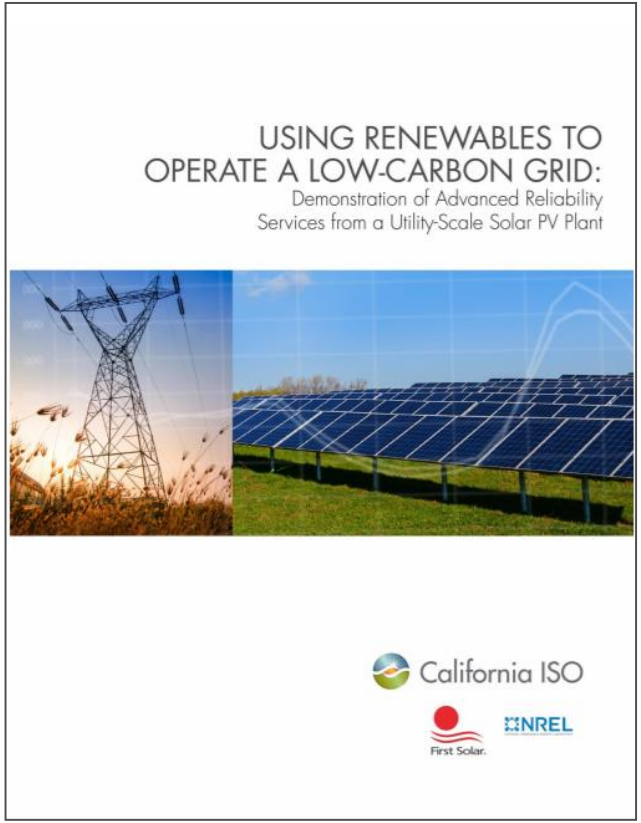
Source: Energy Transition: The German Energiwende, July 2016

Intermittency

Need flexible, dispatchable power generators that can ramp up and down every day within just a few hours

Solar Provides Reliability Services



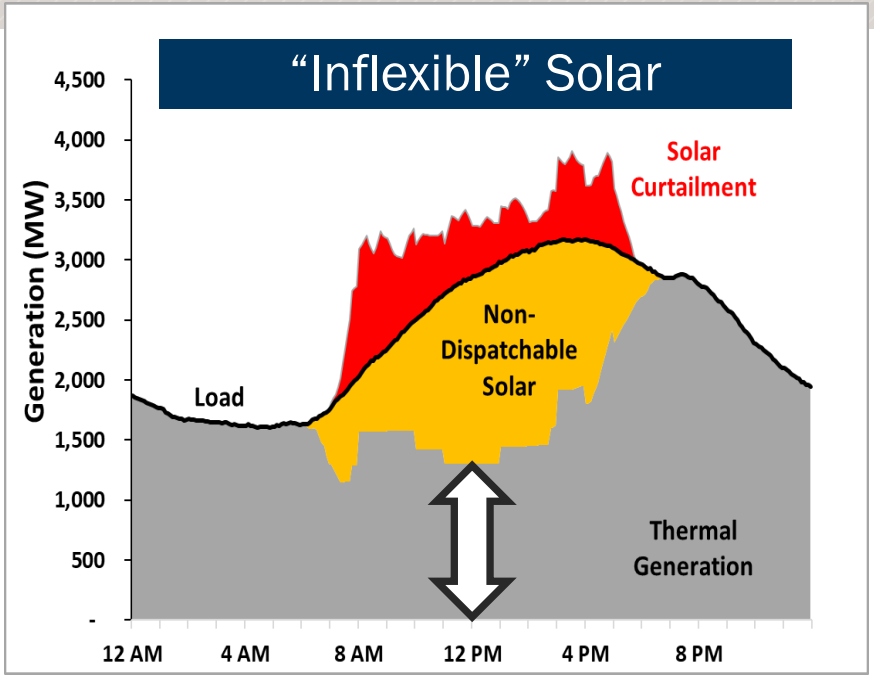


Intermittency

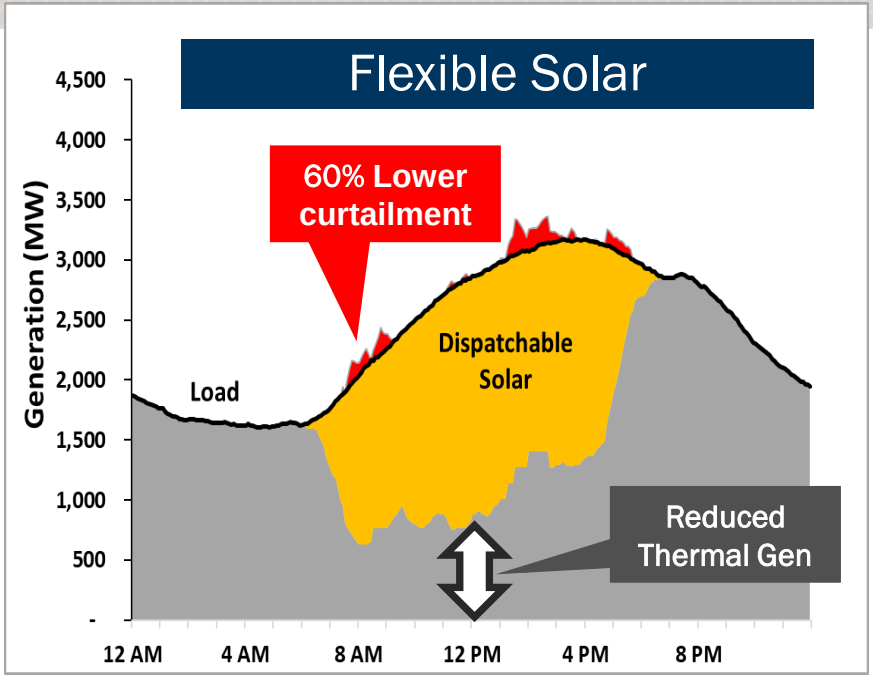
Grid Reliability & Stability

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

Flexible Solar Reduces Curtailment – An Illustration



Solar Provides No Regulation Reserves



Flexible Solar: Provides regulation reserves.

Intermittency → **Grid Reliability & Stability** → **Flexible Generation**

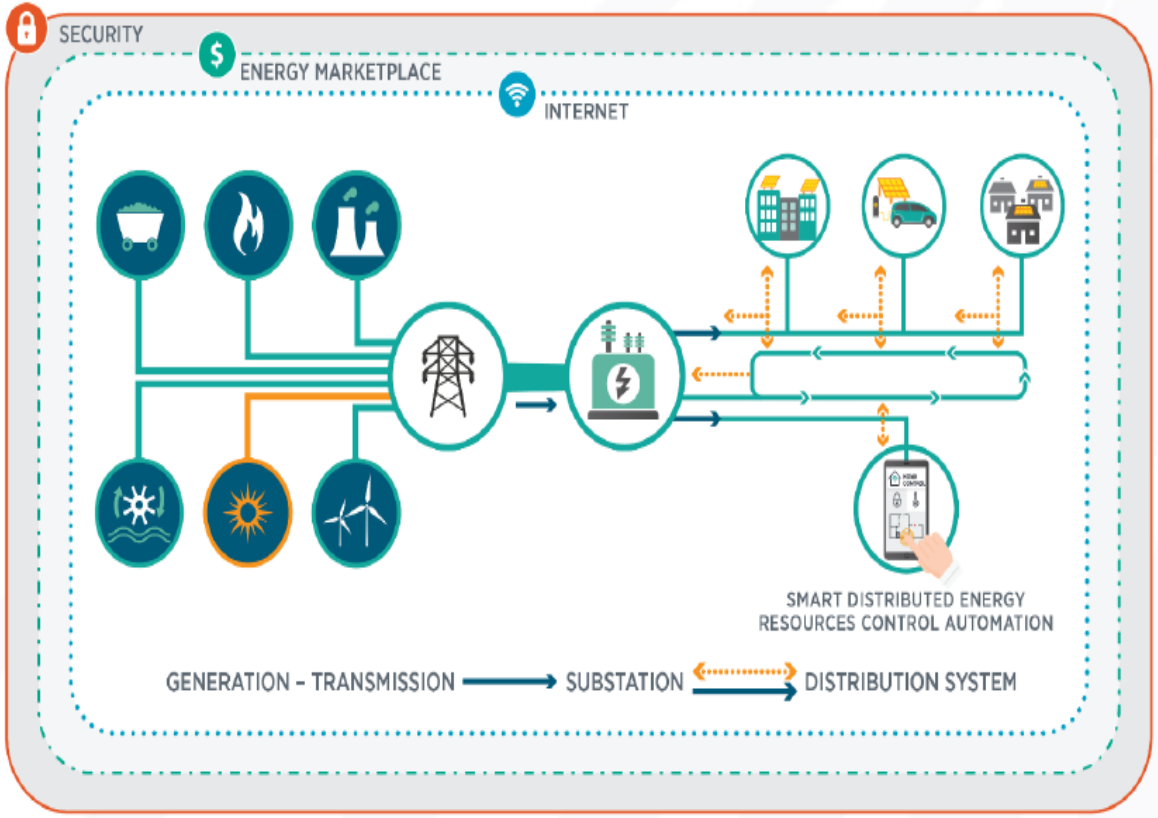
Source: E3,TECO, First Solar Report "Investigating the Economic Value of Flexible Solar Power Plant Operation", https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf

Solar + Storage Provide Clean Dispatchable Generation

The Industry is Changing and So Should We

- Profound shifts are taking place in the industry…
  - Continuing dramatic price reduction in wind, solar and storage technologies
  - Rapid deployment of distributed PV and growing interest in battery storage
  - Forecasting at all levels of spatial and temporal resolution and integration of forecasting into planning and operations
  - Market design and operation for high penetration VG future
  - Power system dynamics with high penetration of VG
- Shift from integrating renewables in the power system to integrating across systems (electric, heat, fuels) for decarbonization of the energy
- Continuing need for education and solving new problems

Technical Challenges Of An Evolving Electric Grid



- 3D: De-Carbonization, Distributed, Digitization
- Increased Complexity of Ensuring Reliable, Resilient, Secure and Affordable Electricity
- Electro-mechanical => Digital Power Electronics Based System
- Limited Operation and Control => Complex Operation with VREs
- Coupling with other Energy Sectors

Graphics Source: Guohui Yuan, Future System Impact of DOE Solar Integration Activities, DOE Sunshot Program

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

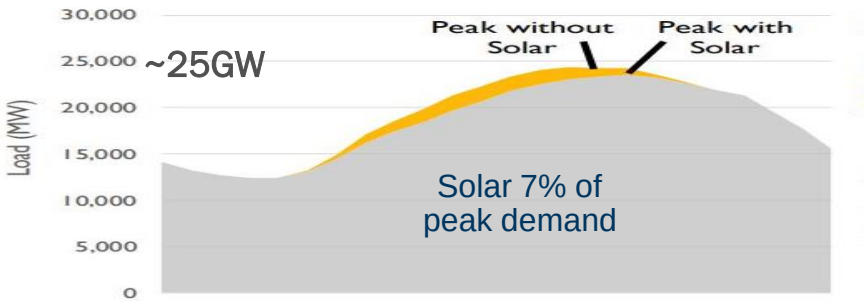
SEPTEMBER 4, 2018 JOHN WEAVER

The duck curve comes to New England

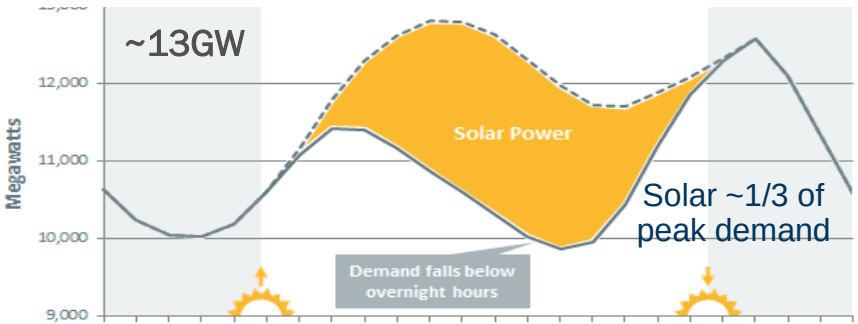
- Electricity price -$2.65/MWh at 3 PM.

MAY 8, 2018 CHRISTIAN ROSELUND

July 3, 2018



April 21, 2018

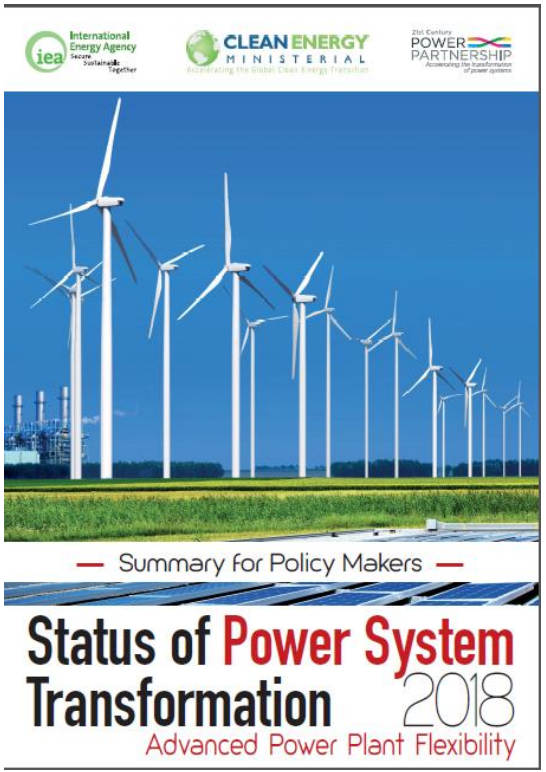


Goal: Increase system value through more solar … while dealing with intermittency challenges on the grid

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/

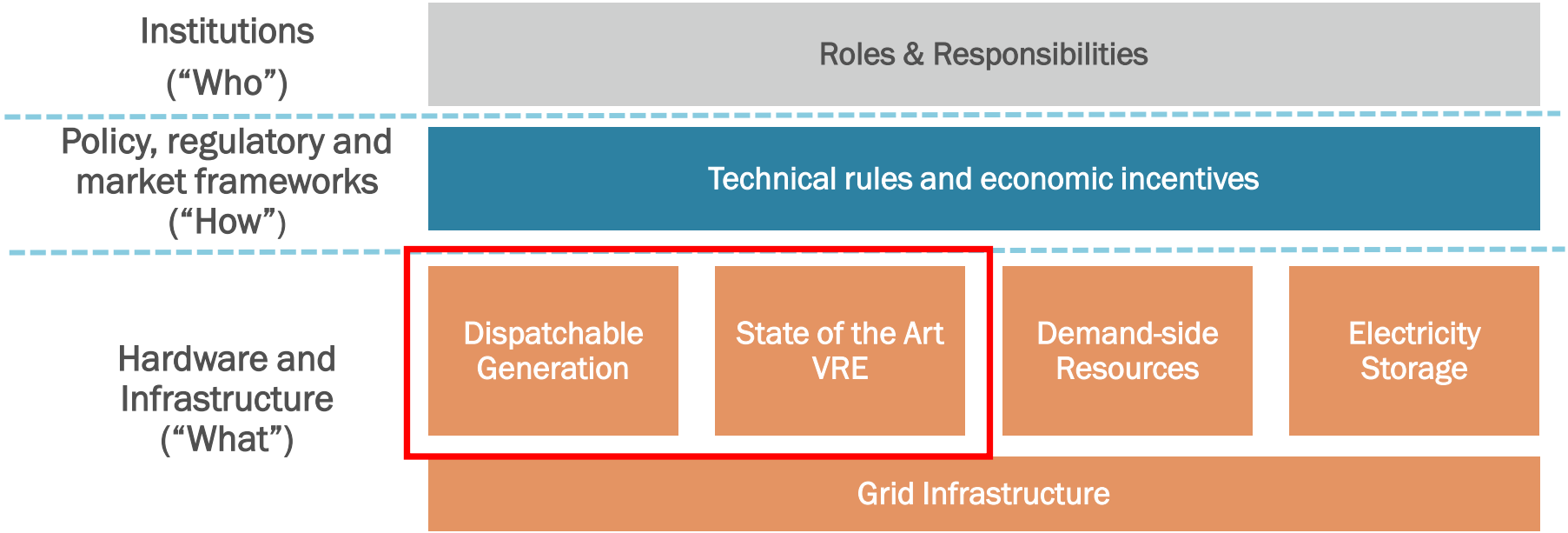
Power System Transformation … *Need Higher Level of System Flexibility*

- 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

Relevant Dimension for Understanding and Unlocking System Flexibility



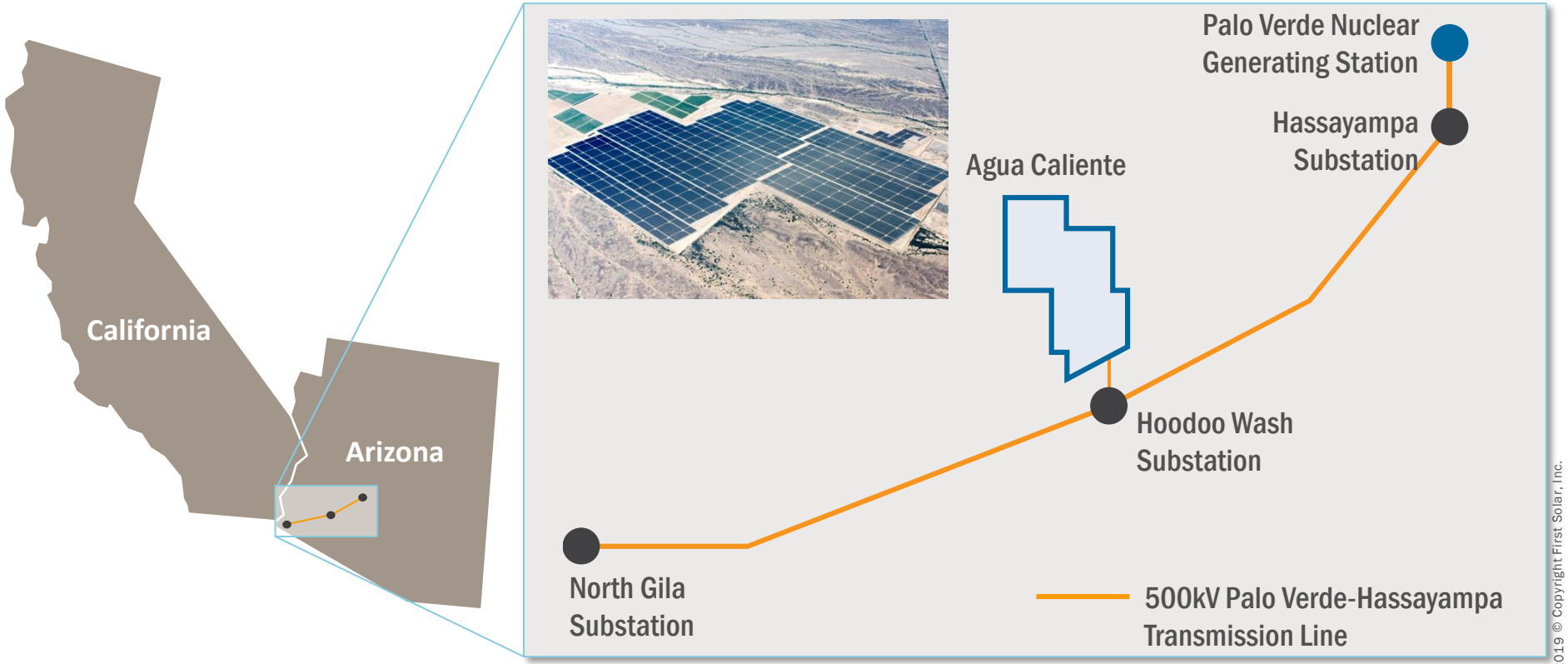
Source:"Status of Power System Transformation", 2018, IEA Report, https://webstore.iea.org/status-of-power-system-transformation-2018
VRE: Variable Renewable Energy

Key Takeaways – Grid Flexibility from Utility-Scale PV Plants

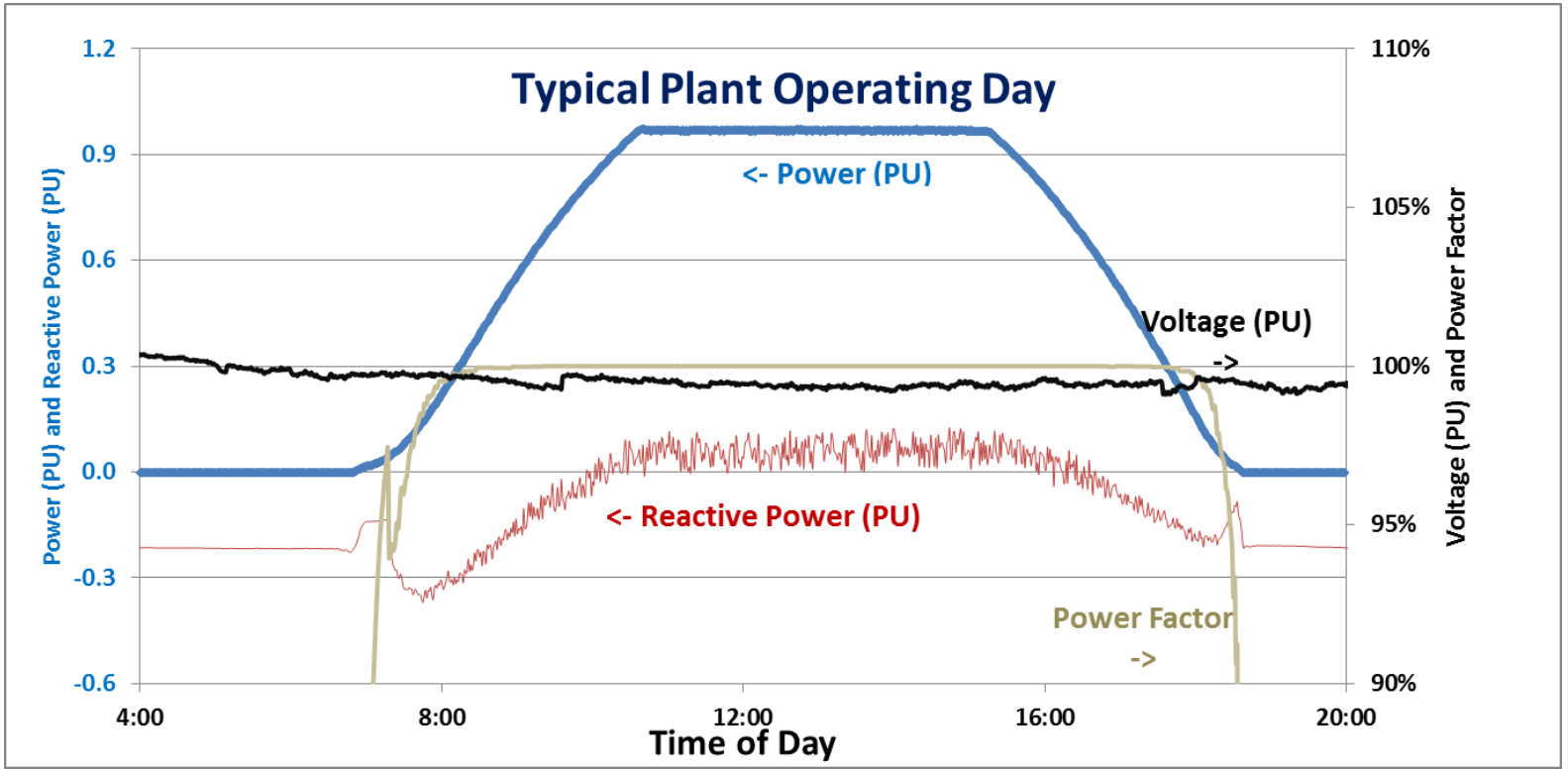
- Higher penetration of VRE (Variable Renewable Energy) needs *Increased System Flexibility* to manage variability & uncertainty on the grid and *reduce potential VRE curtailment*
- Utility-scale PV Plants Can Provide *Grid Flexibility & Essential Reliability Services*
- "VREs with *the right operating 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

Agua Caliente 290MW (AC)

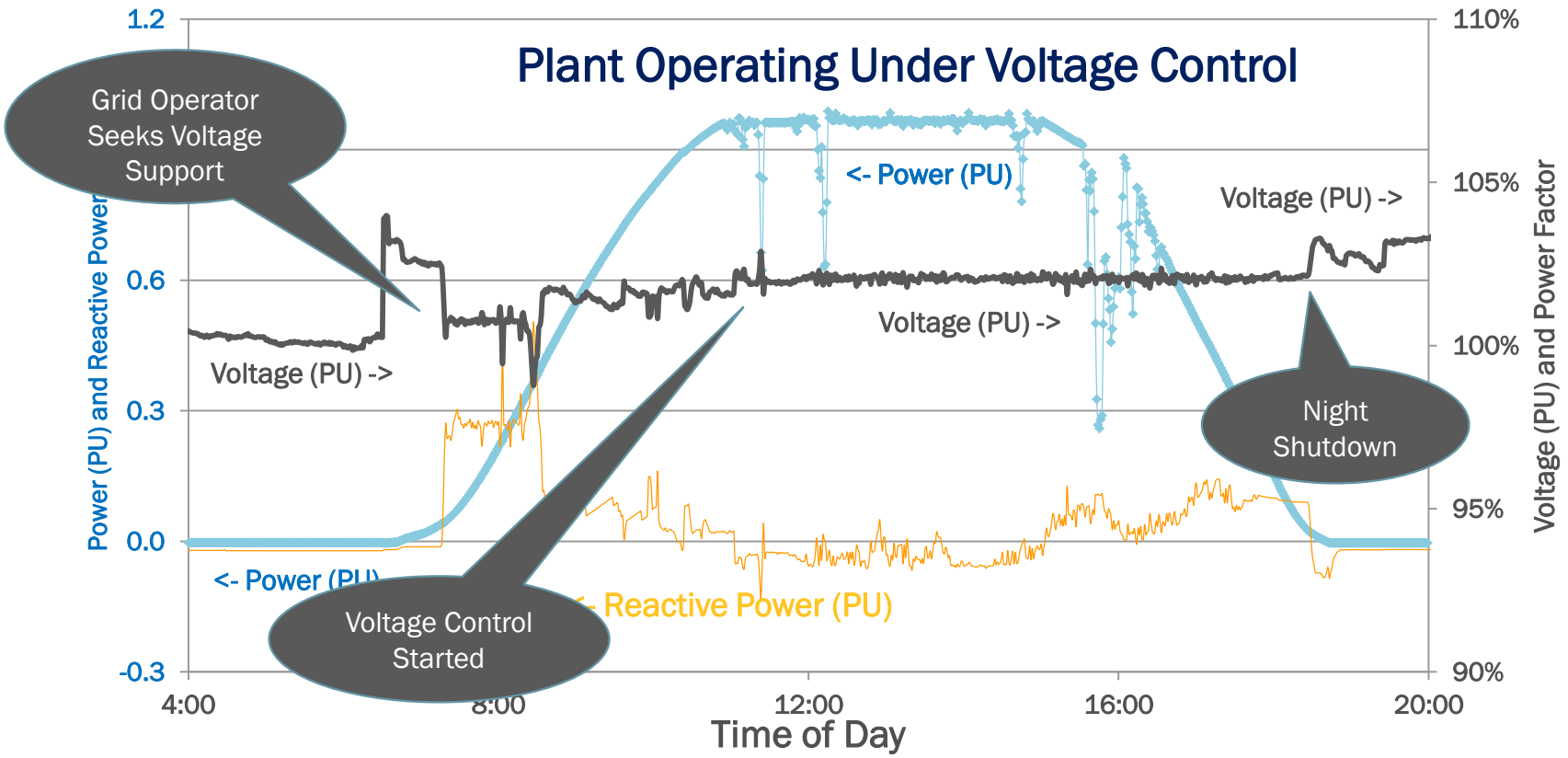


Typical Plant Operation (Unity Power Factor)

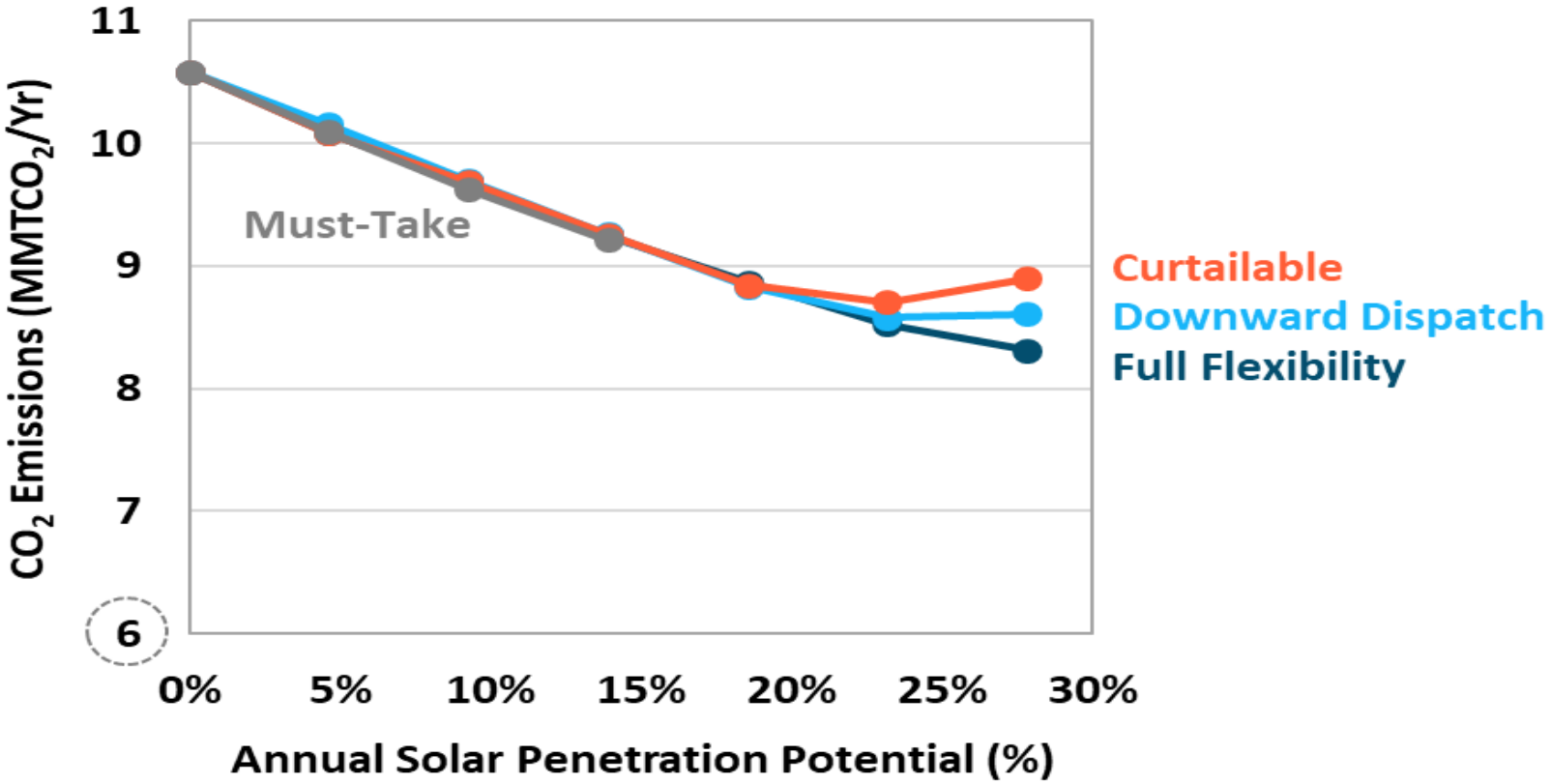


March 21st 2014 Event

VOLTAGE SUPPORT FROM PV PLANT DURING ABNORMAL CONDITION

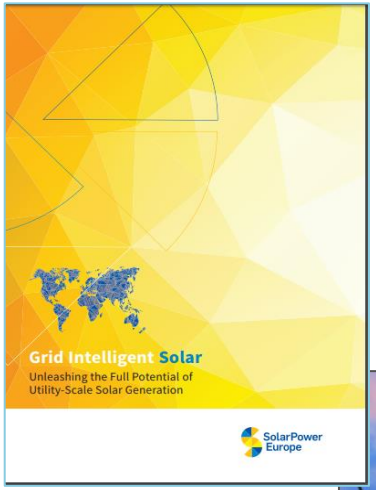


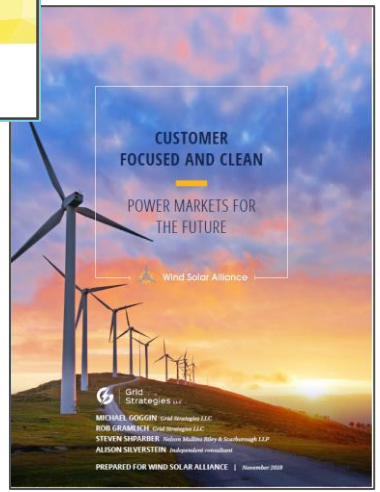
CO_2 Emissions w Solar Penetration



Regulatory, Market and Policy Recommendations

- Attract flexible solar (VRE) through open participation and efficient market pricing
- Allow flexible solar to participate in all reliability services markets
- Ensure capacity markets reflect true capacity contribution of solar
- Favor lowest cost resources with the most flexible capabilities





Lower system costs and reduce emissions

http://www.solarpowereurope.org/wp-content/uploads/2018/12/4018_SPE_Grid_Intelligent_Solar_report_05_hr.pdf

https://windsolaralliance.org/wp-content/uploads/2018/11/WSA_Market_Reform_report_online.pdf