2021 NERC-EPRI-NATF Planning and Modeling Virtual Seminar

November 3, 2021

Day 1 – Planning for a Decarbonized Grid

Policy Reminders

- Open forum
- Obey antitrust laws and guidelines
- Adhere to your organization’s standards of conduct
- Protect confidential information and intellectual property

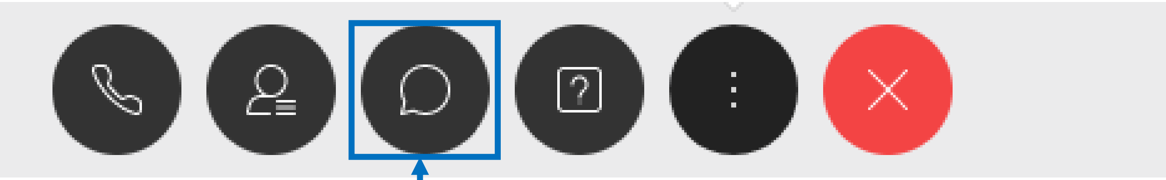
Logistics for Meeting

- All lines were muted on entry
- Attendees may use chat to ask questions or make comments
- Questions will be taken as time permits for each presenter
- Presentations will be posted after the event
  - www.natf.net
  - www.epri.com

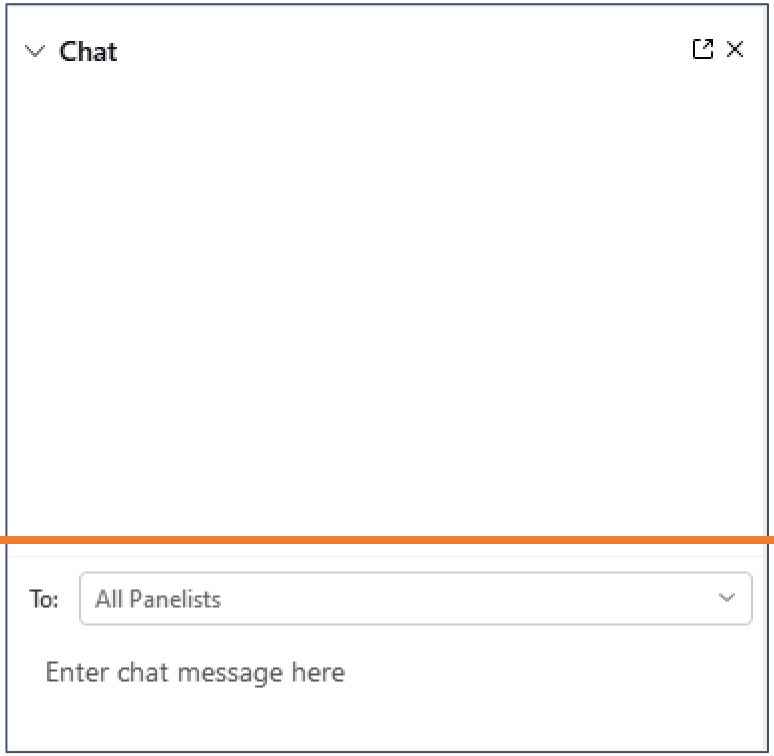
Using the chat feature:

Chat Feature

OR



Chat Feature



Welcome and Introduction

Andy Balascak – *NATF*
Anish Gaikwad – *EPRI*
Ryan Quint – *NERC*

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Agenda

Day One – Planning for a Decarbonized Grid

Session 1 – Integrating the Changing Resource Mix into the Bulk Power System		
Time (ET)	Topic	Presenters
1:00 p.m.	**Welcome and Introduction**	NATF - Andy Balascak EPRI - Anish Gaikwad NERC - Ryan Quint
1:15 p.m.	**Queued Up**	LBNL – Joseph Rand
1:45 p.m.	**Technology Perspectives**	Terabase Energy – Dr. Mahesh Morjaria
2:15 p.m.	**Transmission Planning for Clean Electricity**	ESIG – Dr. Debra Lew
2:45 p.m.	**Break**	
2:55 p.m.	**Planning Experiences for Integrating Changing Resource Mix with Audience Q&A** Moderated by Gayle Nansel – WAPA	Xcel Energy - Hari Singh CAISO – Irina Green MISO - Amanda Schiro Southern Co. - Cindy Hotchkiss
4:00 p.m.	**Day One Wrap-up**	NATF - Andy Balascak

Queued Up

Joseph Rand

Lawrence Berkely National Lab

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Queued Up:

Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2020

Joseph Rand, Mark Bolinger, Ryan Wiser, Seongeun Jeong

Lawrence Berkeley National Laboratory

This work was funded by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.
The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Photo source: National Renewable Energy Laboratory

Contents

- Methods and Data Sources
- Completed and Withdrawn Projects Summary
  - Duration in queues
  - Completion percentages
- Active Queue Projects Summary
  - Trends over time
  - Regional trends
  - Expected online year and interconnection status
  - Duration in queues
  - Hybrid projects
- Conclusions & Next Steps

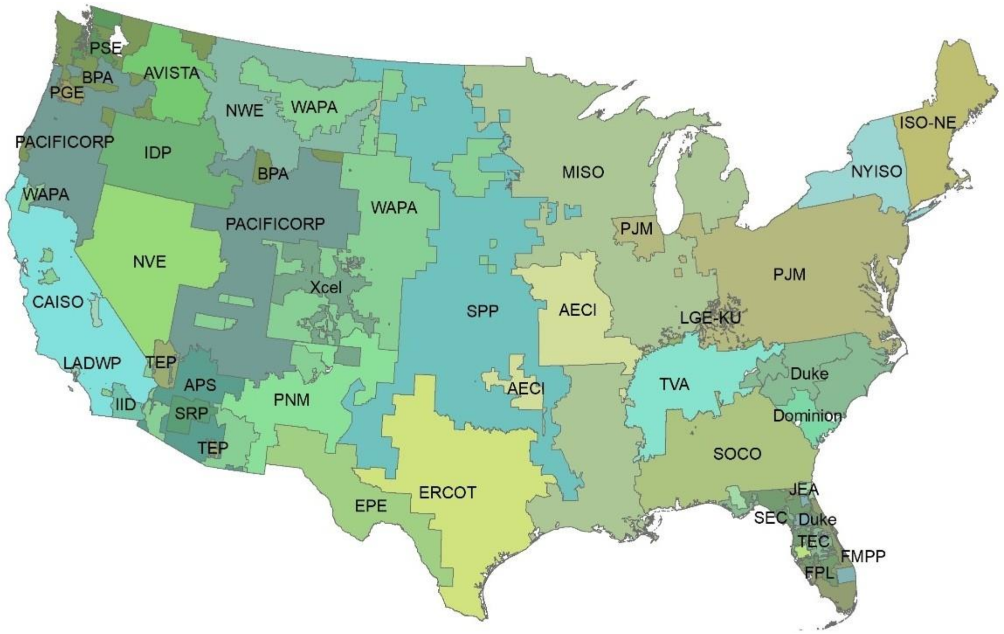
What are interconnection queues?

Utilities and regional grid operators (a.k.a., ISOs or RTOs) require projects seeking to connect to the grid to undergo a system impact study before they can be built. This process establishes what new transmission equipment or upgrades may be needed before a project can connect to the system and assigns the costs of that equipment. The lists of projects in this process are known as “interconnection queues”.

Visit https://emp.lbl.gov/publications/queued-characteristics-power-plants to download the data used for this analysis and to access an interactive data visualization tool

Methods and Data Sources

- Data for “active” projects collected from interconnection queues for 7 ISOs / RTOs and 35 utilities, which collectively represent >85% of U.S. electricity load
  - Projects that connect to the bulk power system: not behind-the-meter
  - Includes all projects in queues through the end of 2020
  - Sample includes 5,639 “active” projects
- “Completed” and “Withdrawn” project data were only available for 5 ISOs (CAISO, ISO-NE, MISO, NYISO, PJM)
  - Sample includes 1,706 “completed”, and 6,896 “withdrawn” projects.
- Hybrid / co-located projects were identified and categorized
  - Storage capacity for hybrids (i.e., broken out from generator capacity) was not available in all queues
- Note that being in an interconnection queue *does not guarantee* ultimate construction: majority of plants are not subsequently built



Coverage area of entities for which data was collected
Data source: Homeland Infrastructure Foundation-Level Data (HIFLD)

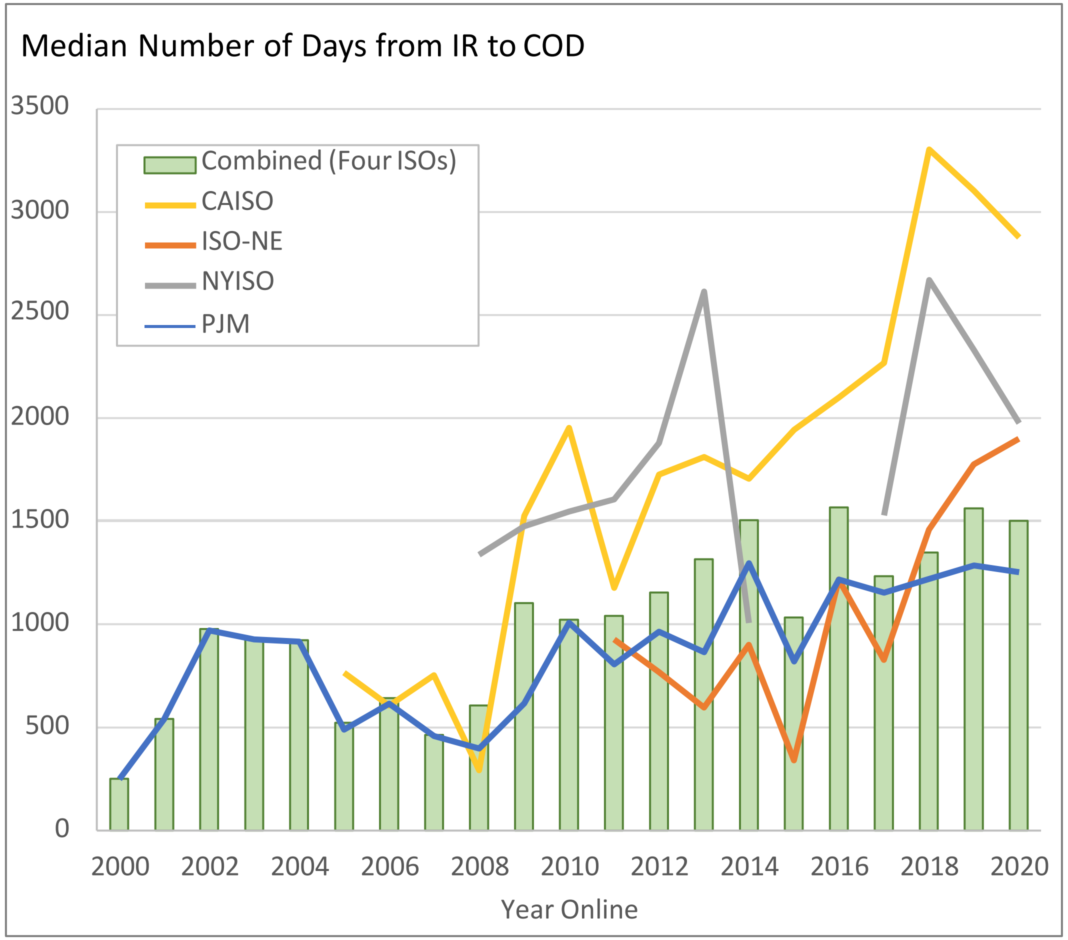
Completed and Withdrawn Projects

Completed and withdrawn data were available from 5 ISOs, and total 1,706 completed projects and 6,896 withdrawn projects.

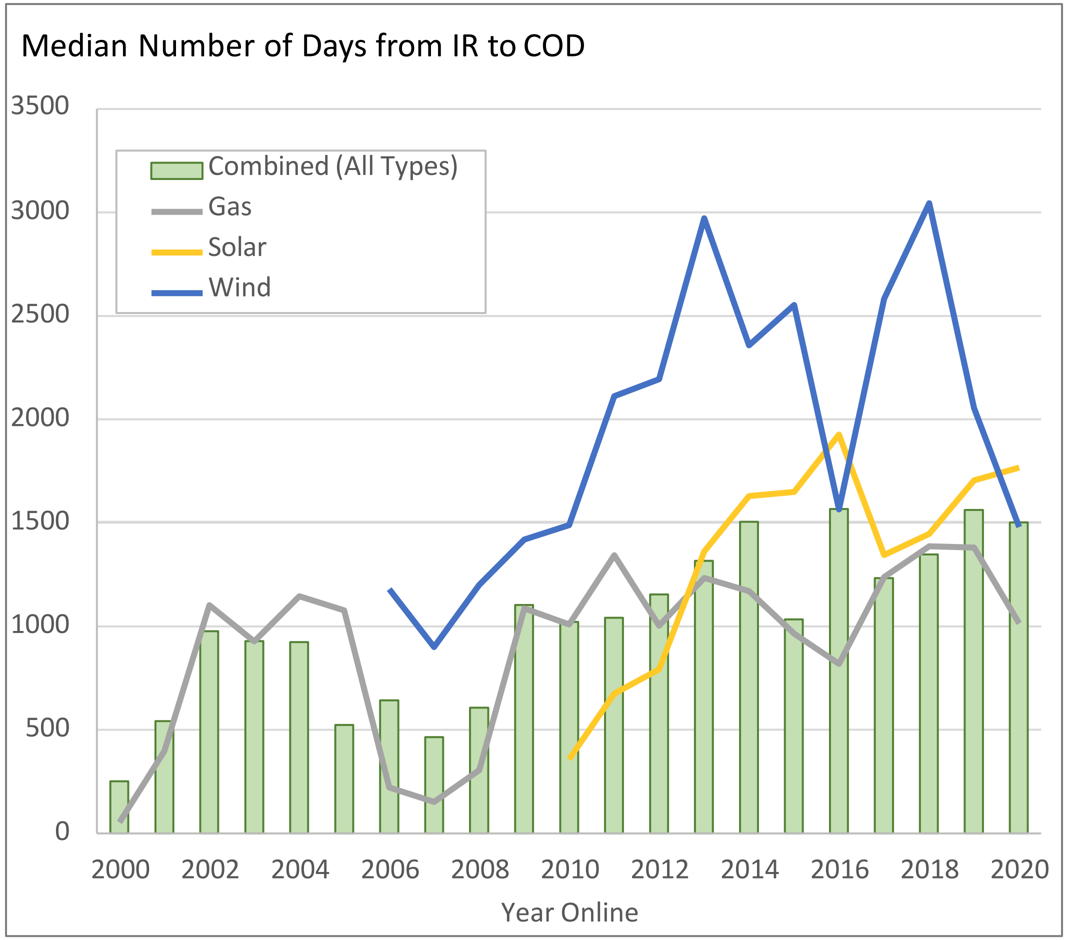
ISO	*n* (Completed)	*n* (Withdrawn)
CAISO	179	1,381
ISO-NE	84	377
MISO	407	1,591
NYISO	86	563
PJM	950	2,984

The time from interconnection request (IR) date to commercial operations date (COD) is increasing for some regions and generator types; typically longer for CAISO and for wind

Completed Projects: Time in Queue, by ISO



Completed Projects: Time in Queue, by Resource



Year	Completed Projects
2000	10
2001	20
2002	27
2003	23
2004	28
2005	25
2006	37
2007	49
2008	69
2009	52
2010	60
2011	81
2012	76
2013	82
2014	72
2015	114
2016	134
2017	82
2018	88
2019	71
2020	73

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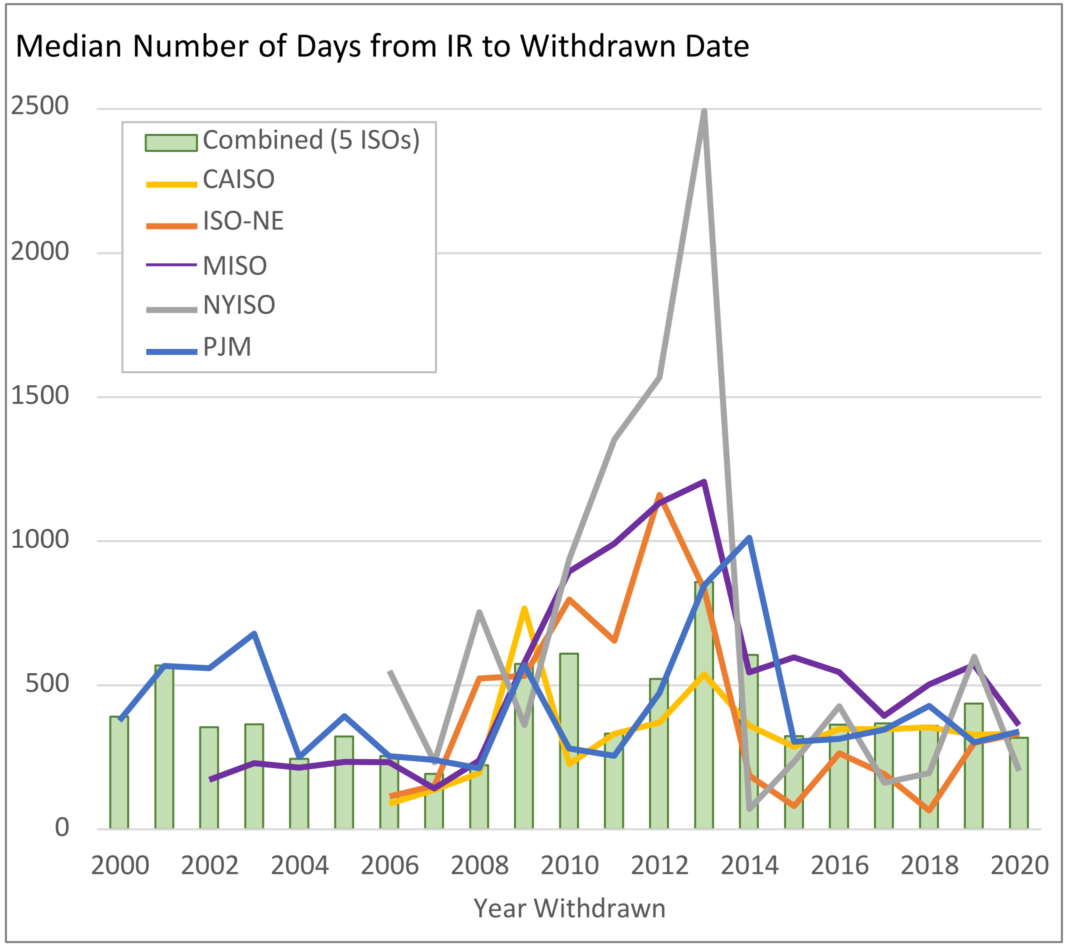
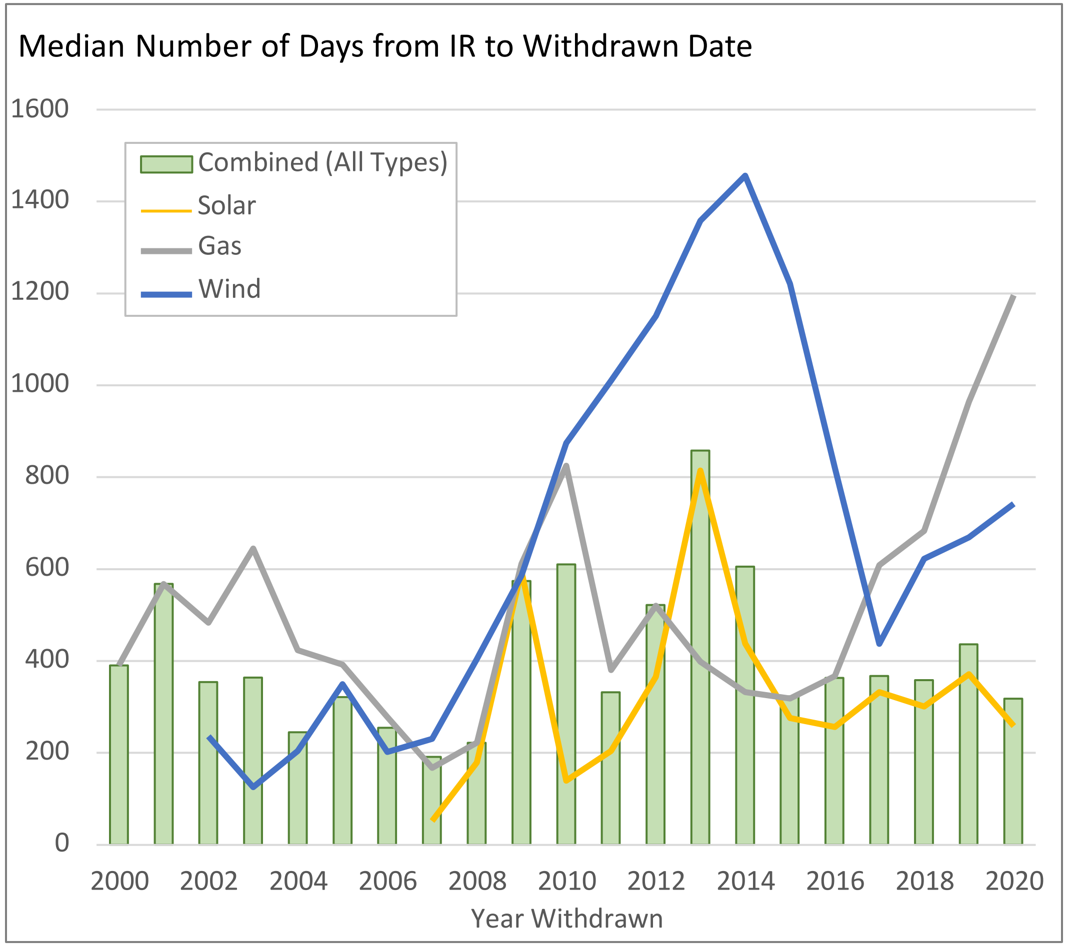
Notes: (1) Data on completed projects were only collected for five ISOs, though only the four shown provided COD. (2) Data are only shown where sample size is >3 for each year. (3) "Time in queues" is calculated as the number of days from the queue entry date to the commercial operations date

Trends are less evident in time from interconnection request to withdrawn date, though a series of queue reforms from 2010-2012[1] *may* have helped reduce backlog

Withdrawn Projects: Time in Queue, by ISO



Withdrawn Projects: Time in Queue, by Resource

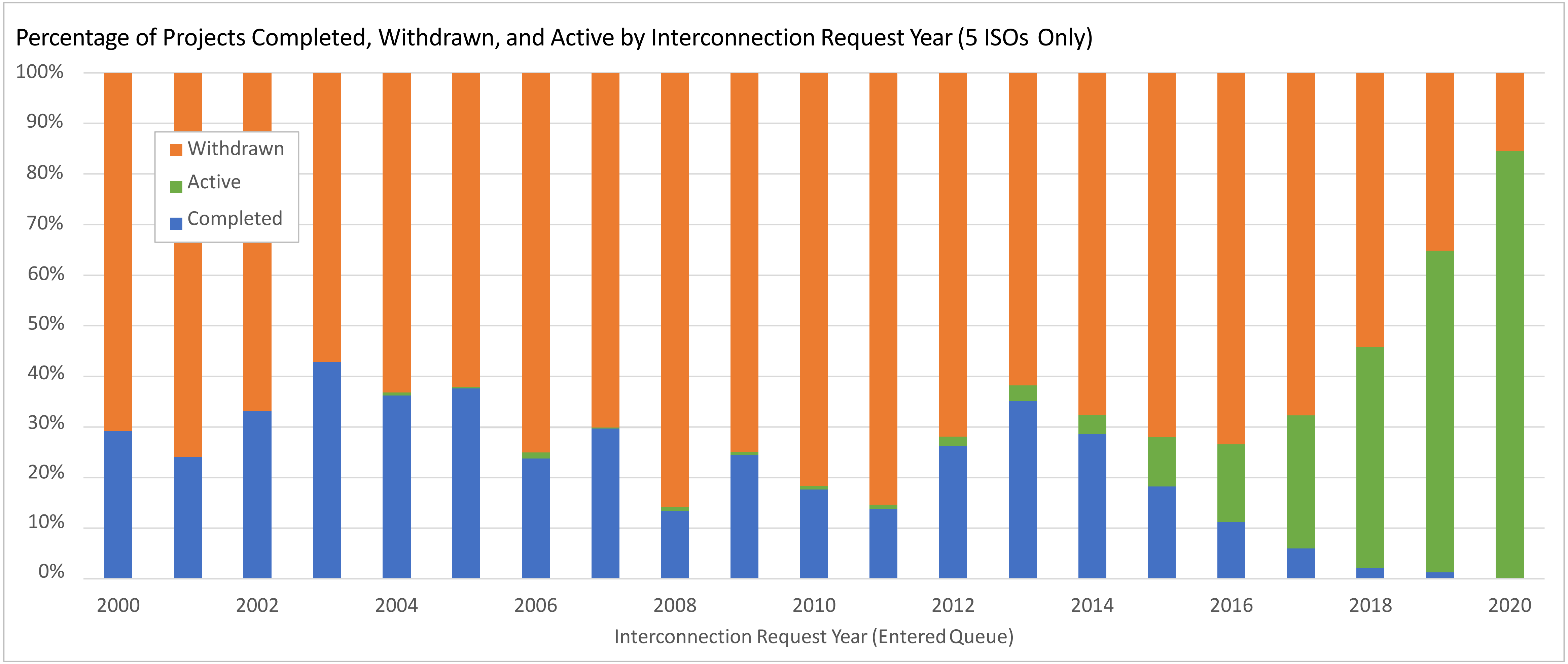


Year	Withdrawn Projects
2000	12
2001	14
2002	97
2003	103
2004	74
2005	76
2006	93
2007	111
2008	371
2009	294
2010	325
2011	544
2012	653
2013	363
2014	308
2015	348
2016	374
2017	540
2018	467
2019	695
2020	729

1. Americans for a Clean Energy Grid. *Disconnected: The Need for a New Generator Interconnection Policy.* January, 2021.
Notes: (1) Data on withdrawn projects were only collected for the five ISOs shown. (2) Data are only shown where sample size is >3 for each year. (3) "Time in queues" is calculated as the number of days from the queue entry date to the date the project was withdrawn from queues.

Across the five ISOs studied, just 24% of projects proposed from 2000-2015 have reached commercial operations

The completion rate may have increased temporarily after 2010-2012 queue reforms[1] but appears to be declining for projects proposed from 2014-2016. Trends for projects proposed in 2017 and after cannot yet be determined.



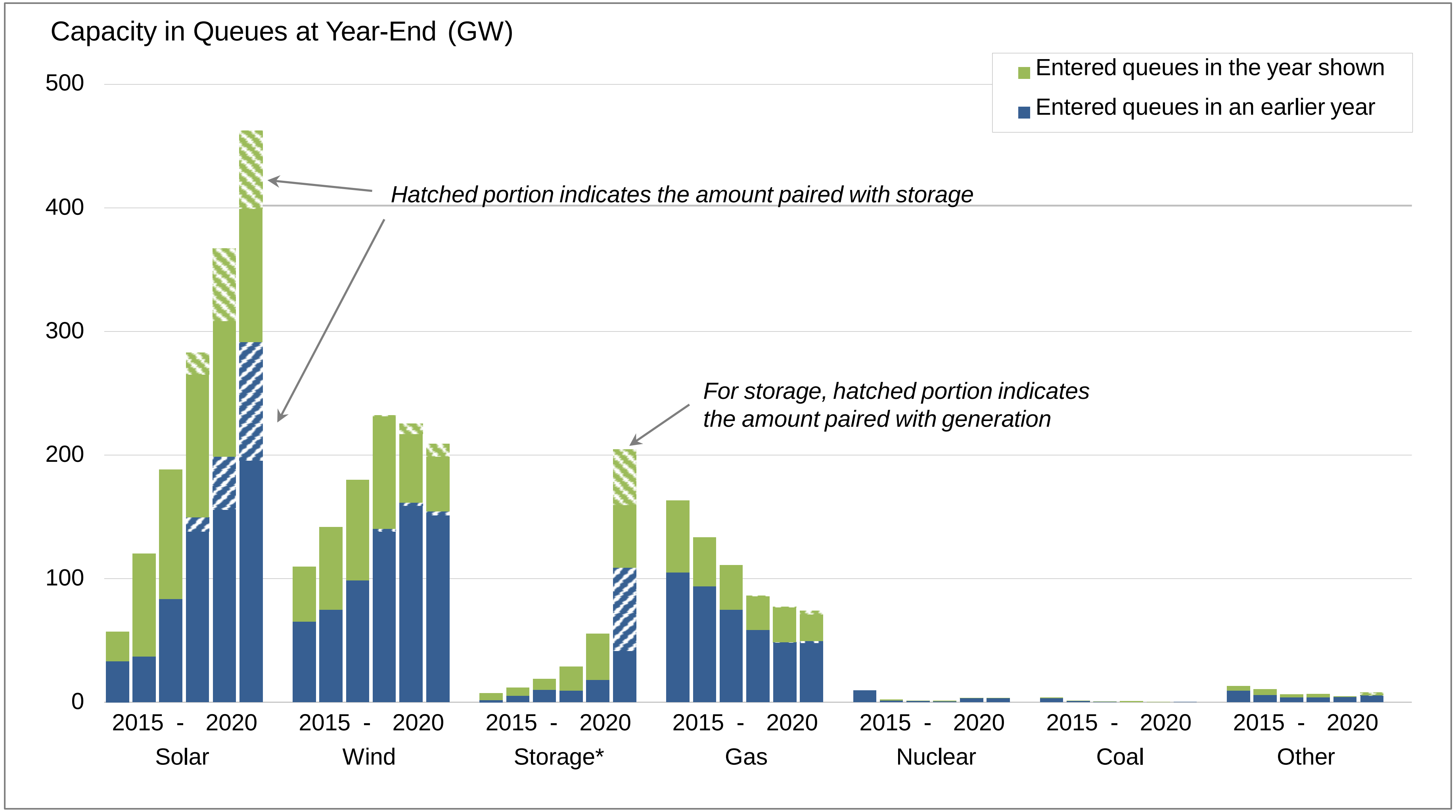
1. Americans for a Clean Energy Grid. *Disconnected: The Need for a New Generator Interconnection Policy.* January, 2021.
Note: Only includes data from five ISOs: CAISO, MISO, PJM, NYISO, ISO-NE

Active Projects in Interconnection Queues

Includes data from all 7 ISOs and 35 non-ISO utilities, totaling 5,639 proposed projects

Region	***n* (Active)**
CAISO	346
ERCOT	527
ISO-NE	263
MISO	580
NYISO	308
PJM	1,541
SPP	498
Southeast (non-ISO)	728
West (non-ISO)	848

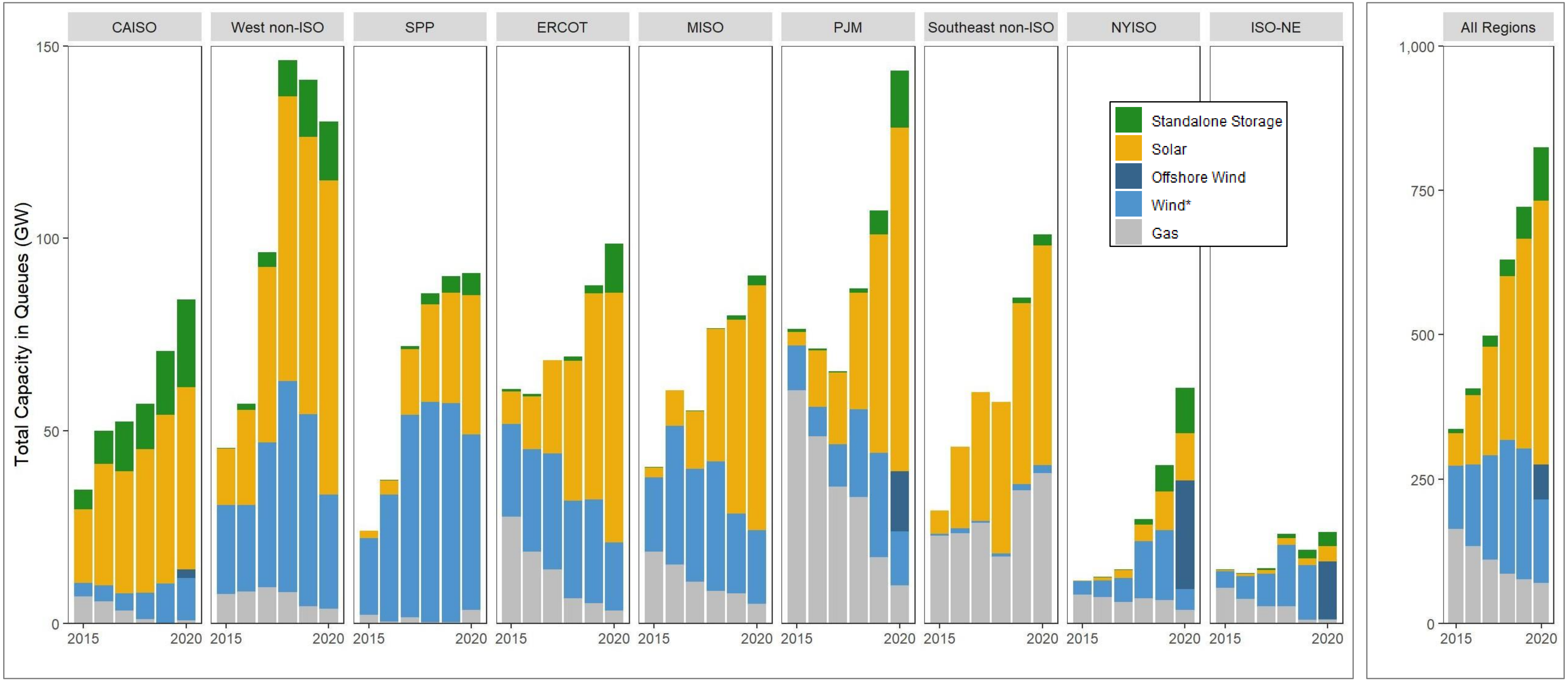
Interconnection queues indicate that commercial interest in solar and storage has grown, including via hybridization; wind and gas have declined



- "**Wind**" includes both onshore and offshore.
- "**Other**" includes
  - Hydropower
  - Geothermal
  - Biomass/biofuel
  - Landfill gas
  - Solar thermal
  - Oil/diesel
- "**Storage**" is primarily (98%) battery, but also includes pumped storage hydro, compressed air, gravity rail, and fuel cell projects.

**Hybrid storage capacity is estimated using storage:generator ratios from projects that provide separate capacity data*
Storage capacity in hybrids was not estimated for years prior to 2020.
Note: Not all of this capacity will be built

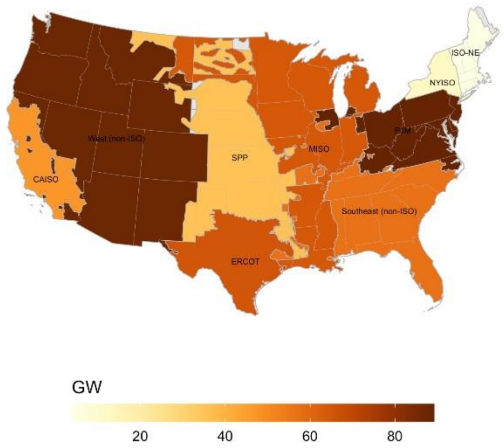
Trends over time vary somewhat by region: Wind capacity has contracted in some regions, solar and storage see consistent growth, gas largely declines



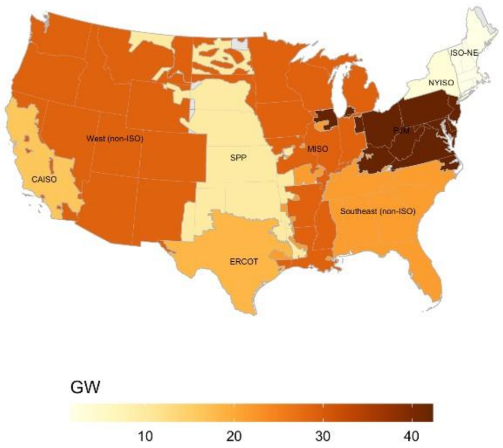
Wind capacity includes onshore and offshore for all years, but offshore is only broken out starting in 2020.
Notes: (1) Storage capacity only includes standalone storage – storage in hybrid configuration is not included here.
(2) Hybrid generation capacity is included in all generator categories. (3) Not all of this capacity will be built.

Regional: Proposed solar is widespread, with less in SPP and Northeast; Most wind in SPP with new offshore in NY; Most storage in CAISO, West, ERCOT, and PJM; Gas is largely in the Southeast

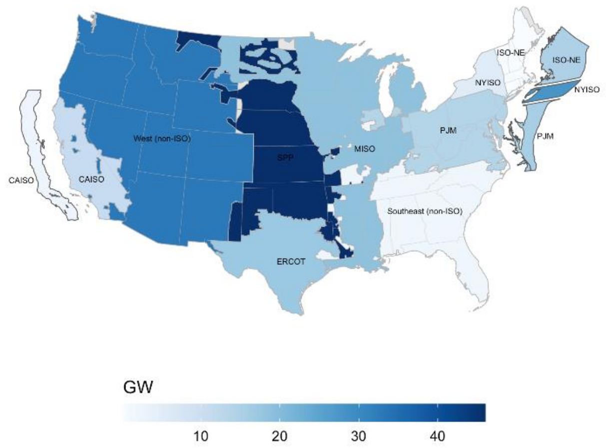
Total Solar Capacity in
Interconnection Queues at the end of 2020



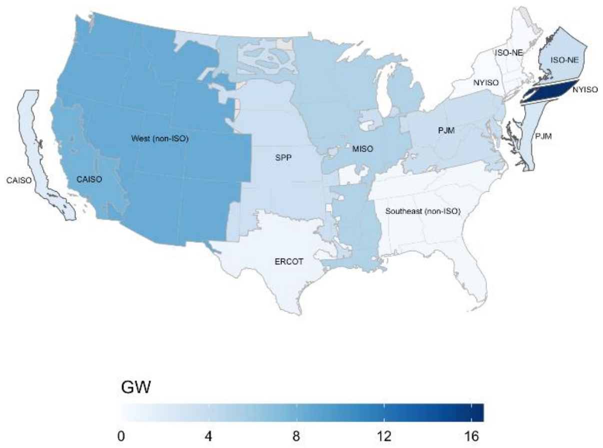
New Solar Capacity Added to
Interconnection Queues in 2020



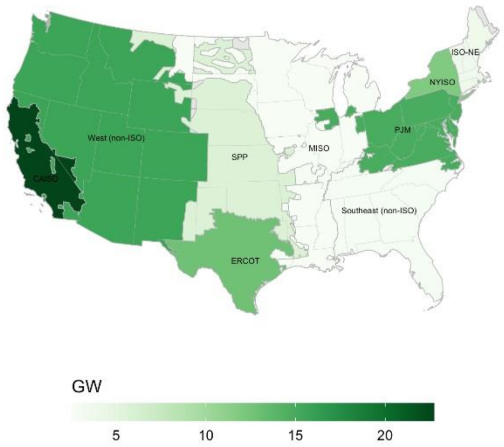
Total Wind Capacity in
Interconnection Queues at the end of 2020



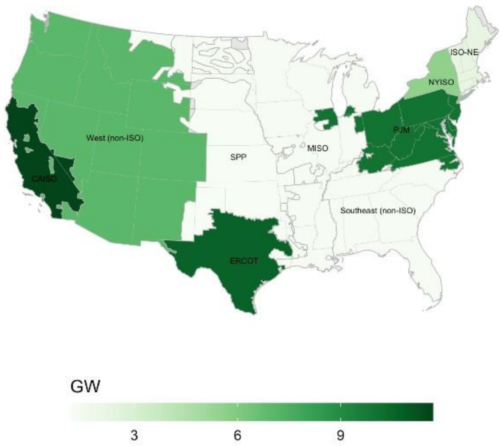
New Wind Capacity Added to
Interconnection Queues in 2020



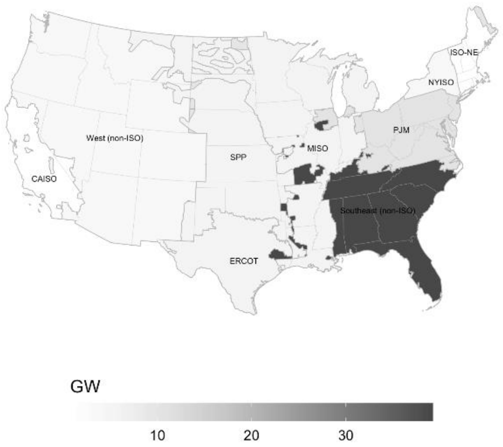
Total Standalone Storage Capacity in
Interconnection Queues at the end of 2020



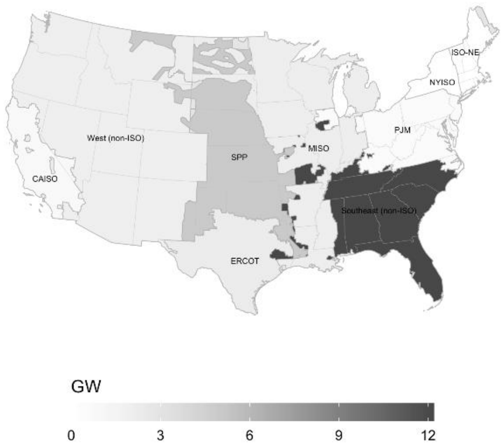
New Standalone Storage Capacity Added to
Interconnection Queues in 2020



Total Gas Capacity in
Interconnection Queues at the end of 2020

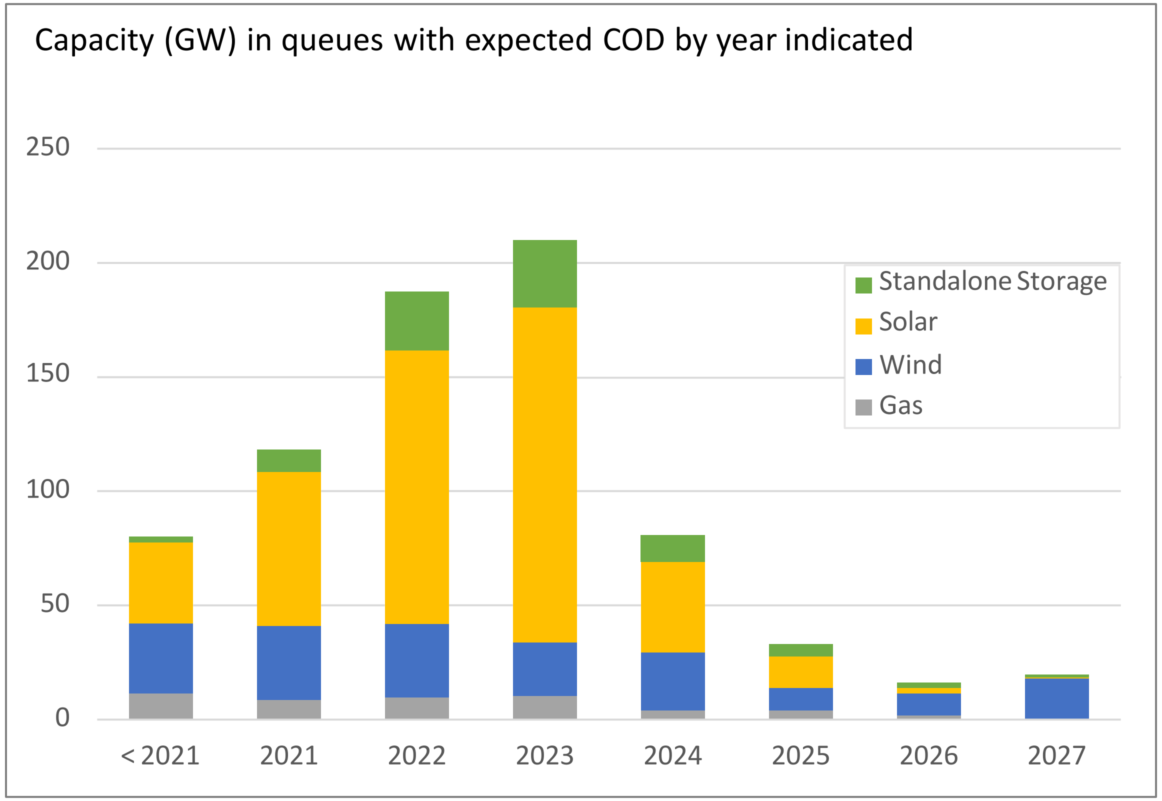


New Gas Capacity Added to
Interconnection Queues in 2020

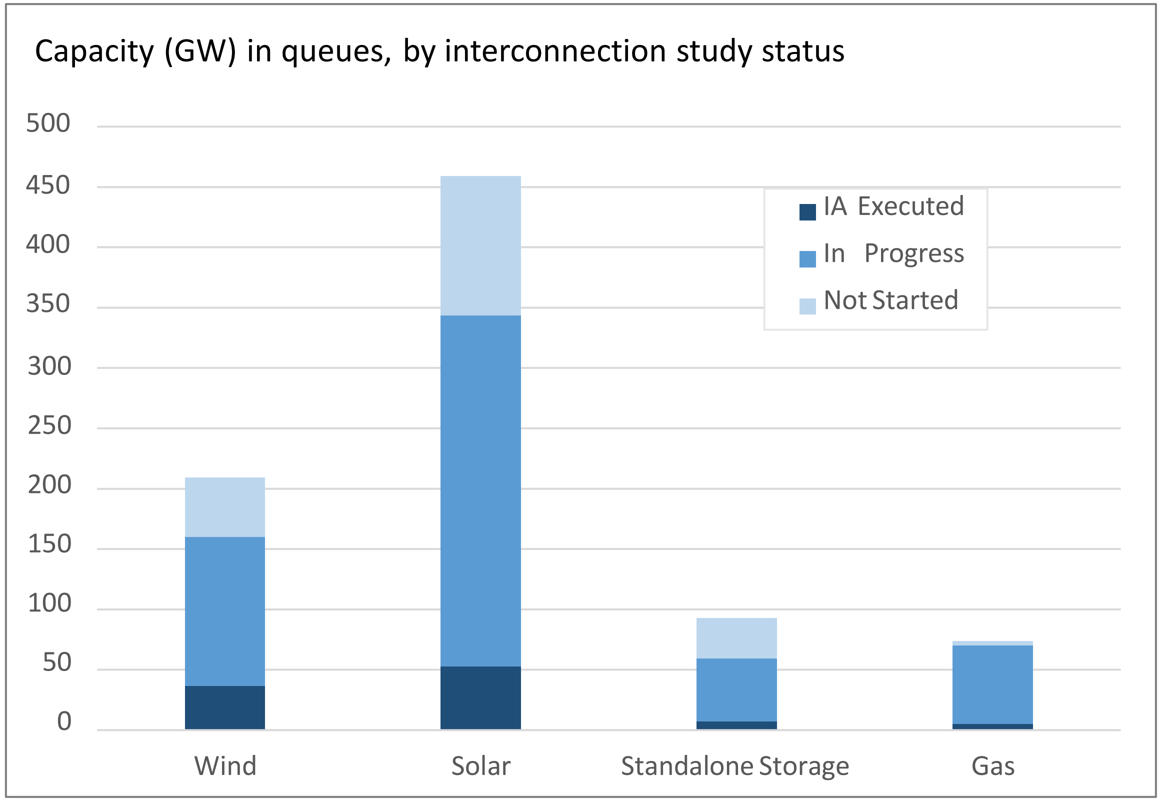


71% (653 GW) of total capacity in queues has expected online date by end of 2023; 13% (117 GW) has an executed interconnection agreement (IA)

Requested online year:

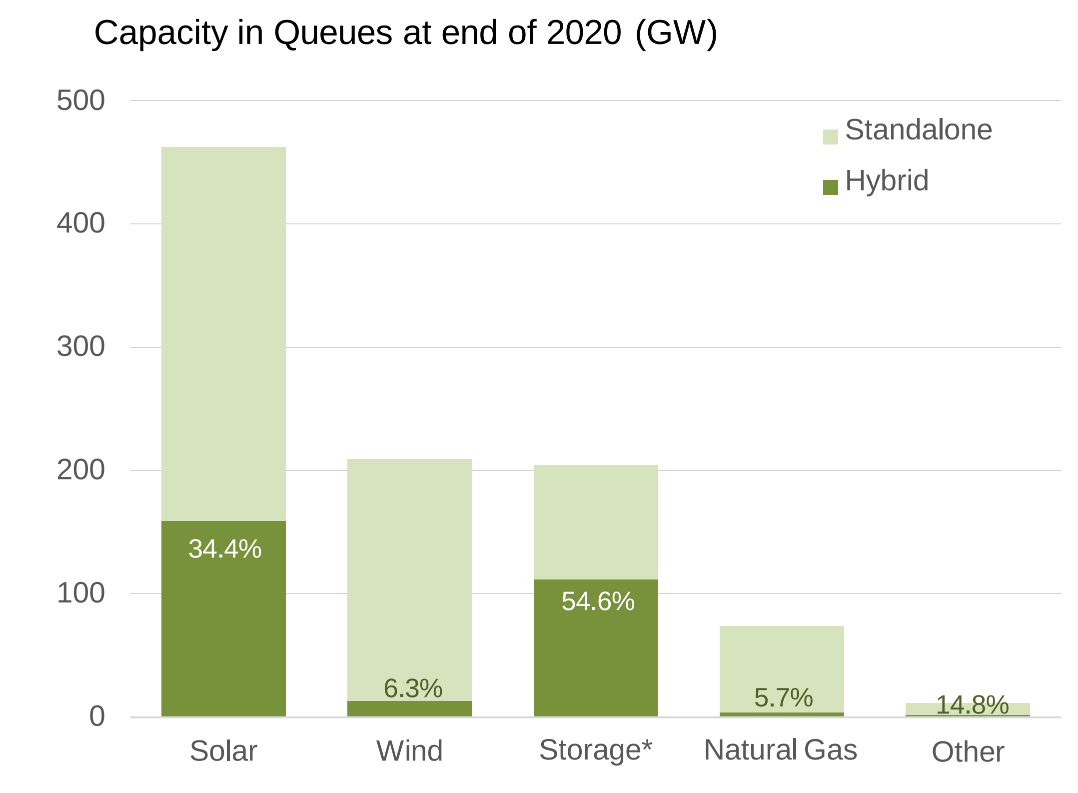


Status of interconnection study:

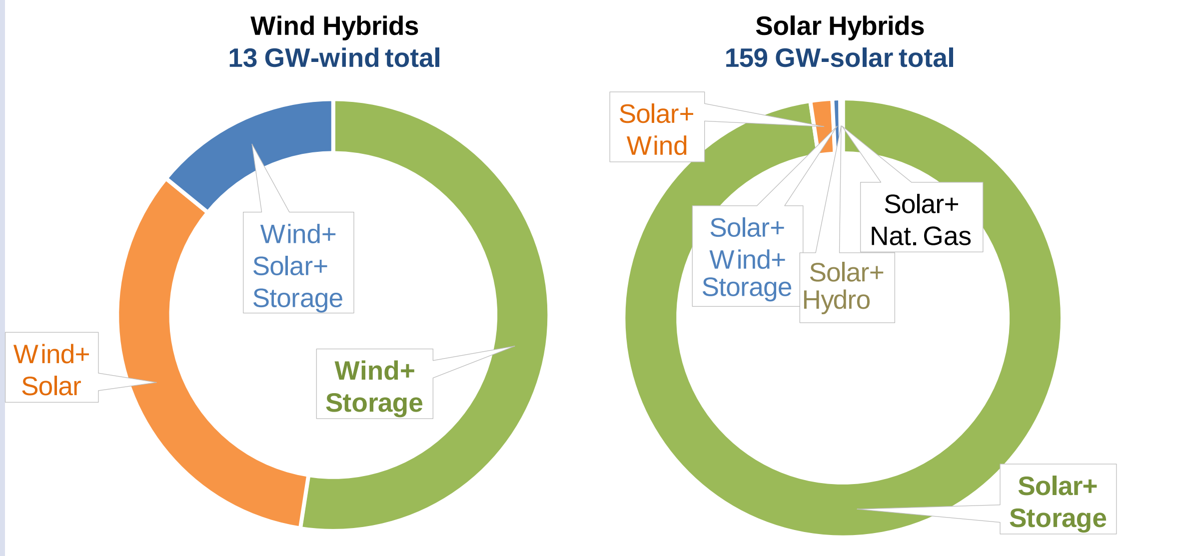


Note: Not all of this capacity will be built

Interest in hybrid plants has increased: 34% of solar (159 GW) proposed as hybrids, 6% of wind (13 GW) proposed as hybrids (up from 28% and 5% in 2019, respectively)



Solar+Storage and Wind+Storage configurations are more common than other hybrid types



**Hybrid storage capacity is estimated using storage:generator ratios from projects that provide separate capacity data*

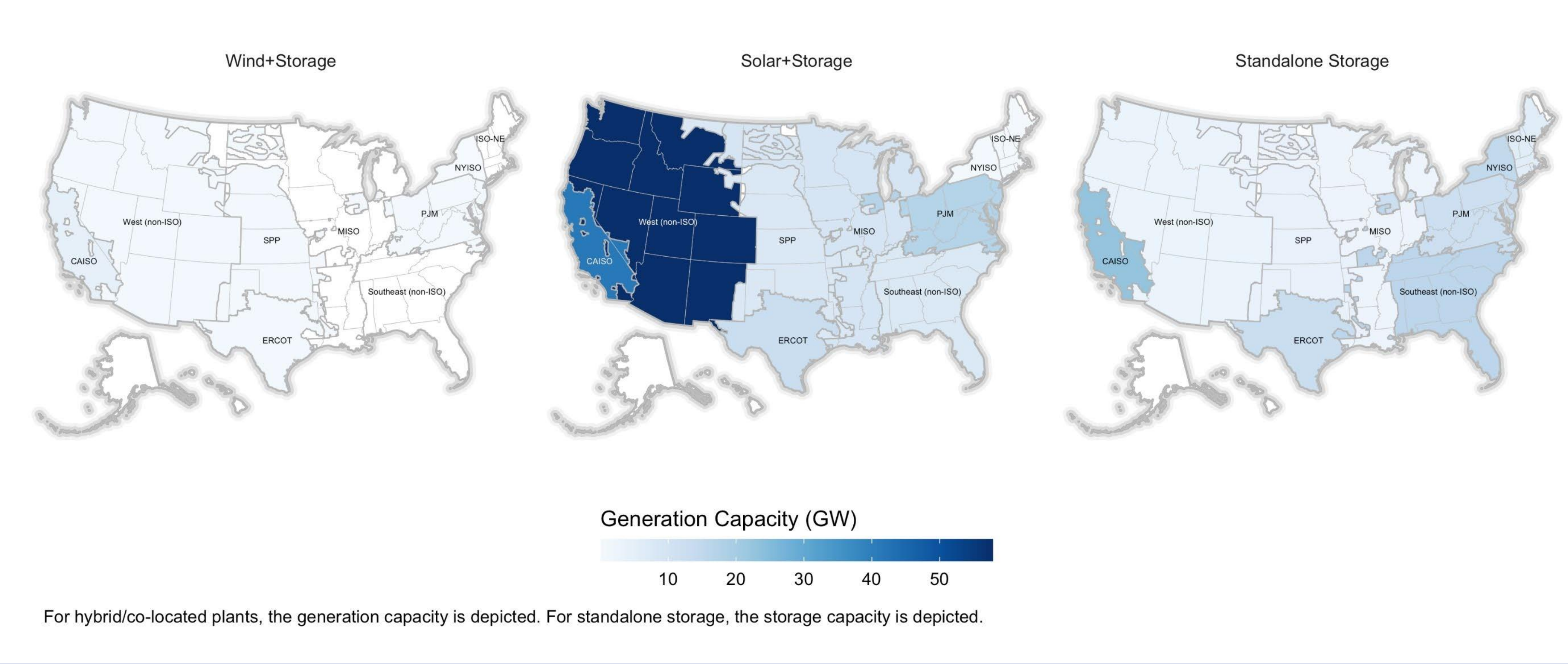
Notes: (1) Not all of this capacity will be built; (2) Hybrid plants involving multiple generator types (e.g., wind+PV+storage, wind+PV) show up in all generator categories, presuming the capacity is known for each type.

Hybrids comprise a sizable fraction of all proposed solar plants in multiple regions; proposed wind hybrids dominated by CAISO

Region	% of Proposed Capacity Hybridizing in Each Region			
	Wind	Solar	Nat. Gas	Battery
CAISO	37%	89%	0%	64%
ERCOT	6%	21%	34%	37%
SPP	4%	22%	33%	38%
MISO	5%	18%	0%	n/a
PJM	1%	19%	1%	n/a
NYISO	0%	5%	6%	2%
ISO-NE	0%	12%	0%	n/a
West (non-ISO)	13%	67%	6%	n/a
Southeast (non-ISO)	0%	13%	1%	n/a
TOTAL	**6%**	**34%**	**6%**	**n/a**

- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (89%) and non-ISO West (67%), and is above 20% in SPP and ERCOT
- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (37%) and non-ISO West (13%), and is less than 7% in all other regions

Solar+storage is dominant hybrid type in queues, wind+storage is much less common; CAISO & West of greatest interest so far



Note: Not all of this capacity will be built

Conclusions

As of the end of 2020, there were over 5,600 projects seeking grid interconnection across the U.S., representing over 755 GW of generation and an estimated ~204 GW of storage.

- Solar (462 GW) accounts for >60% of all active generator capacity in the queues, though substantial wind (209 GW) and gas (74 GW) capacity is also in development. Notably, 29% of the wind capacity in queues is offshore (61 GW).
- Considerable standalone (89 GW) and hybrid (~112 GW[1]) battery capacity is also in development, along with 4 GW of other storage.
- Growth in proposed solar and storage capacity is consistent across regions. Wind has contracted in some regions, but continues to grow in those with proposed offshore development. Gas is declining in most regions.
- Hybrids now comprise a large – and increasing – share of proposed projects, particularly in CAISO and non-ISO West.
- The vast majority (71%) of capacity in the queues has requested to come online by the end of 2023.
- The time projects spend in queues before reaching COD may be increasing. For the four ISOs studied[2], the typical duration from IR to COD went from ~1.9 years for projects built in 2000-2009 up to ~3.5 years for those built in 2010-2020.
- Historically only ~24% of projects in the queues were built, and less for wind (19%) and solar (16%). There are growing calls for queue reform to reduce cost, lead times, and speculation.

Notes: (1) Hybrid battery capacity is estimated using storage:generator ratios from projects that provide separate capacity data. (2) Data on completed projects were only collected for five ISOs, though only the four shown provided COD. (3) See https://gridlab.org/2035-report/

Next Steps:

Berkeley Lab is updating and expanding the scope of this analysis, including the following steps:

- **Improving the geographic resolution of analysis**
  - Understand clustering of proposed projects and constraints at the county level, rather than state/region
- **Refine duration analysis**
  - Collect and analyze additional data to inform trends in time spent in queues, and diagnose the causes of lengthening timelines
- **Analyze interconnection cost data**
  - Extract and analyze cost allocation data reported in interconnection studies, across active, completed, and withdrawn projects, highlighting trends over time and across regions
- **Update data through 2021**
  - In January 2022, we will collect new data and update this analysis to include queue data through 2021

Contact:

Joseph Rand (jrand@lbl.gov)

More Information:

Visit https://emp.lbl.gov/publications/queued-characteristics-power-plants to download the data used for this analysis and to access an interactive data visualization tool

Technology Perspectives

Dr. Mahesh Morjaria
Terabase Energy

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Technology Perspective:
EPRI-NERC-NATF Forum

November 2021

Mahesh Morjaria, Ph.D.
EVP, Plant Operational Technology
MMorjaria@Terabase.Energy

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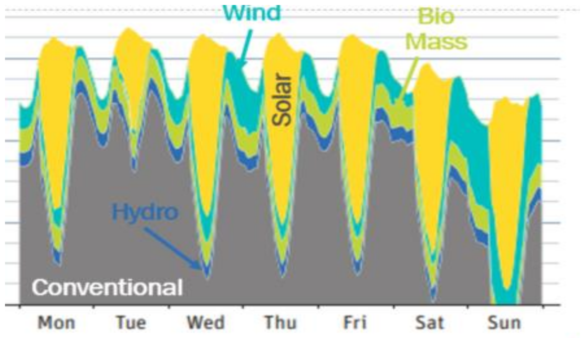
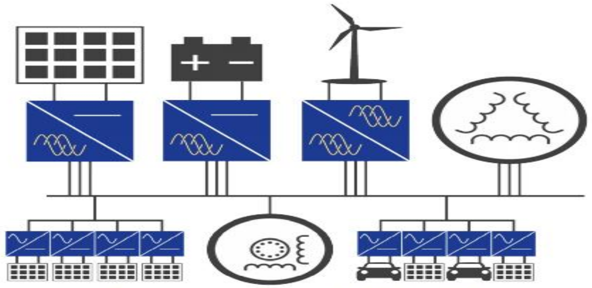
Main Theme





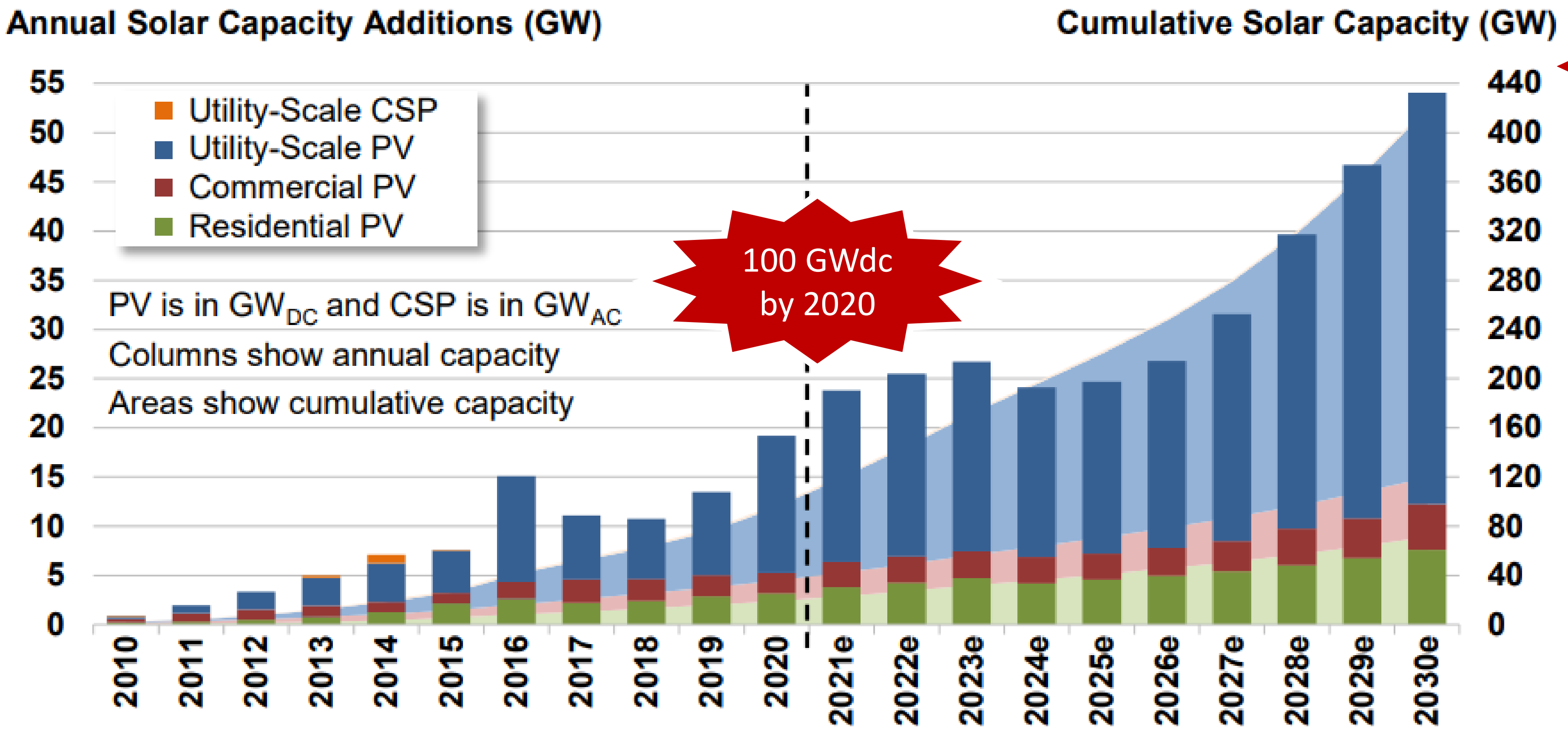
- Solar generation capacity in US to increase from 100 GW to over 400 GW by 2030 …driven by **emission reduction policy** and **favorable solar economics**

- Key Technical Challenge: **Maintain grid stability & reliability** while integrating increasing amounts of **variable** generation

- Inverter-based resources (IBRs) provide **essential reliability services**, **firm capacity** and will enable transformation to a future "**digital grid**"

…*enabling consistent deployment is necessary*

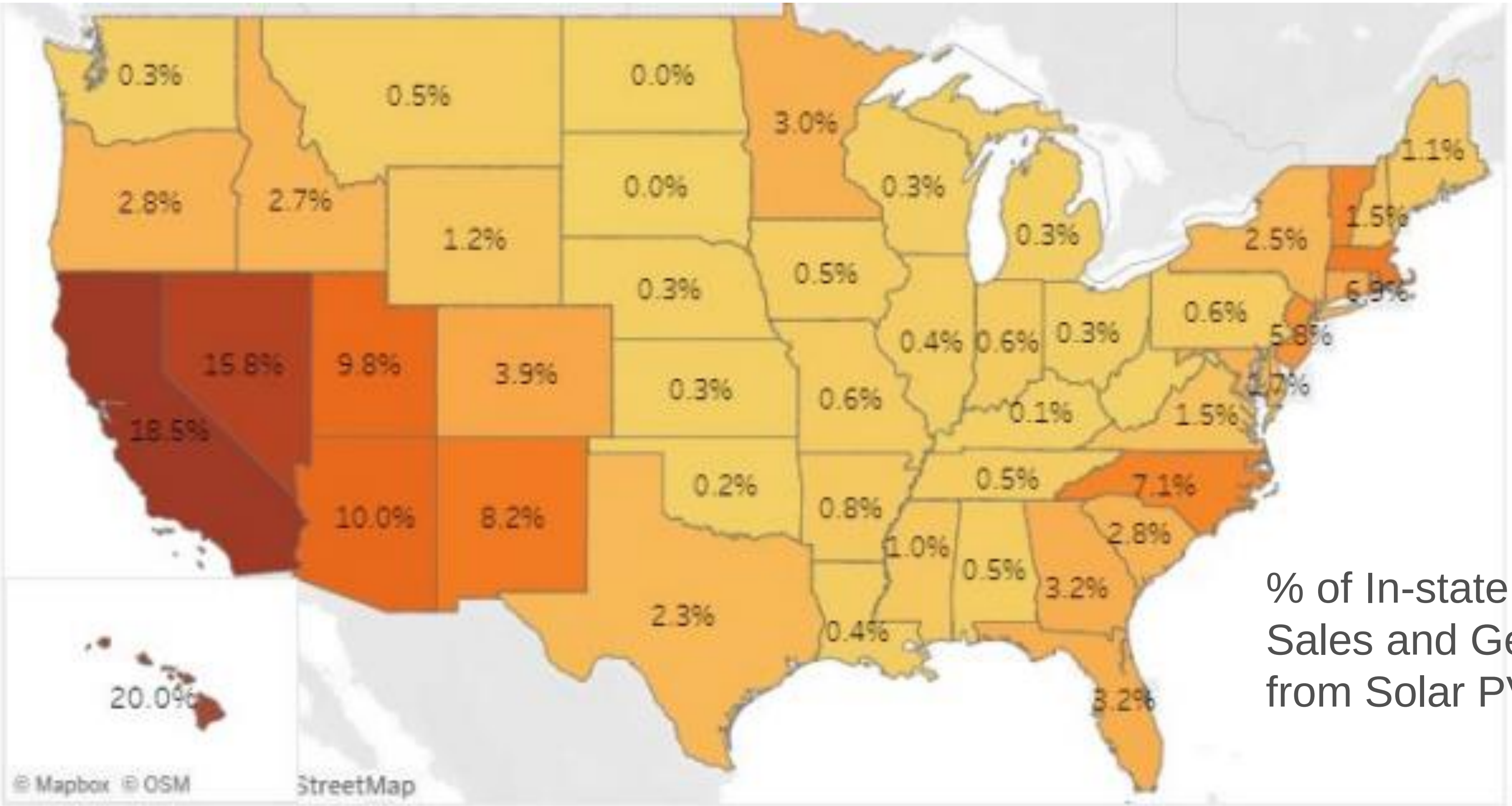
US Cumulative Solar PV Installations



To exceed 400 GWdc by 2030

Sources: *Wood Mackenzie/SEIA Solar Market Insight Reports, Berkeley Lab*

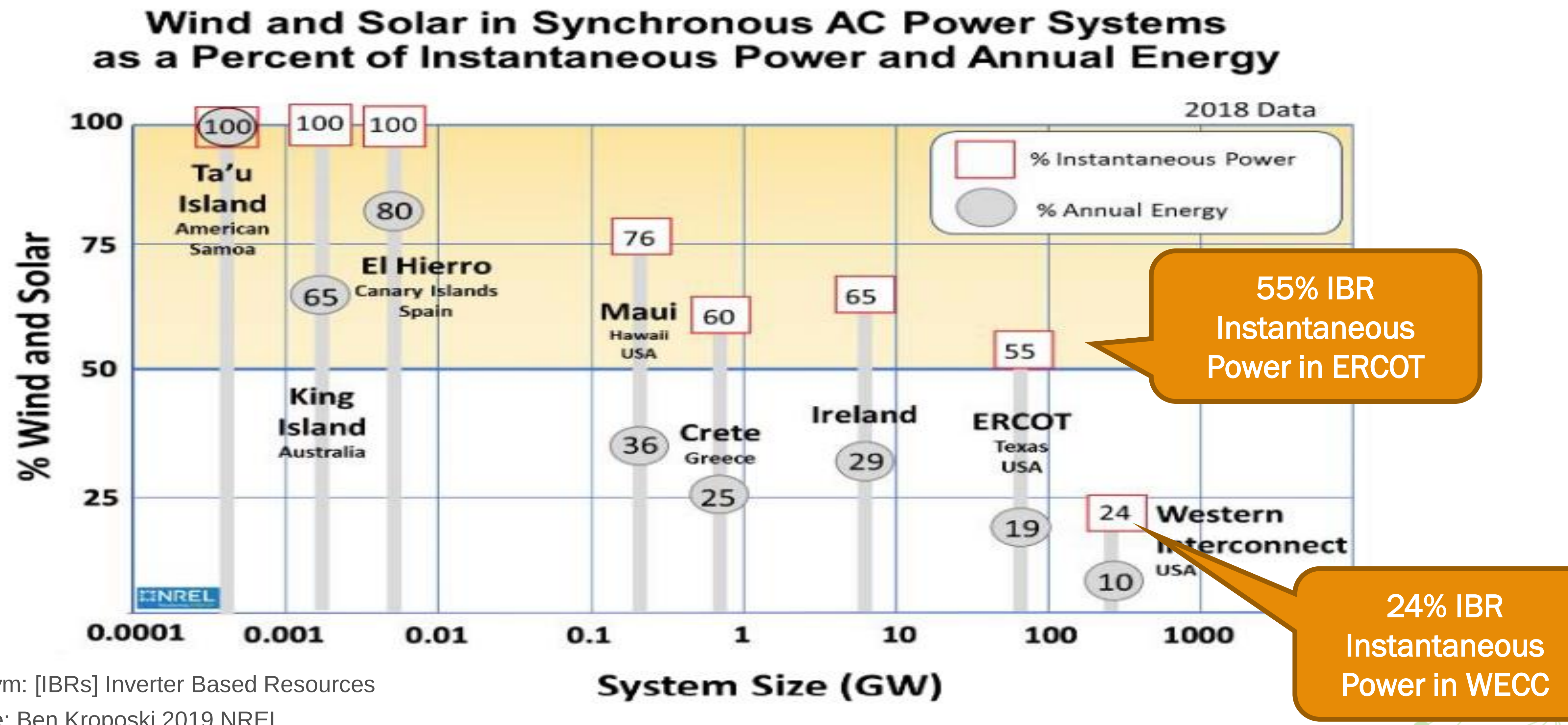
Solar penetration rates ~10% or higher in five states



% of In-state Electricity Sales and Generation from Solar PV as of 2020

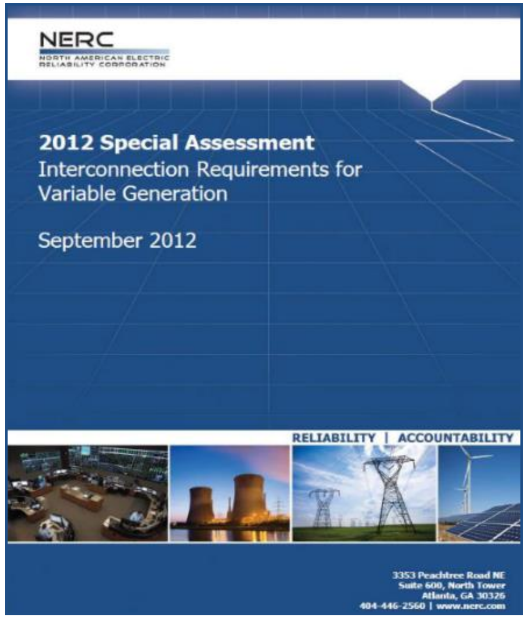
Source: Utility-Scale Solar, 2021 Edition. [Utility-Scale Solar | Electricity Markets and Policy Group (lbl.gov)]

Instantaneous IBR Penetration is Increasing



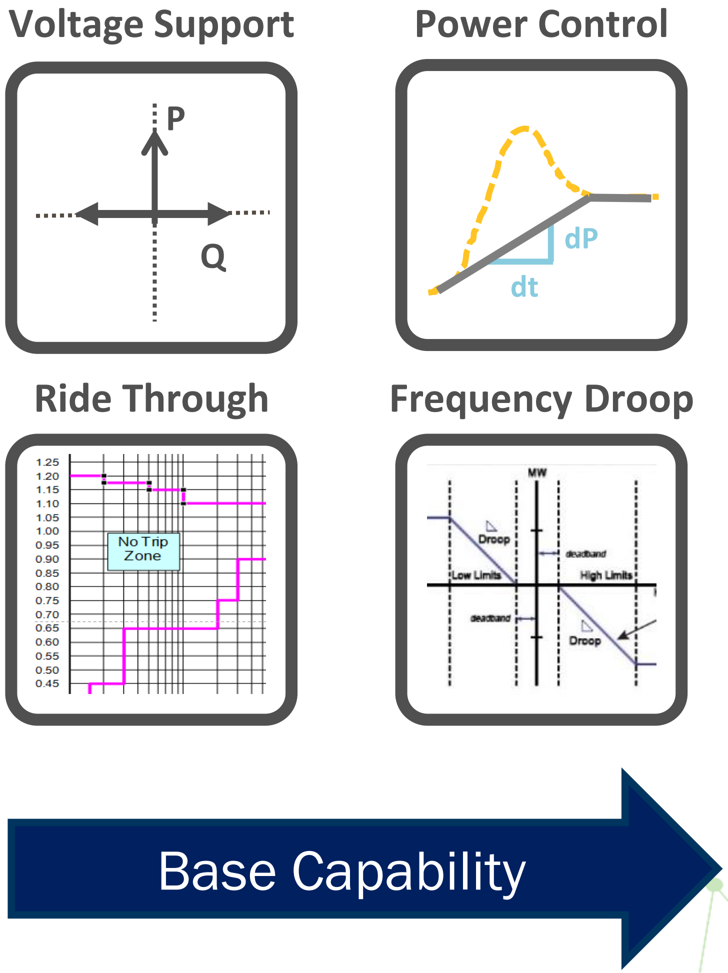
Acronym: [IBRs] Inverter Based Resources
Source: Ben Kroposki 2019 NREL

Grid-Friendly Solar IBR is now Well Established



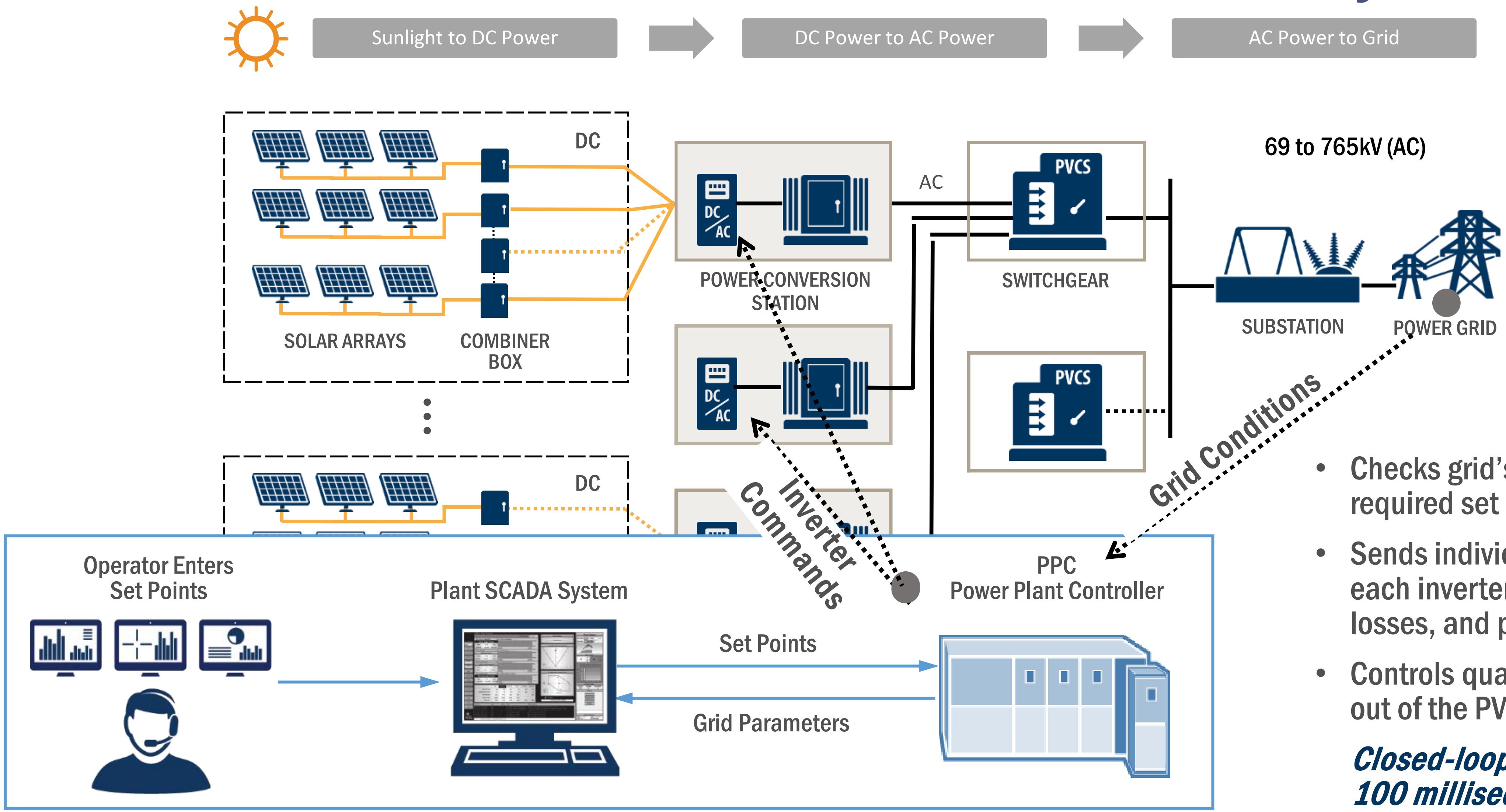
Features Required by NERC to be a Good Grid Citizen:

- Voltage regulation
- Active power control (ramping. curtailment)
- Grid disturbance ride through (voltage and frequency excursions)
- Primary frequency droop response
- Short circuit duty control



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)

Smart Plant Control/Inverters Enable Grid Friendly Features



- 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

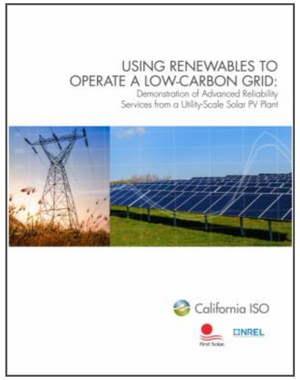
Closed-loop controls at 100 milliseconds!

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

Solar Plant Provides Essential Reliability Services Too

NERC: Essential reliability services

- Frequency Control
- Ramping capability or flexible capacity



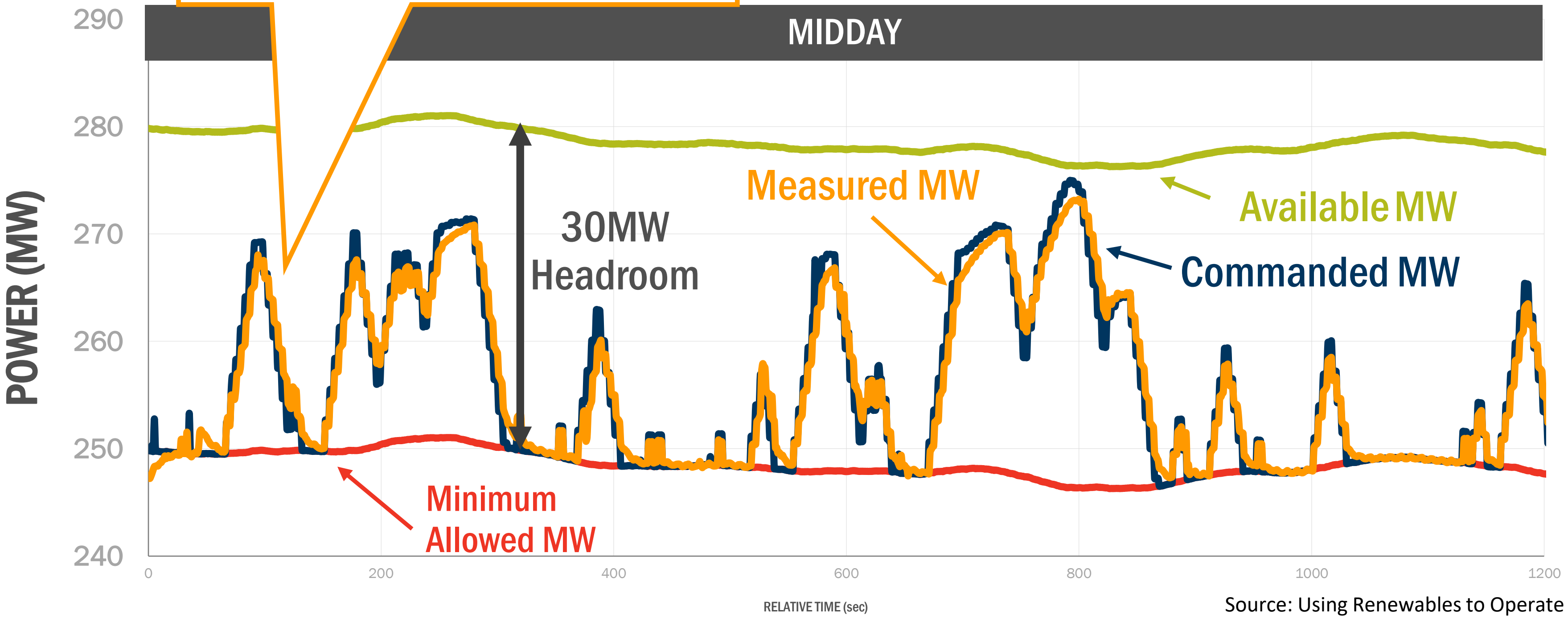
2017 NARUC Award Winner

2018 Intersolar Outstanding Project Winner

Power Regulation

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

Regulation is ~27 %points more accurate than best conventional generation

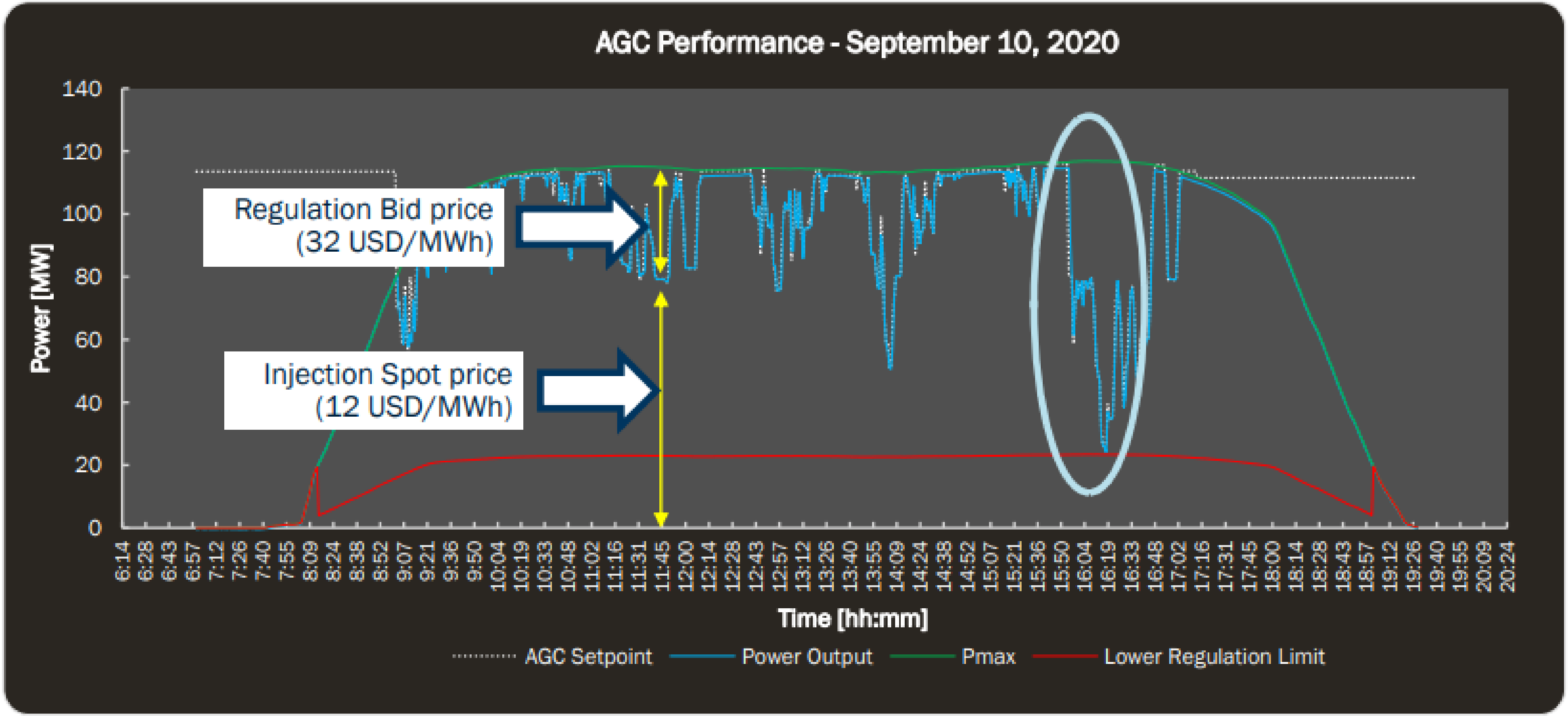


Grid Reliability Services

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

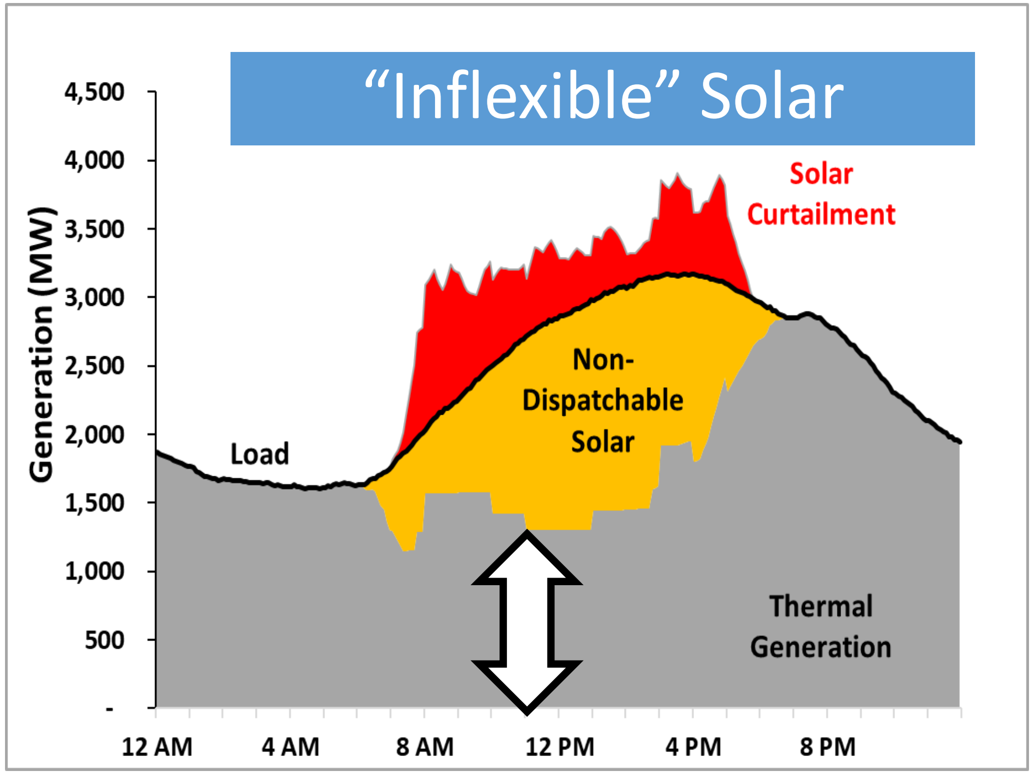
Commercialization of Solar AGC in Chile Market

- Chilean regulation created a day ahead market for the provision ancillary services.
- Luz del Norte bids offering a reserve for frequency regulation at a certain price

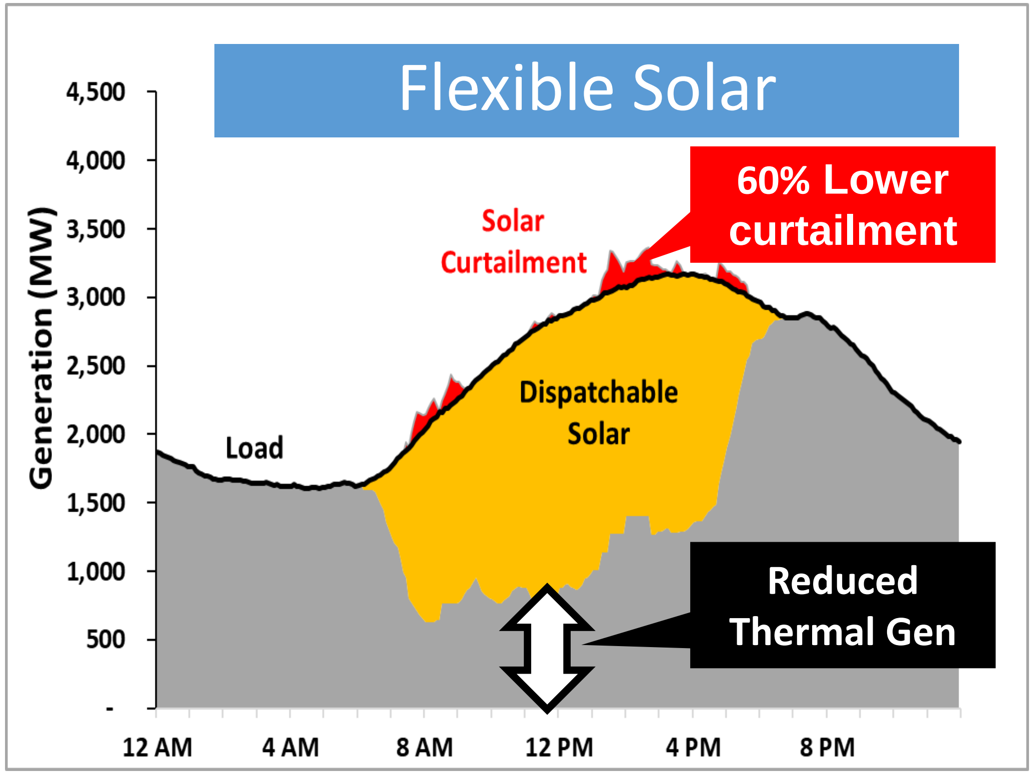


Source: Gabriel Ortiz Mercado, First Solar

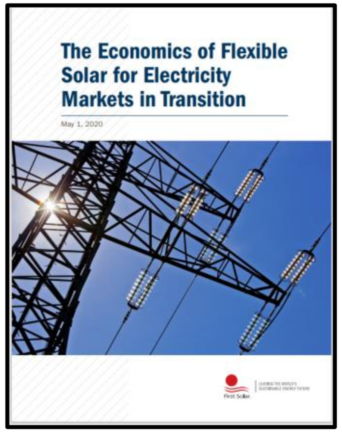
Flexible Solar Reduces Curtailment under High Solar Penetration

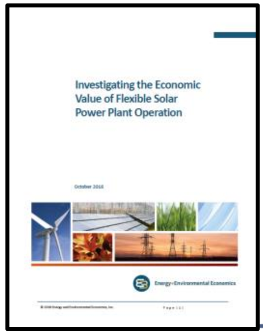


Solar Provides No Regulation Reserves



Flexible Solar: Provides regulation reserves.





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

TECO ENERGY AN EMERA COMPANY

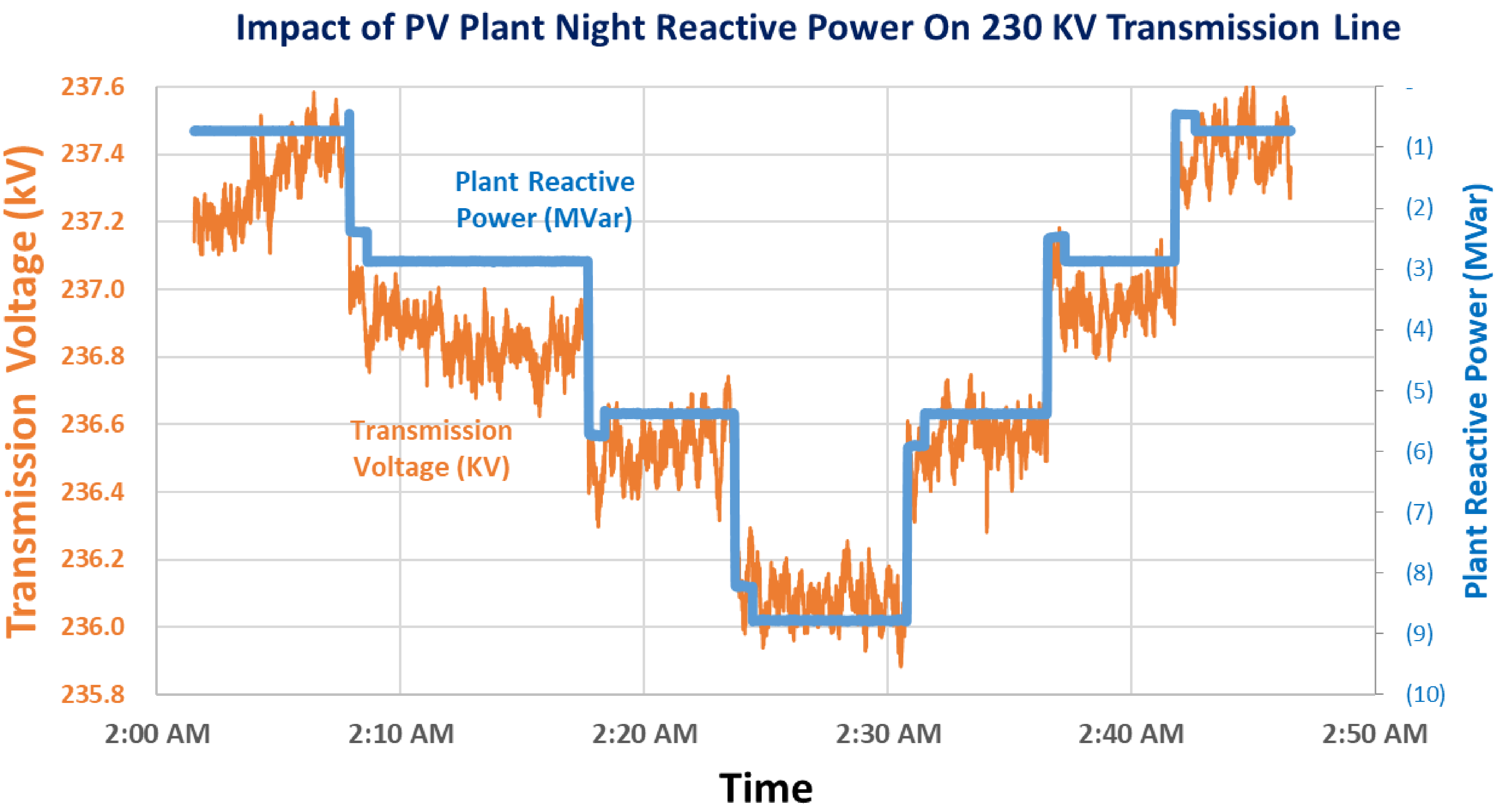
Energy+Environmental Economics

First Solar.

Study: Flexible solar reduces California system costs by $172 million

http://www.firstsolar.com/-/media/First-Solar/Documents/Grid-Evolution/The_Economics_of_Flexible_Solar_for_Electricity_Markets_in_Transition.ashx?la=en

PV Plant Reduces Over-Voltage on Transmission



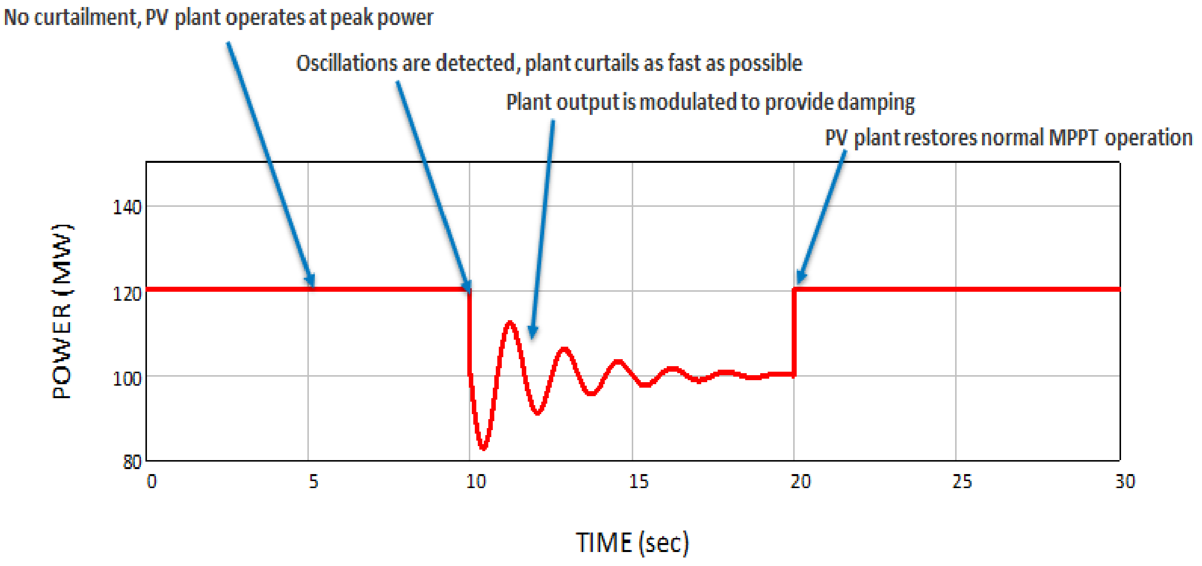
Open Distribution

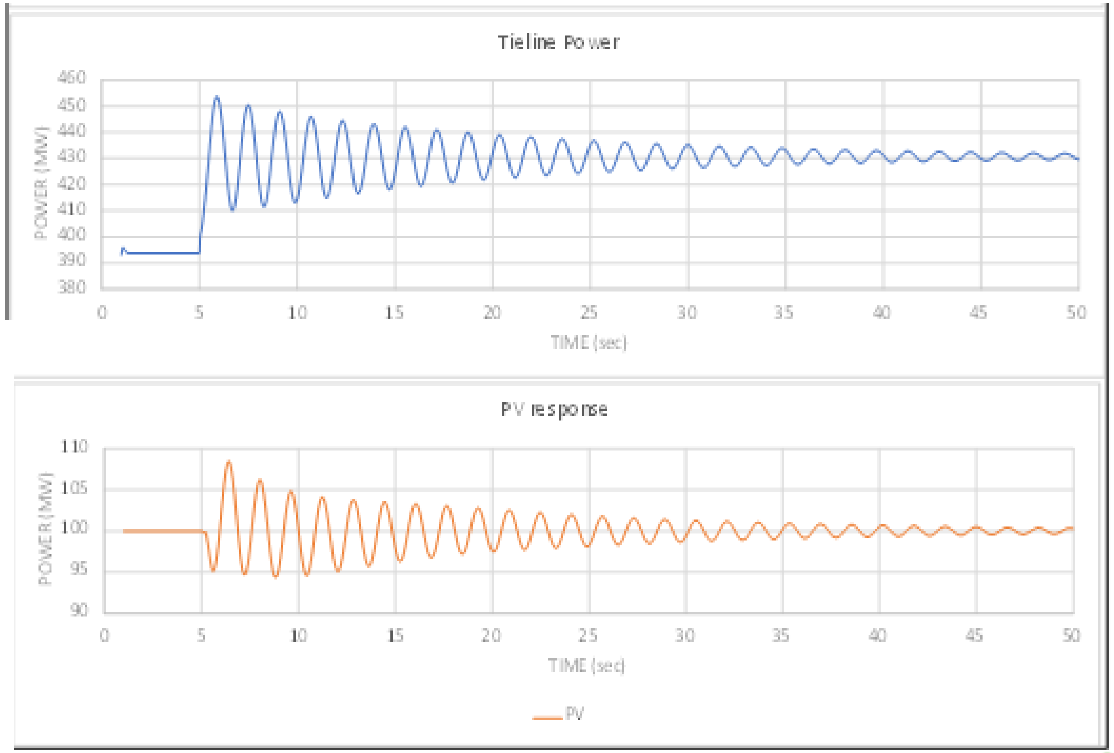
Power Systems Stabilization Capability on PV Plants

- An ERCOT 2019 study identified ~1.8 Hz oscillations between synchronous condensers in the Panhandle area and the rest of the ERCOT synchronous generation.
- NERC is proposing that Hybrid IBR resources should have PSS capability, which actively damps out power oscillations within the range of typically 0.2-2 Hz when the resources are on-line and operational.

PV Plant and Battery Energy Storage System Integration at NREL's Flatirons Campus

NREL: V. Gevorgian, P. Koralewicz, S, Shah, E. Mendiola, R. Wallen, H. Villegas
First Solar: M. Morjaria, K. Collins, A. Sridhar





PV Plant curtails when oscillations are detected and modulates power output to provide damping

http://www.ercot.com/content/wcm/key_documents_lists/196631/4_5_ERCOT_RIW_03172020_IBR_Damping_Support_and_Dynamic_Model_Improvement_Proposal.pdf

IBR Standards Are Being Established – IEEE P2800

>99% Approval

TS owner can require additional capability

Raising the minimum bar

Capability Required in P2800

General Requirements
- Measurement accuracy
- Controls Prioritization
- Control responses
- Applicability to Diverse IBR Plants

Frequency Response
- Fast Frequency Response
- Primary Frequency Response

Reactive Power – Voltage Control
- Q for voltage control at zero active power
- Automatic Voltage Regulation Functions
- Reactive Power

Power Quality
- Harmonic Voltage Limitations
- Prevent Transient Overvoltage
- Harmonic Current Limitations
- Phase Unbalance
- Rapid Voltage Change
- Flicker Limitations

Ride-Through Capability and Performance, Protection
- Unbalanced Current Injection
- Balanced Current Injection
- Voltage Ride-through
- Frequency & Phase-jump Ride-through
- Coordination Of Protection

Modeling & Validation, Measurement Data, and Performance Monitoring
- Process and criteria for model validation
- High Fidelity Performance Monitoring
- Validated Models

Tests and verification requirements
- Post-commissioning Monitoring
- Plant-level Evaluation & Modeling
- Commissioning Tests
- Type tests

Source: IEEE P2800 Draft Standards

IEEE P2800 IBR Technical Minimum Capability Requirements

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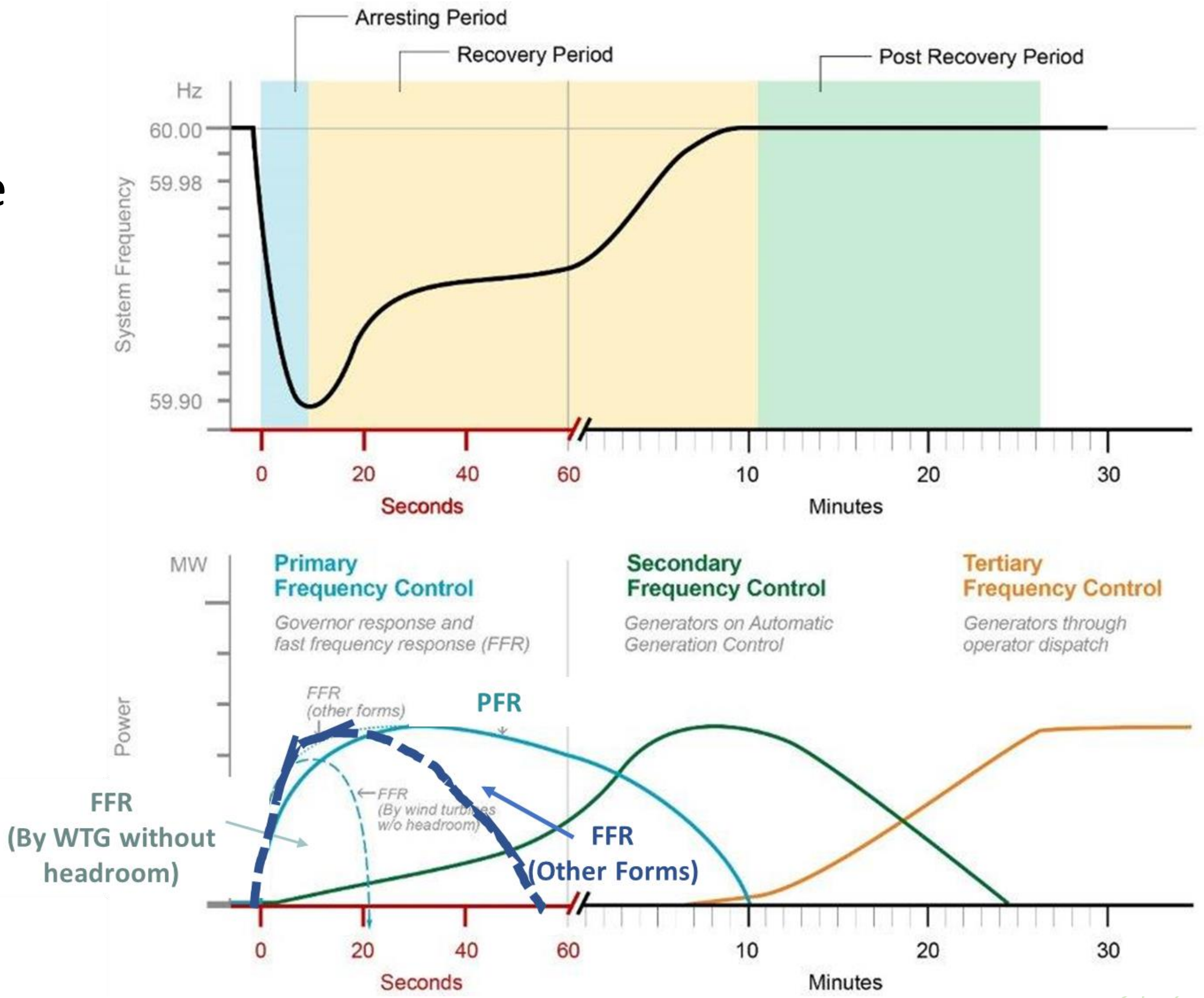
IBR Fast Frequency Response Capability – "Virtual Inertia"

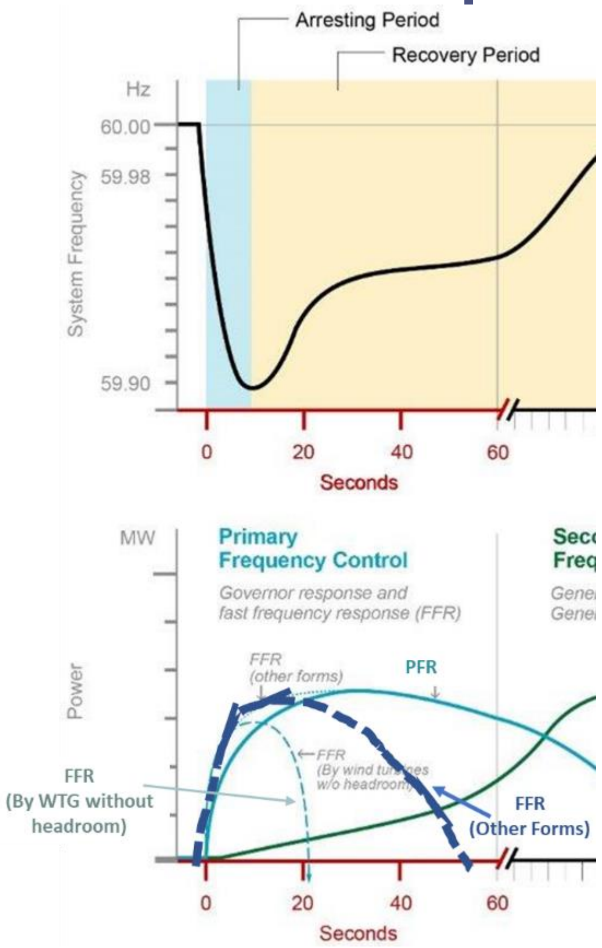
- Fast Frequency Response (FFR) supports arresting Rate Of Change Of Frequency (ROCOF) following a large generation change
- FFR is an essential reliability service as inertial contribution from synchronous generators declines

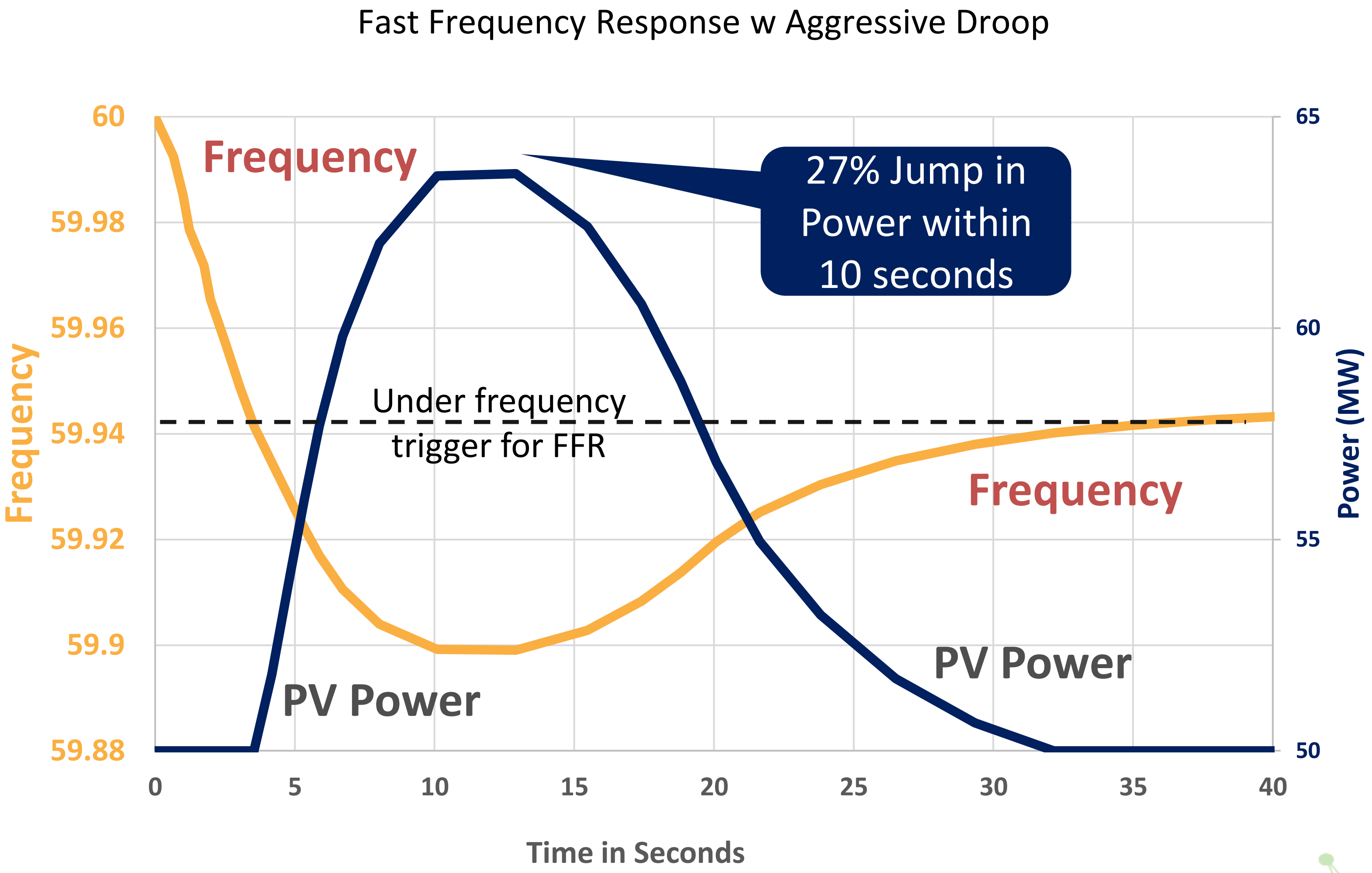
PFR: Primary Frequency Response
FFR: Fast Frequency Response

Source: IEEE P2800 Draft Standards



Fast Frequency Response of a PV Plant With Reserve





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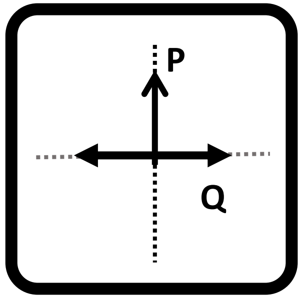
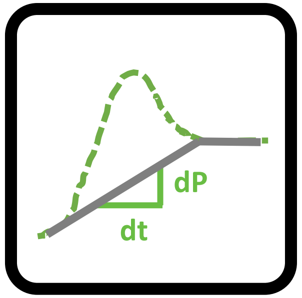
Adding Storage Enhances Grid Capability of a PV IBR Plant

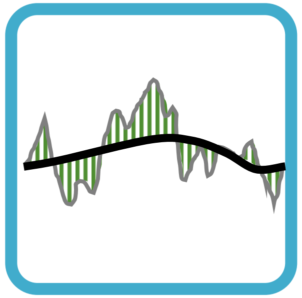
Voltage Support



Ramp Control



Power Regulation



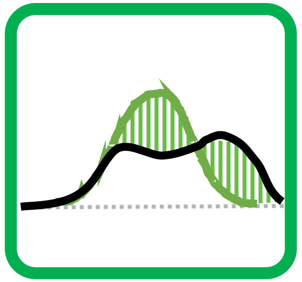
- AGC
- Up-Regulation
- Down-Regulation
- Frequency Regulation

Base Capability → Grid Reliability Services

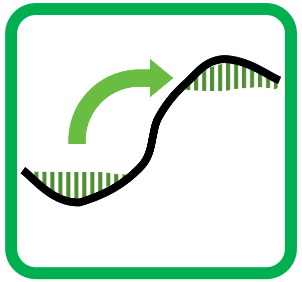
\+

Capacity Firming

Energy Shifting



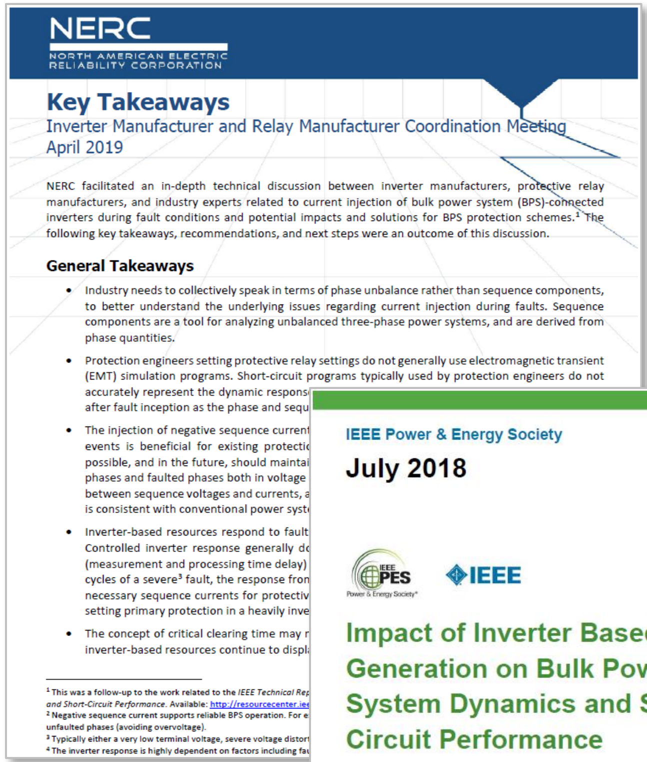
Flexibility



Grid Capabilities Enhanced with Hybridization

NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Guidelines and Reports on Inverter-Based Resource Performance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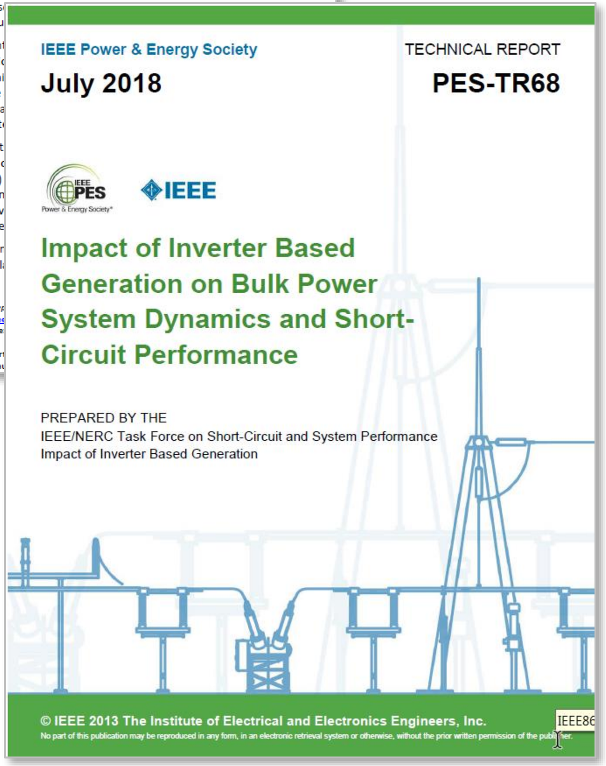
Key Takeaways
Inverter Manufacturer and Relay Manufacturer Coordination Meeting
April 2019

NERC facilitated an in-depth technical discussion between inverter manufacturers, protective relay manufacturers, and industry experts related to current injection of bulk power system (BPS)-connected inverters during fault conditions and potential impacts and solutions for BPS protection schemes.[1] The following key takeaways, recommendations, and next steps were an outcome of this discussion.

General Takeaways

- Industry needs to collectively speak in terms of phase unbalance rather than sequence components, to better understand the underlying issues regarding current injection during faults. Sequence components are a tool for analyzing unbalanced three-phase power systems, and are derived from phase quantities.
- Protection engineers setting protective relay settings do not generally use electromagnetic transient (EMT) simulation programs. Short-circuit programs typically used by protection engineers do not accurately represent the dynamic respons…


IEEE Power & Energy Society

July 2018

TECHNICAL REPORT

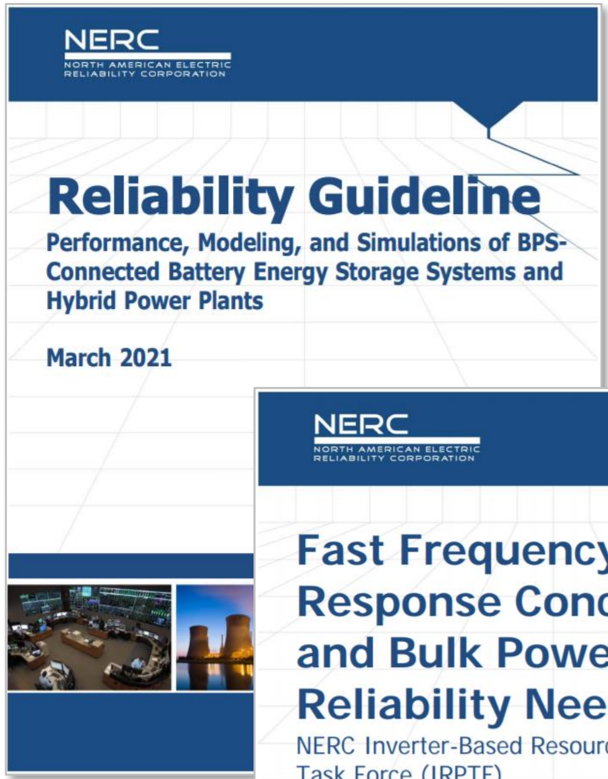
PES-TR68

IEEE PES Power & Energy Society

IEEE

Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance

PREPARED BY THE
IEEE/NERC Task Force on Short-Circuit and System Performance
Impact of Inverter Based Generation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Reliability Guideline
Performance, Modeling, and Simulations of BPS-Connected Battery Energy Storage Systems and Hybrid Power Plants

March 2021


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Fast Frequency Response Concepts and Bulk Power System Reliability Needs
NERC Inverter-Based Resource Performance Task Force (IRPTF)
White Paper

March 2020

RELIABILITY | RESILIENCE | SECURITY

3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com

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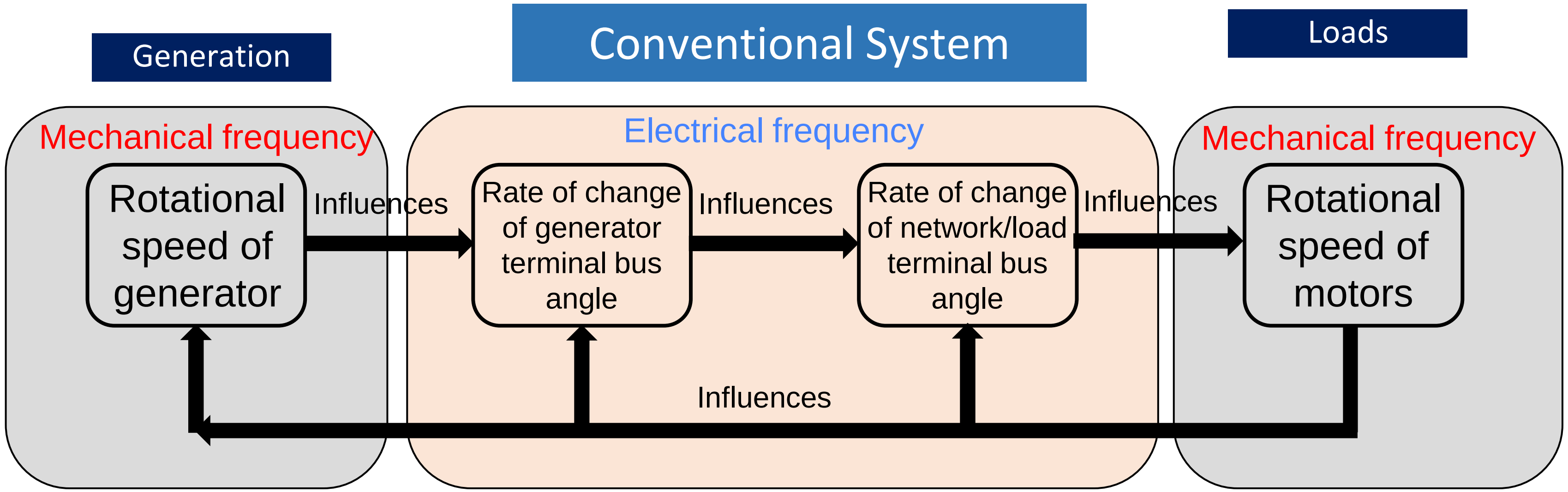
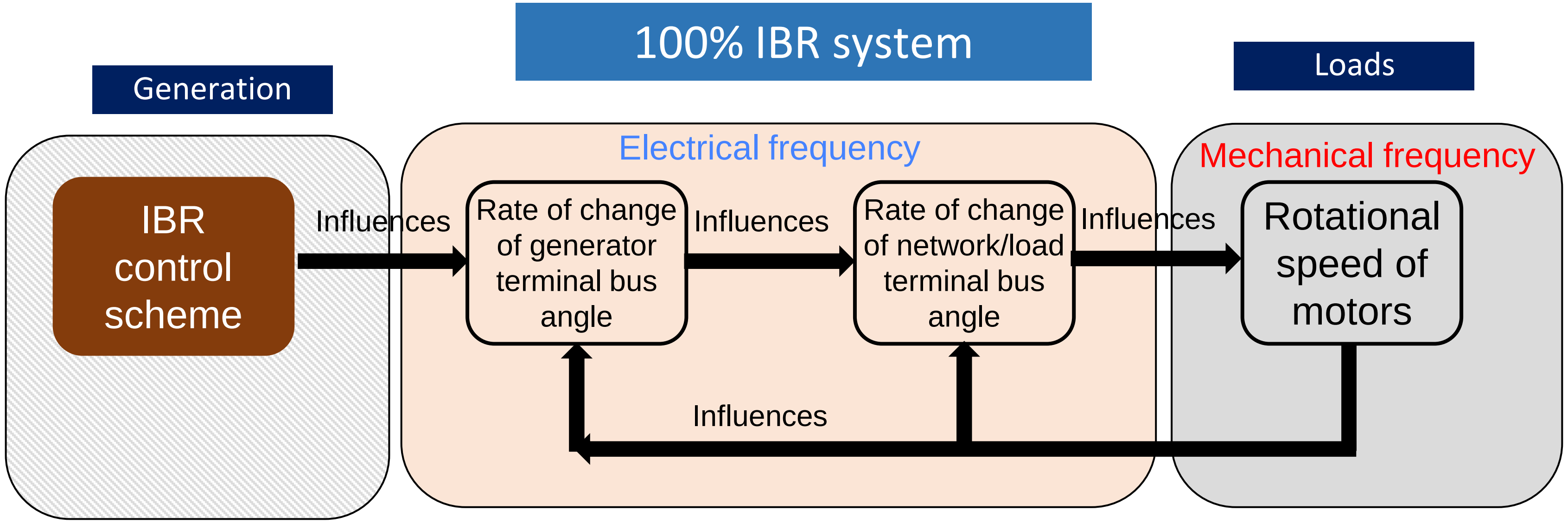
Frequency in a 100% IBR system… “*Decoupled from Generation*”



- Electromagnetic properties of the equipment and grid lock their behavior to be in sync
- System frequency is governed by speed of rotating machines



- Break in the electromagnetic link between IBR and grid
- Desired IBR control scheme can be *programmed … to bring about superior frequency control*

Source: Deepak Ramasubramanian, EPRI, “ Frequency Control in a 100% Inverter Based Grid”, ESIG Webinar, Jan 2021

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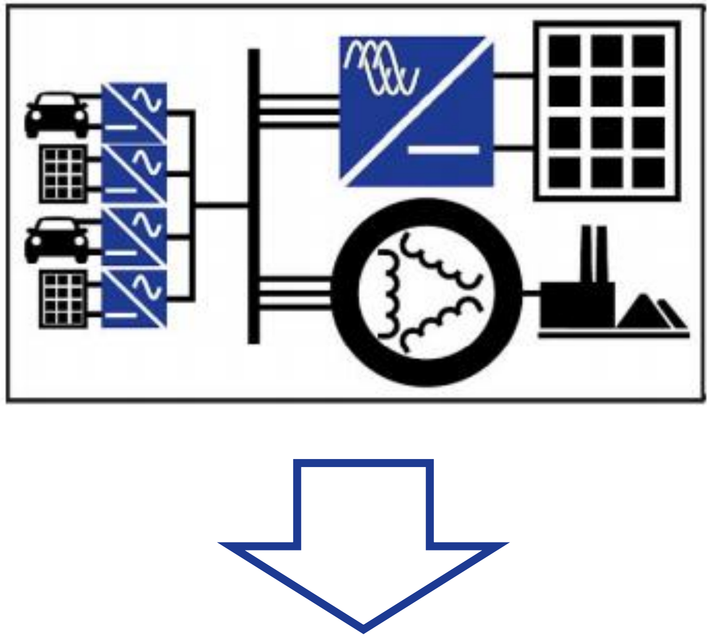
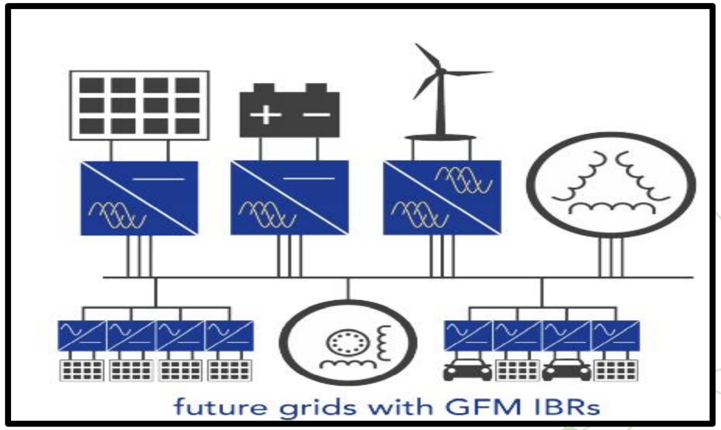
Journey From "Analog" Grid to a "Digital" Grid

- We've learned to live with synchronous machines, but it doesn't mean their behavior is always desirable or optimal
- Present grid-following inverters (GFL) *need a grid to follow* and present practice (mainly) rely on synchronous machines
- With inverters, we can go beyond the characteristics of synchronous machines, and have a broader spectrum of <u>programmable</u> options to make the grid work better
- *"Why make your Ferrari drive like a Dump Truck"?*

Nick Miller





Sources: 1. Nick Miller, Large System Perspective on Inertia, Frequency and Stability, ESIG Workshop 2018. Principal, HickoryLedge LLC. (Retired GE Energy Consulting)
2. Figures adopted from NREL led UNIFI Consortium

Acronyms: [GFM] Grid-forming; [IBRs] Inverter Based Resources; [GFL] Grid-following

Grid Following vs Grid Forming Inverters

Grid Following (GFL) Inverter

- It operates as a current source to achieve commanded active & reactive power set points.
- It needs a grid voltage (established by other generators) to synchronize to and feed-in or draw power of the grid.
- It controls its current wave form (amplitude and angle) to achieve the requested set-points
- It provides energy
- In case of a grid disturbance, it sets its current to the requested values as per the grid codes.

Grid Forming (GFM) Inverter

- It operates as a voltage source like a synchronous machine (also referred to as a virtual synchronous machine)
- It maintains control of an internal voltage phasor instead of output current and responds instantaneously to system changes.
- It provides energy **and many of the grid services when synchronous generators are stood down**
- In case of a grid disturbance, it can supply **fault current and contribute the system inertia**

Sources: 1. Prof Tim Green, Imperial College; Gary Custer, SMA; Julian Leslie, Naitional Grid ESO; Presentations at ESIG Grid-Forming Workshop, March 2021.
Acronyms: [GFM] Grid-forming; [IBRs] Inverter Based Resources; [GFL] Grid-following

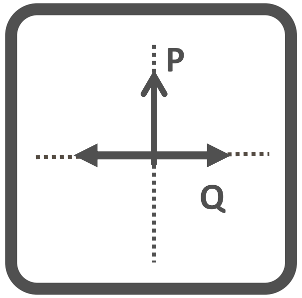
Significant GFM R&D Needed to Address Open Questions

Source: NREL-Univ of Washington-EPRI co-lead UNIFI Consortium

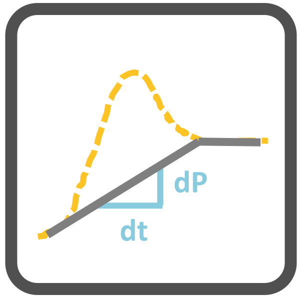
Acronyms: [GFM] Grid-forming Inverter

Summary – Journey to a "Digital Grid"

Voltage Support



Ramp Control



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

PV Grid Reliability Services

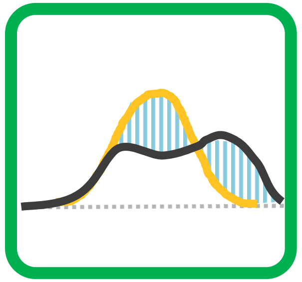
"Digital Grid"

Future grid that is affordable, secure, reliable, clean, and resilient realized with an arbitrary mix of machines and IBRs at any scale

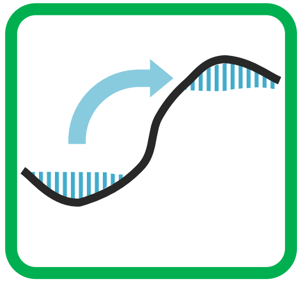
+

Capacity Firming

Energy Shifting



Flexibility

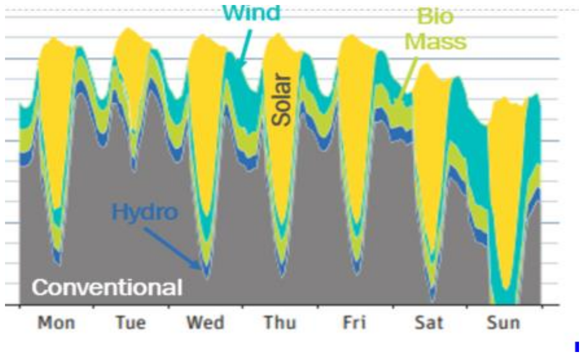


Grid Capabilities Enhanced in Hybrid Plants

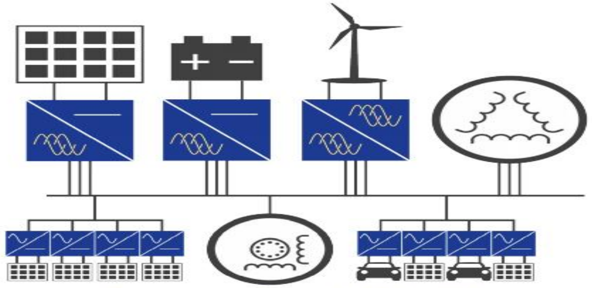
Acronym: [IBRs] Inverter Based Resources
GFM: Grid Forming Inverters

To Summarize …

- Solar generation capacity in US to increase from 100 GW to over 400 GW by 2030 …driven by **emission reduction policy** and **favorable solar economics**



- Key Technical Challenge: **Maintain grid stability & reliability** while integrating increasing amounts of **variable** generation



- Inverter-based resources (IBRs) provide **essential reliability services**, **firm capacity** and will enable transformation to a future "**digital grid**" …enabling consistent deployment is necessary

terabase
ENERGY

Mahesh Morjaria
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North American Transmission FORUM

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

EPRI

Transmission Planning for Clean Electricity

Dr. Debra Lew

Energy Systems Integration Group

NERC-EPRI-NATF Planning and Modeling Virtual Seminar

November 3, 2021

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Transmission Planning for Clean Electricity

Dr. Debra Lew, Associate Director, ESIG
NERC/EPRI/NATF Planning and Modeling Forum
Nov 3, 2021

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ESIG
ENERGY SYSTEMS INTEGRATION GROUP

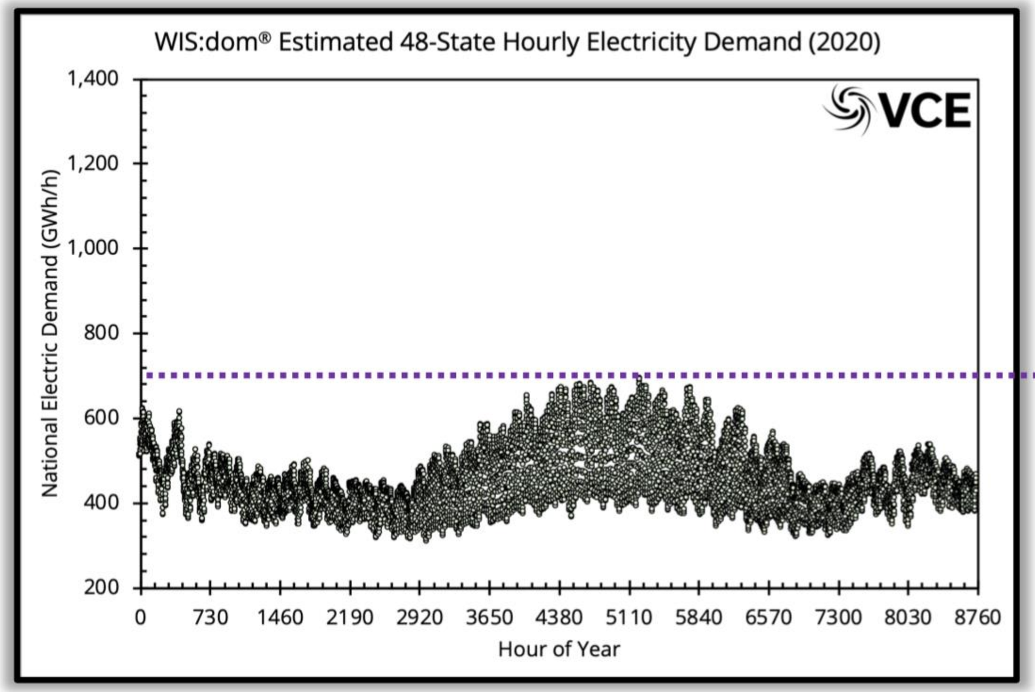
What is ESIG?

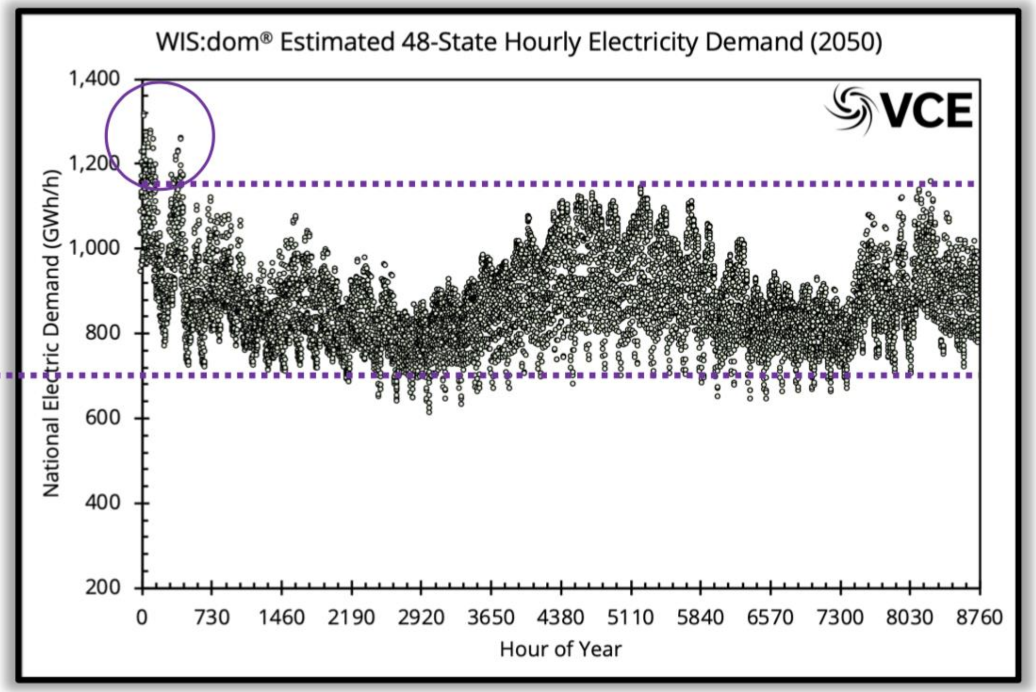
- ESIG addresses the technical challenges for transforming energy systems through collaboration, education and knowledge sharing. Workshops, webinars, reports available freely at esig.energy.
- 175 members worldwide broadly focused on decarbonization and integration of energy systems
- ESIG is part of the Global Power System Transformation Consortium and leads their System Operator Research and Peer Learning pillar.

We need transmission to deliver significant resources

- Demand will increase due to electrification
- We may need 1000 GW+ of new wind and solar to meet 100% clean electricity goals.
- DERs will contribute but are not sufficient on their own

MISO RIIA 100% buildout [MW]			
	DPV	UPV	wind
MISO	32,190	67,975	129,647
SPP	8,139	14,700	41,750
TVA	40,174	85,275	7,300
SERC	85,119	180,825	15,250
PJM	41,174	93,100	185,600
NYISO	8,483	19,675	31,600
Total	**215,279**	**461,550**	**411,147**





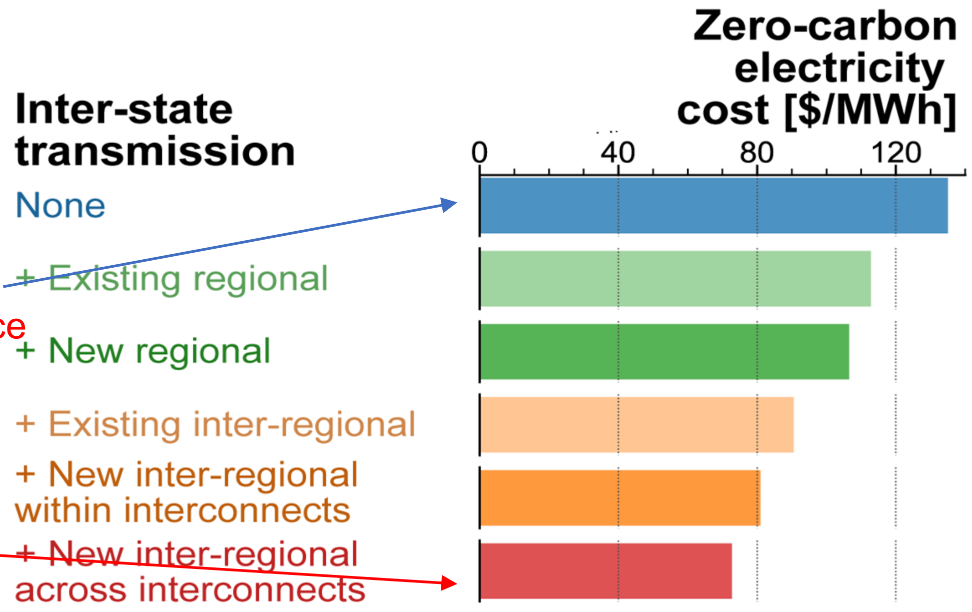
Source: C. Clack, IEEE PES GM 2021; MISO, RIIA 2020

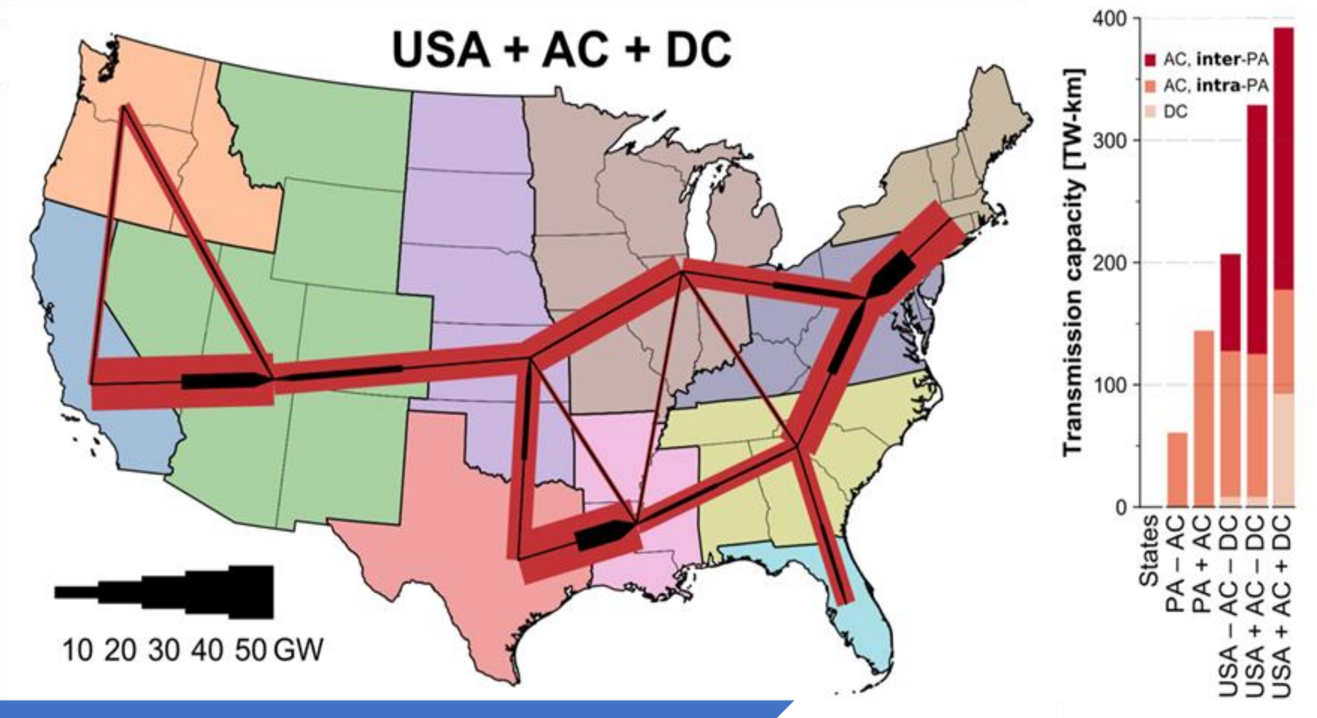
ESIG Open Distribution

MIT Study - Value of Transmission for Decarbonization

- What is the value of coordination within regions, between regions and nationally?
- Co-optimized capacity expansion and dispatch model with 7 years of hourly weather
- Least-cost plan results in nearly double today's transmission system (in MW-miles) with 29 GW transfers between east and west and 74 GW between ERCOT and east
- Finds that an "every state for itself" approach has a levelized capital and O&M cost of $135/MWh. Inter-regional coordination and transmission expansion approach reduces this cost by 46% (to $73/MWh)

"Every state for itself" costs twice as much as the nationally optimized and coordinated approach

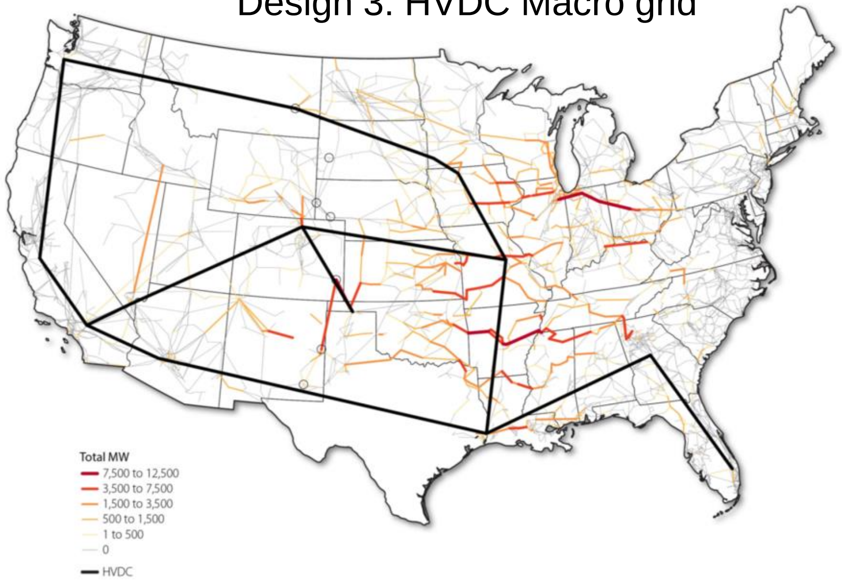




Interconnections Seam Study

- What's the value of interconnecting the east and west?
- Crossing the seam allows you to build the solar in the west and the wind in the east and share
- 50% renewables case: macro grid adds $19B to transmission costs but saves $48B (generation capacity, O&M and emissions), for a benefit/cost ratio of 2.5
- 85% renewables case (95% clean electricity): macro grid builds <u>40GW</u> transfers across seam with a benefit/cost ratio of 2.9

Design 3: HVDC Macro grid



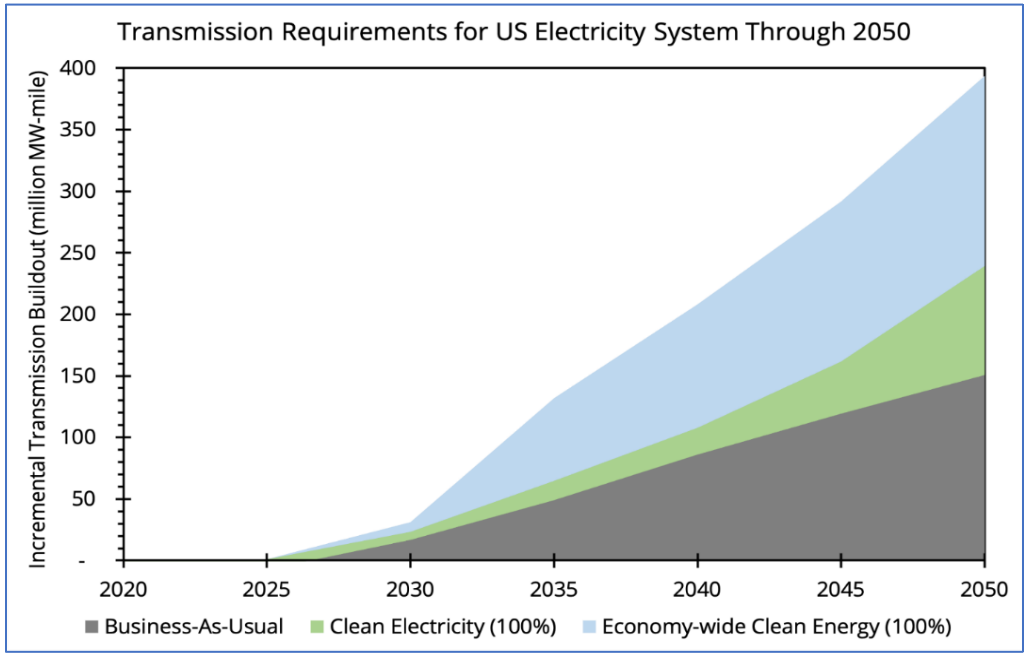
50% Renewables case	BAU across seams	HVDC Macro grid	
Objective function	**Design 1**	**Design 3**	**Delta**
Line investment (B$)	61.21	80.10	18.89
Generation investment (B$)	704.03	700.51	-3.52
Operation and maintenance (B$)	1336.36	1300.70	-35.66
Emission cost (B$)	171.10	162.50	-8.60
35-yr B/C ratio	-	-	2.52

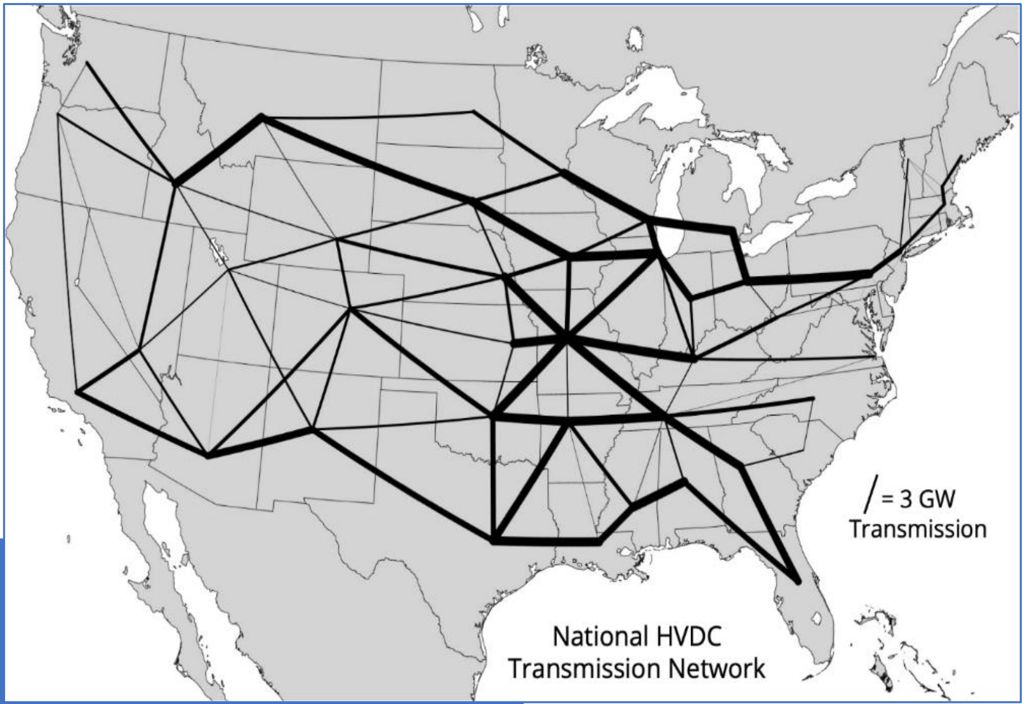
https://www.nrel.gov/analysis/seams.html

ZeroByFifty

- What is the optimal resource and transmission expansion to decarbonize the whole energy economy including massive electrification?
- Considers widespread DERs, new nuclear, CCS, and hydrogen
- Co-optimize generation (utility-scale and distributed), storage and transmission; combines capacity expansion and production simulation
- Transmission expansion costs are $200B and $350B for 100% clean electricity and energy, respectively
- Transmission depends on scenario: ~38GW between east/west; 30GW between east and ERCOT; 8 GW between west and ERCOT
- Finds that if a macro grid is NOT built, it costs an additional $1 Trillion to get to 100% clean energy by 2050

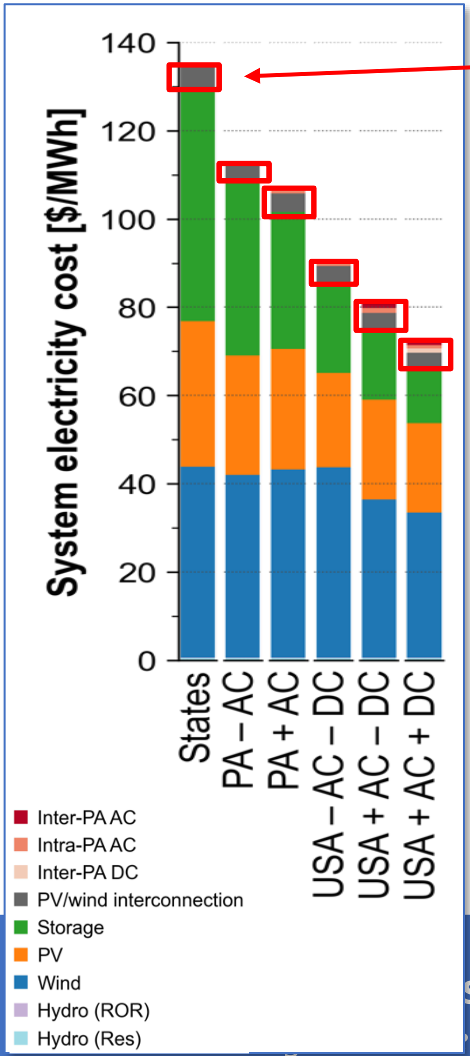
https://www.esig.energy/download/keynote-presentation-100-clean-by-2050-what-does-it-look-like-christopher-clack/#

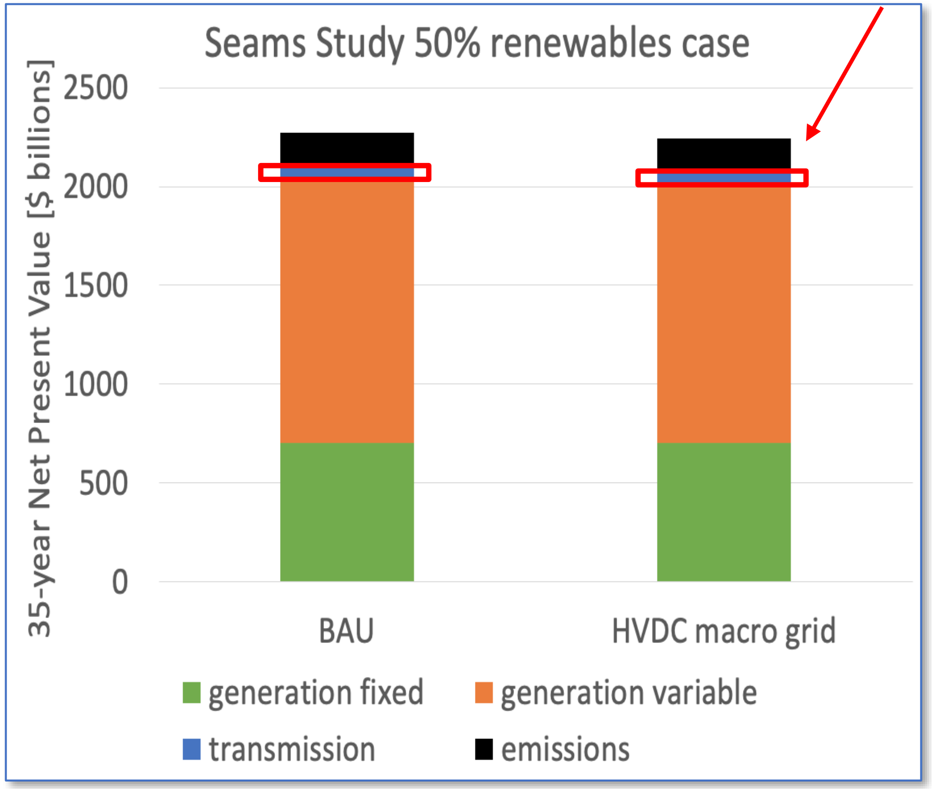


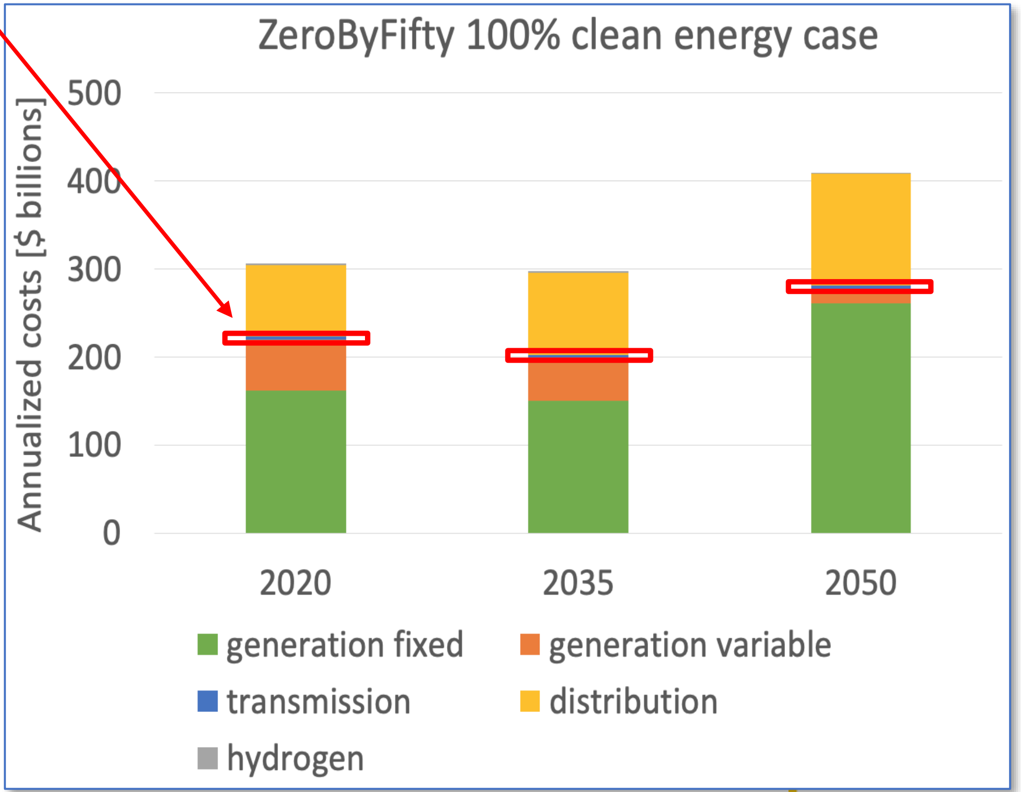


Transmission costs are tiny compared to other clean resources/infrastructure

TRANSMISSION COSTS







s Integration Group

of Energy Systems Integration and Operations

Brown and Botterud, 2020; NREL Interconnection Seams study; Preliminary results from VCE's ZeroByFifty Study

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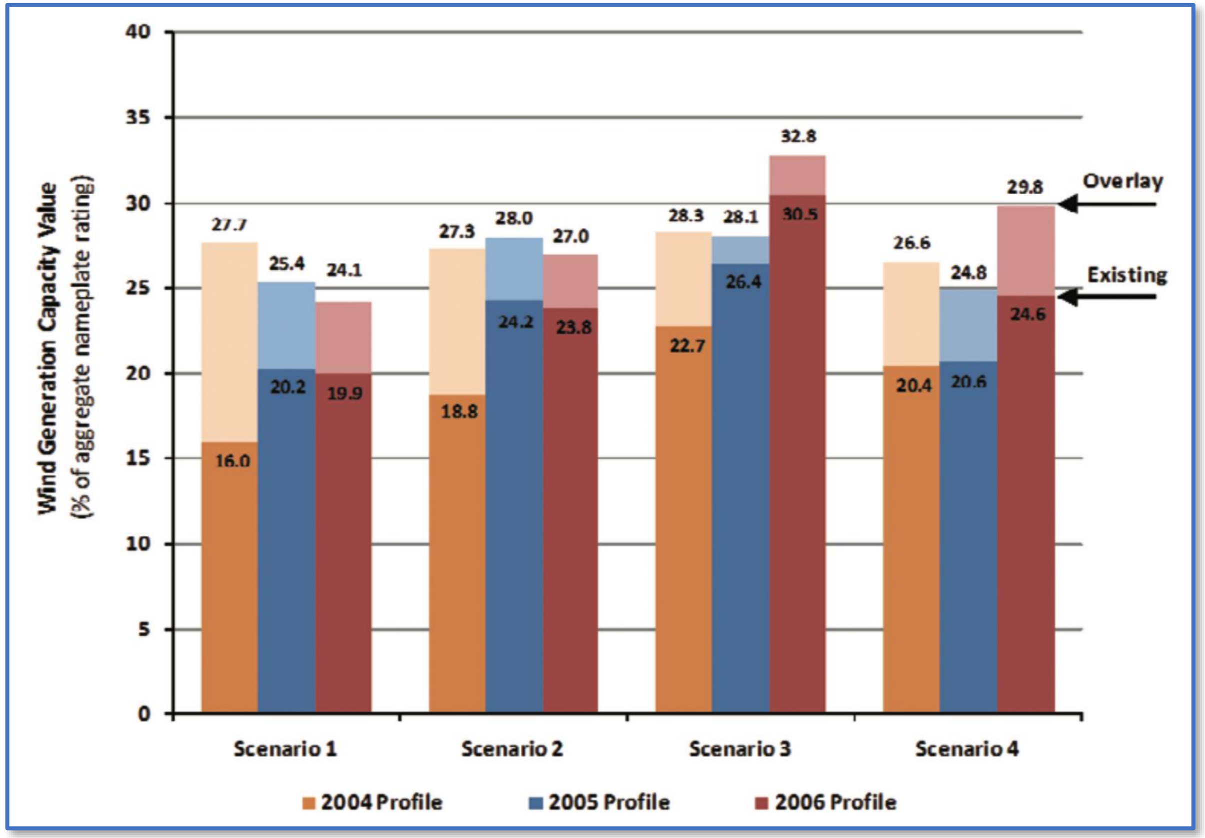
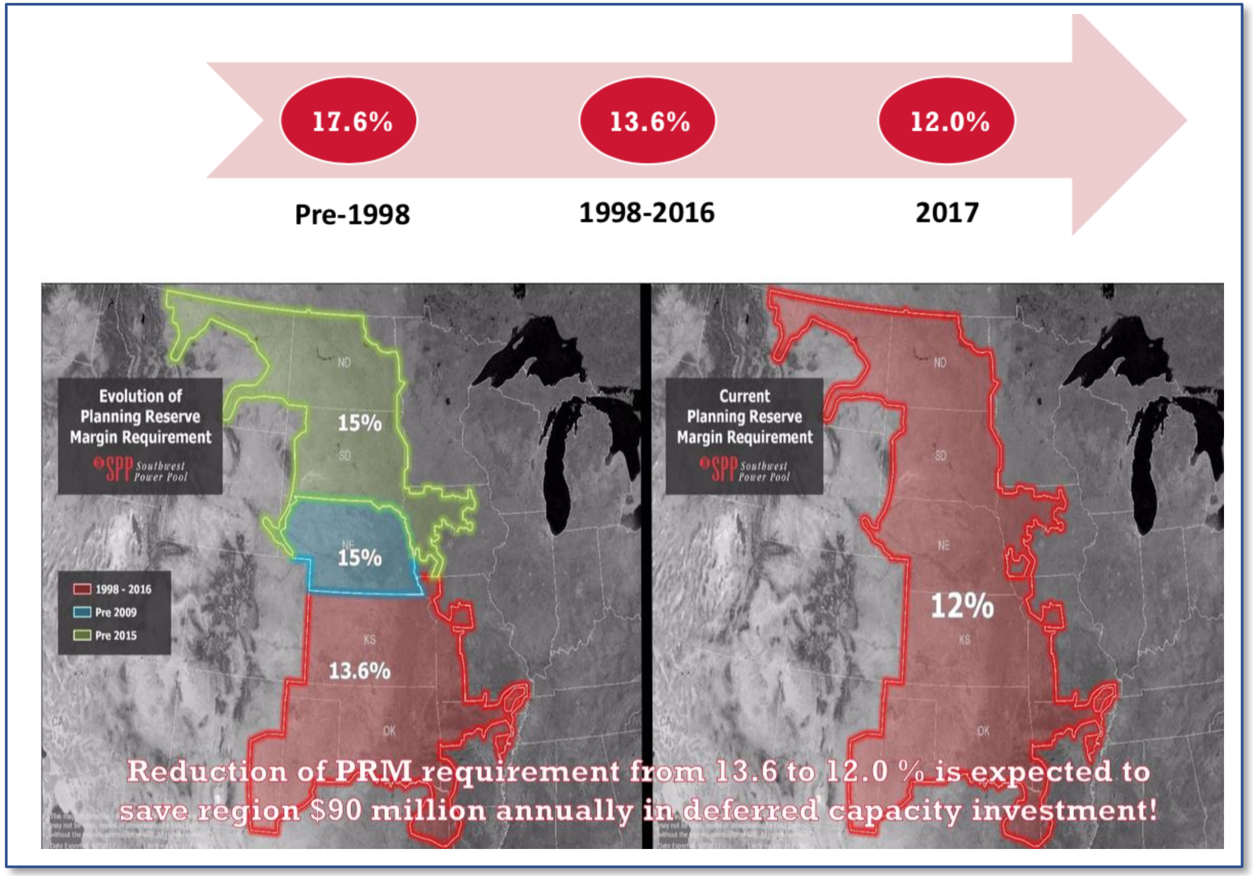
Transmission contributes to resource adequacy

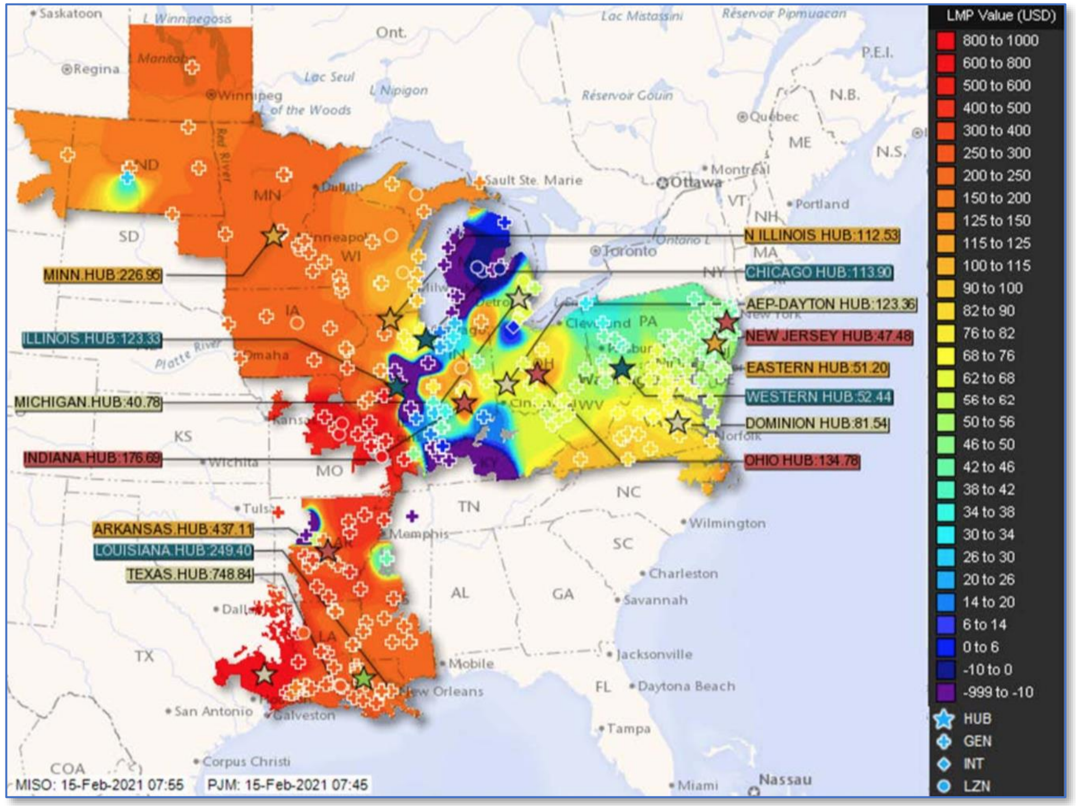


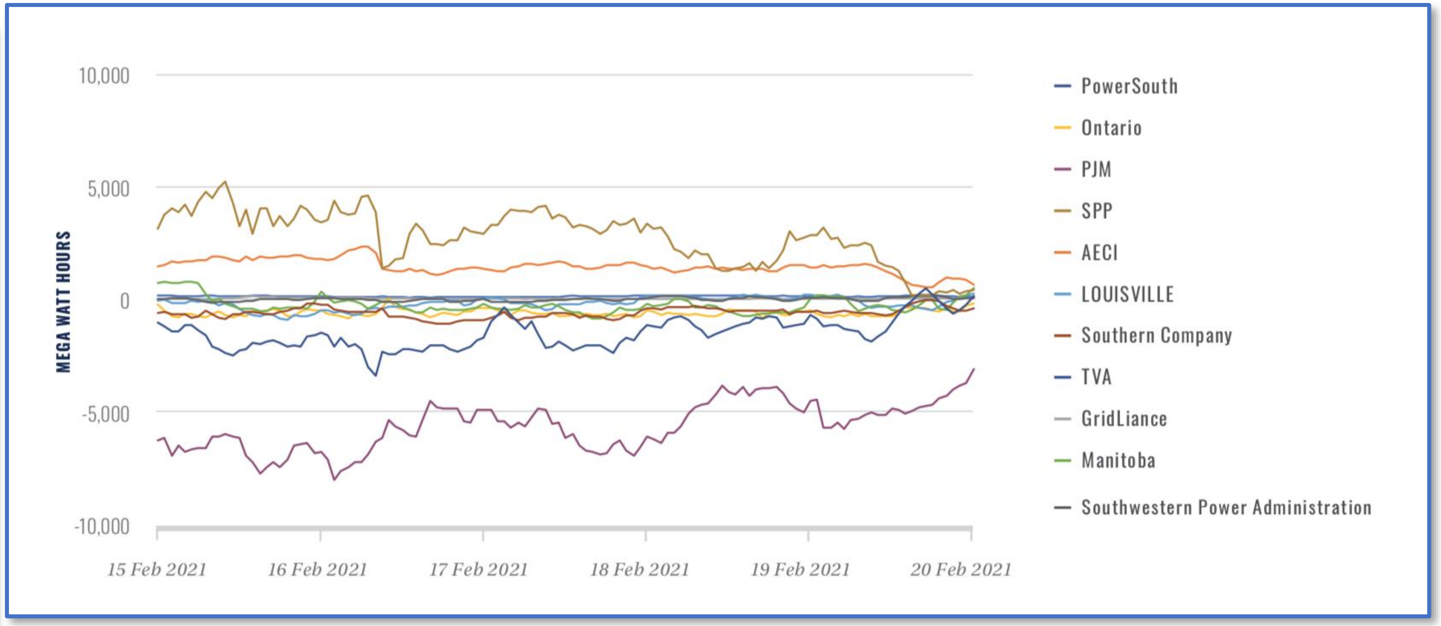


Transmission smooths all time scales of weather variability

Source: Enernex, EWITS, NREL/SR-550-47078, 2010; L. Nickell, SPP, CREPC Spring meeting, 2017

Transmission contributes to resiliency

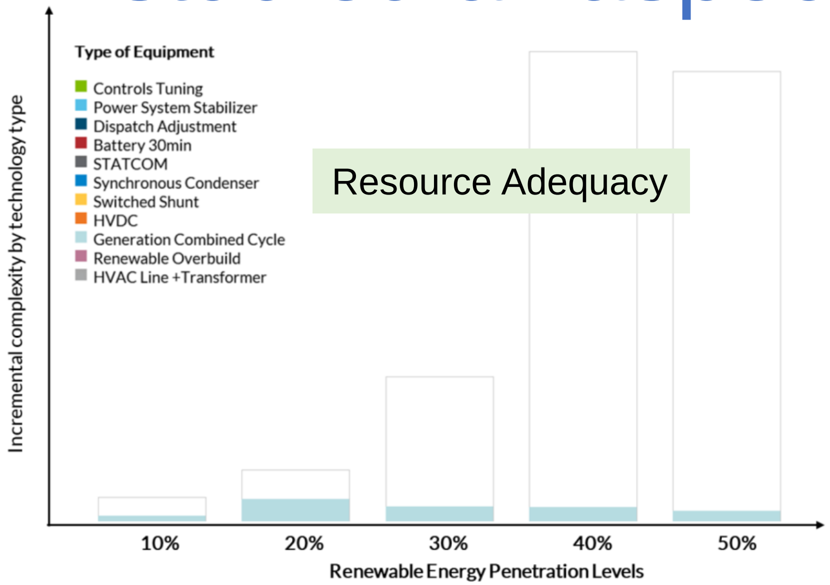


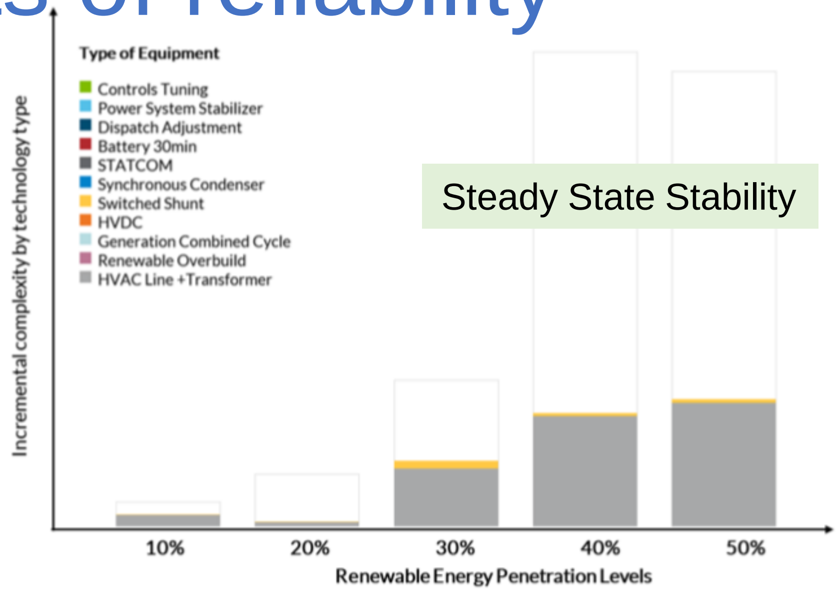


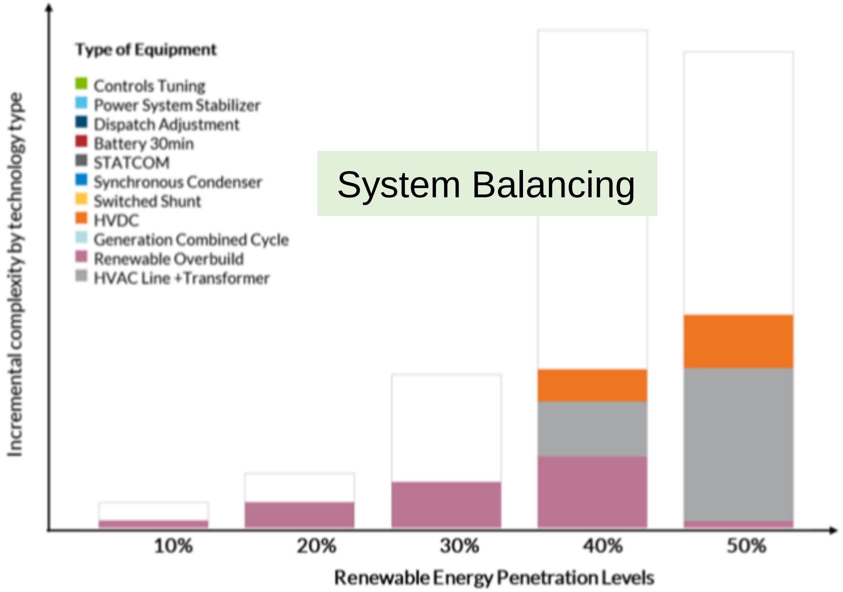
- Additional 1 GW of transmission capacity between ERCOT and TVA during winter storm Uri in Feb 2021 would have saved $993M and kept the lights on for hundreds of thousands of customers
- Southern Cross line would have paid for itself in value from that storm

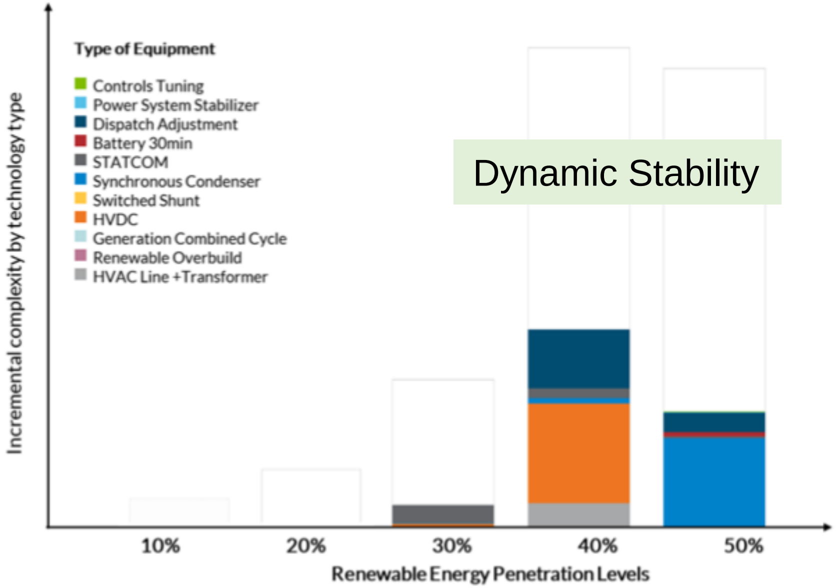
Goggin and Gramlich, July 2021 from Joint and Common Market contour map and from MISO interchange

MISO's Renewable Integration Impact Assessment studied all aspects of reliability







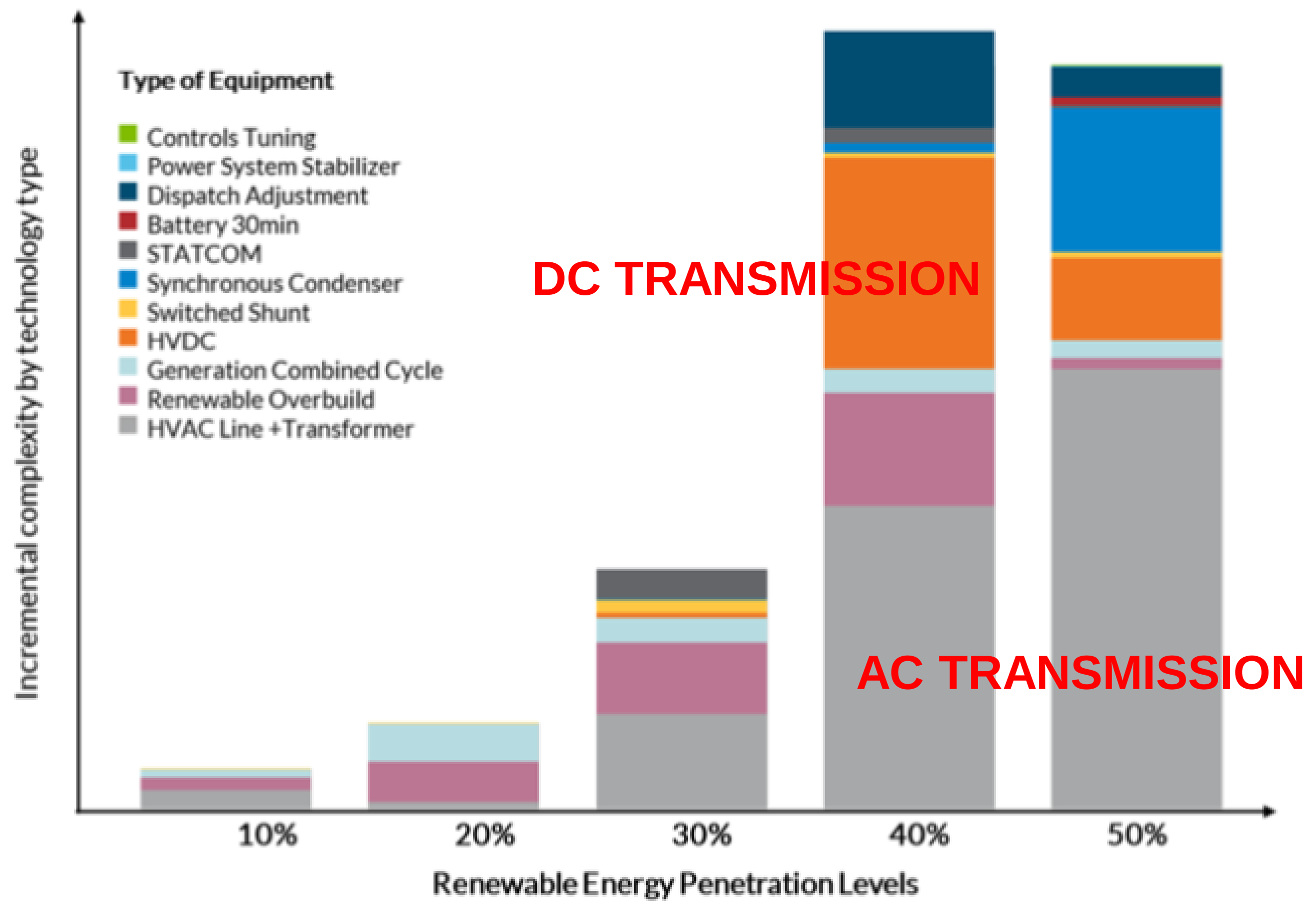


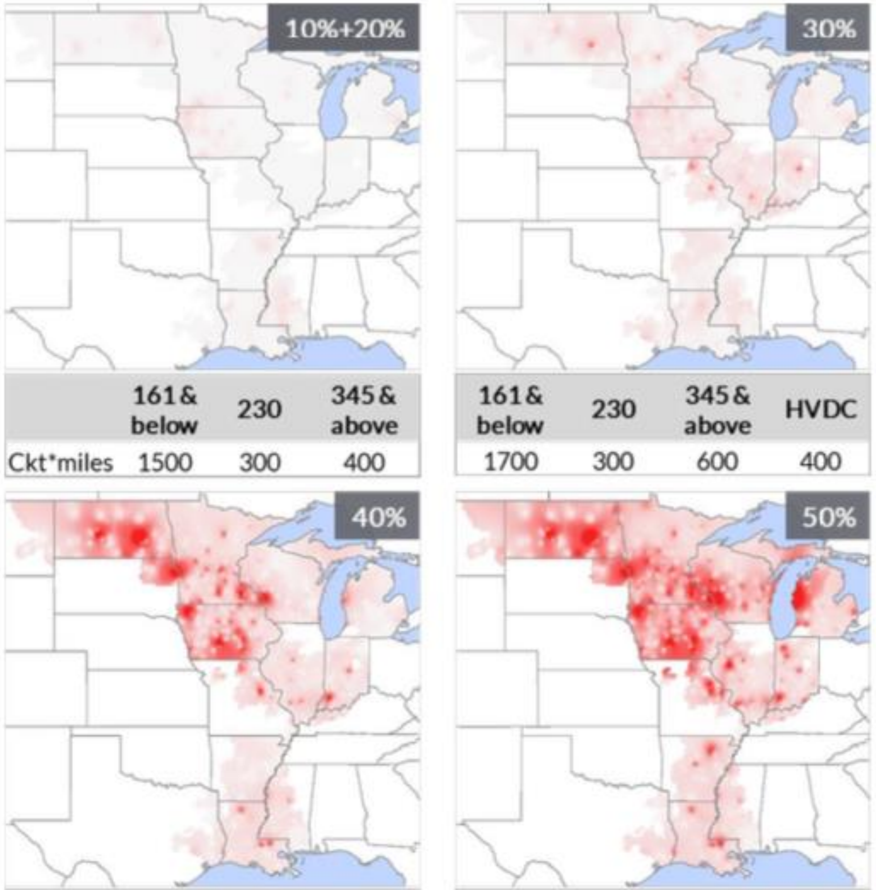
- Increased annual wind and PV penetration in 10% increments for Eastern Interconnection
- At each increment, reliability issues were identified and fixed using least-cost, commercially available solutions

https://cdn.misoenergy.org/RIIA%20Summary%20Report520051.pdf

ESIG

Transmission infrastructure is the biggest investment needed to make the 50% wind/PV case work





10%+20%

	161 & below	230	345 & above
Ckt*miles	1500	300	400

30%

161 & below	230	345 & above	HVDC
1700	300	600	400

40%

161 & below	230	345 & above	HVDC
1600	900	3800	1600

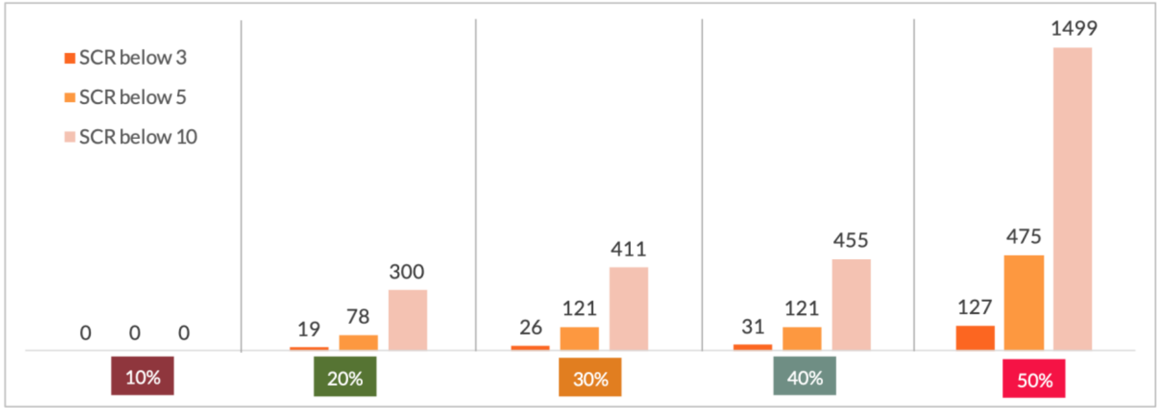
50%

161 & below	230	345 & above	HVDC
500	800	5200	700

https://cdn.misoenergy.org/RIIA%20Summary%20Report520051.pdf

ESIG
Open Distribution

Managing weaker and lower inertia systems



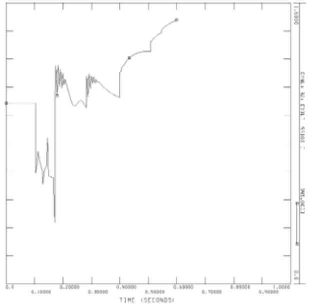
Area of stability	Ranked concern	Performance metric	Impacts	Possible mitigations	Concerned MISO group	Issue first seen	Impact of renewable penetration	Capital cost share to mitigate
Inverter-based stability and voltage stability	1. Transient voltage stability in weak areas	Short circuit ratio, undamped voltage and current oscillations, interactions between the controls of equipment	Local area, observed at many substations system-wide	• Control tuning • Synchronous condensers • STATCOM • HVDC	EP*, GI†	30%		
Frequency stability	2. Frequency response	Frequency nadir, rate of change of frequency (RoCoF), NERC BAL-003 obligations	Interconnection wide	• Additional planned online headroom • Batteries	Operations	50%		
	3. Small signal stability	Damping ratio of low frequency oscillations	Interconnection wide	• Must-run units with power system stabilizers • Specially tuned batteries	EP*, Operations	30%		
Rotor-angle stability	4. Transient rotor angle stability	TO's local planning criteria, NERC criteria	Local area	• Faster protection schemes • Transmission facilities	EP*, GI†	50%		-

*EP: Expansion Planning
†GI: Generator Interconnection

https://cdn.misoenergy.org/RIIA%20Summary%20Report520051.pdf

ERCOT Panhandle

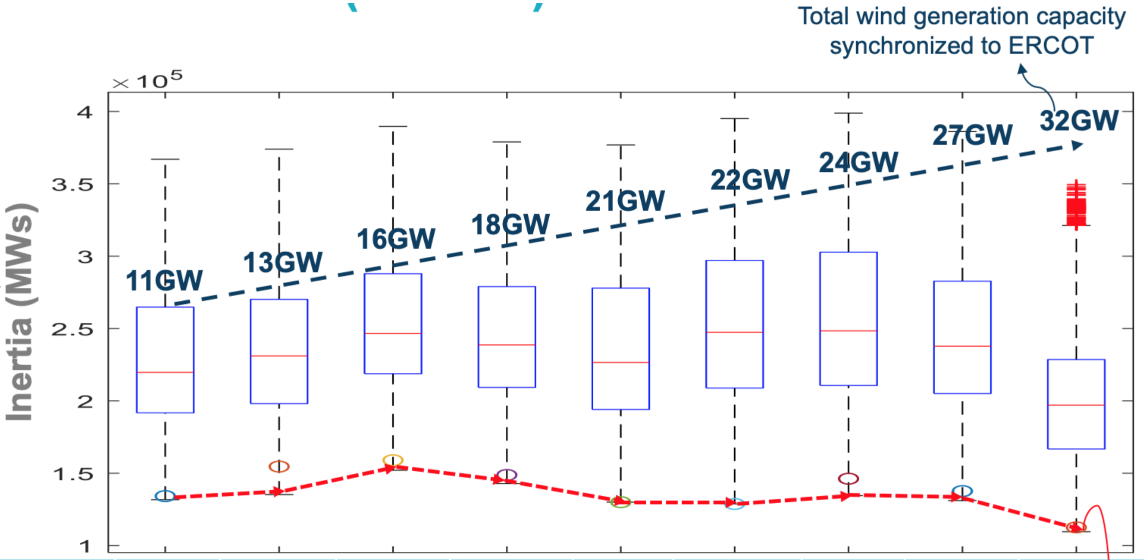
- > 10 GW IBRs connect to Panhandle and nearby Panhandle
  - IBRs are located at remote areas (high IBR penetration)
  - Limited/no online synchronous generators (low short circuit)
  - Long distance large power transfer (high impedance)
- Indicators of weak grid
  - High frequency oscillation or numerical instability in PSS/e
  - High voltage overshoot or even high voltage collapse
  - Low WSCR (weighted short circuit ratio)
- Improvement Options
  - Two synchronous condensers were added to Panhandle: stability associated with condensers needs to be checked
  - Reduce impedance: adding new circuits
  - Control tuning and coordination



ercot

UBLIC

Today ERCOT has localized weak grid issues but has not yet hit its inertia floor



Date	2013	2014	2015	2016	2017	2018	2019	2020	2021
Min synch. Inertia (GW*s)	132	135	152	143	130	128.8	134.5	131.1	109
System load at min. synch. Inertia (GW)	24.7	24.6	27.2	27.8	28.4	28.4	29.9	30.7	32.6
Non-synch. Gen. in % of System Load	31	34	42	47	54	53	50	57	65

Courtesy, J. Matevosyan, ERCOT, WECC
GFM Workshop, 2021

Is storage a replacement for transmission?

Interconnection

Delivering resources to load

Reliability

Security of operation
Meeting NERC criteria

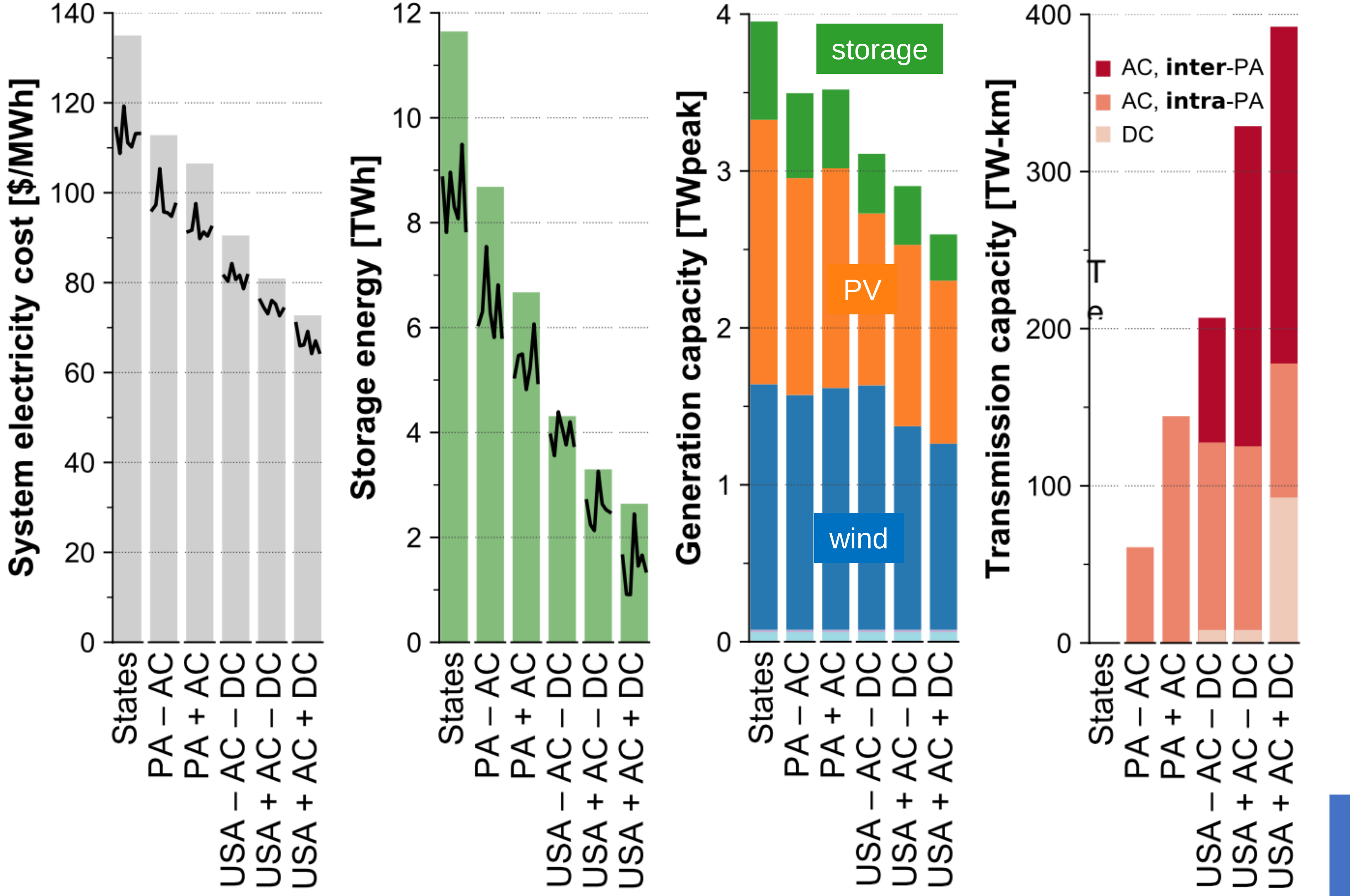
Economics

Reduce congestion

Managing Variability

Aggregating geographic diversity

Increased transmission reduces storage capacity



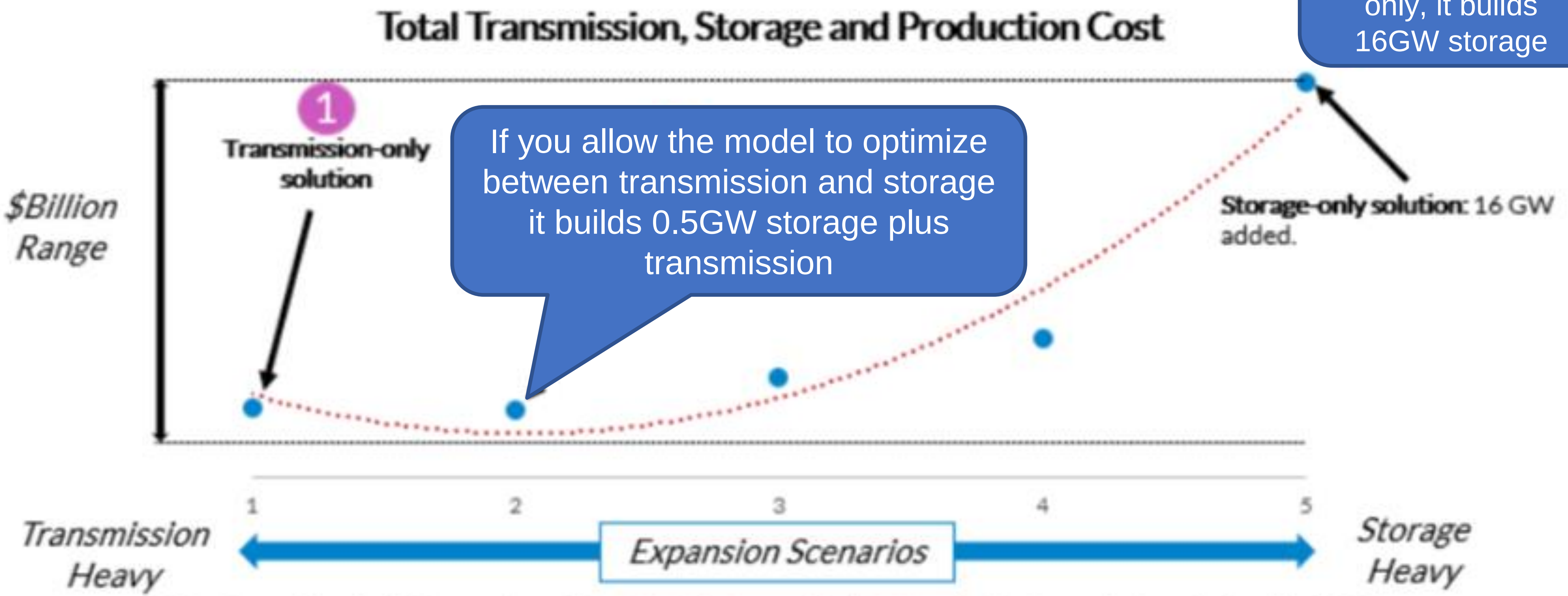
This study examines 100% clean electricity in the US under scenarios with increasing geographic levels of transmission expansion and operations

Source: Brown and Audun, “The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity System,” Joule 5, 1-20, Jan 20, 2021

Open Distribution

Storage-only solutions are more expensive and don't address all the issues

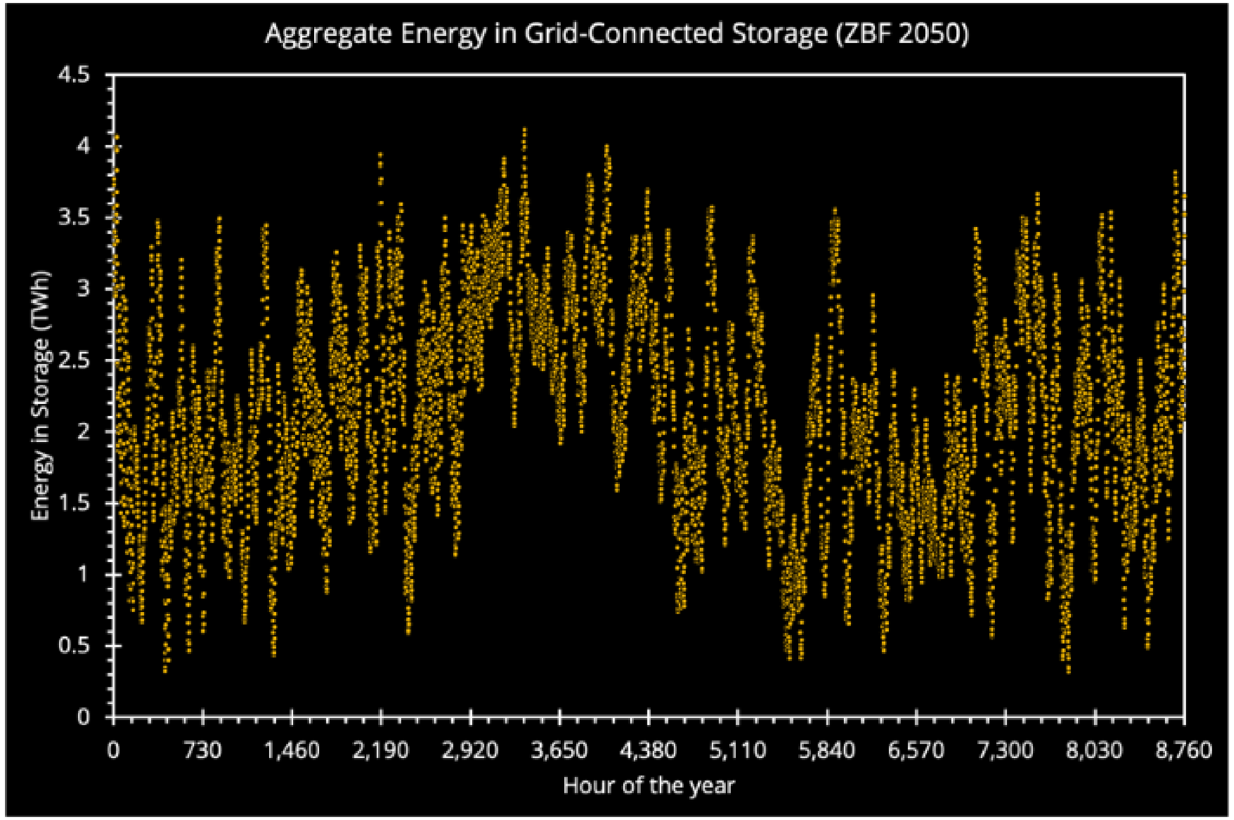
If you allow the model to optimize size of storage only, it builds 16GW storage

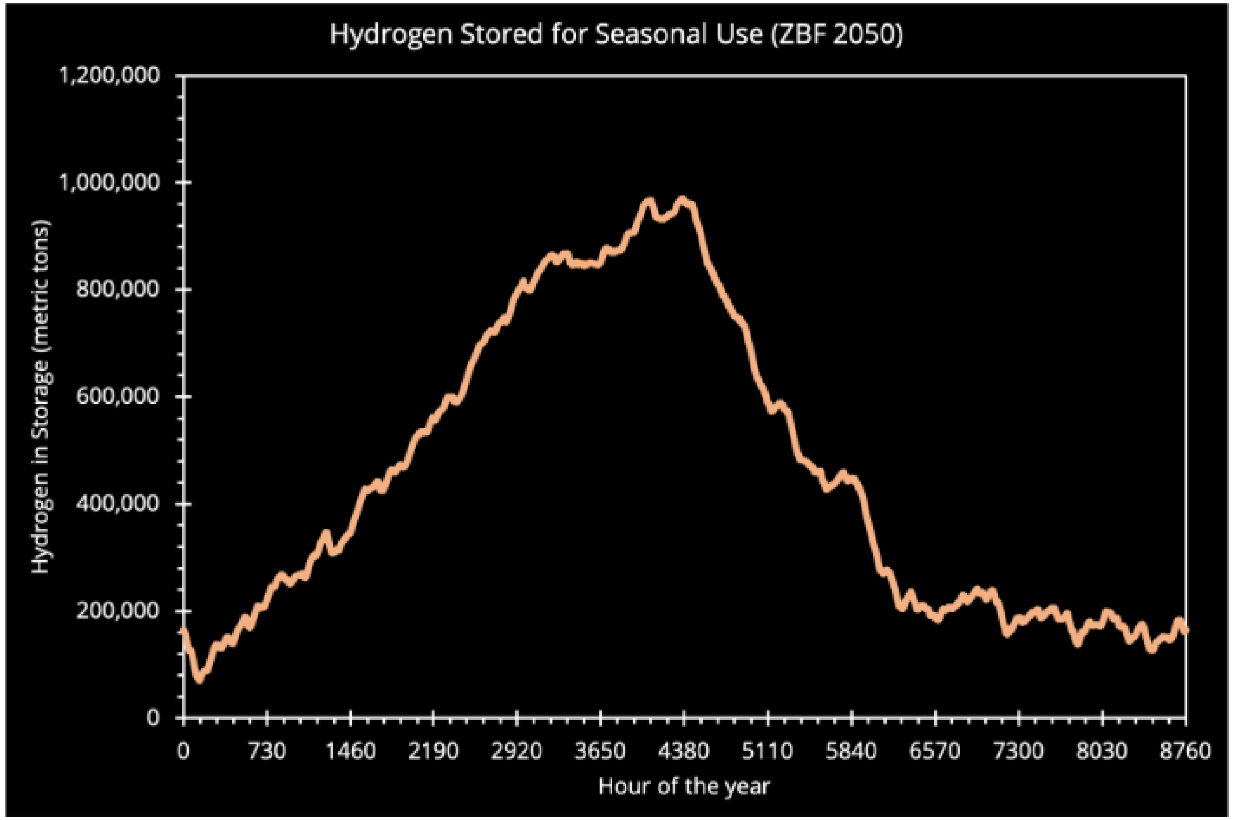


Note: Expansion simulation performed for 40% milestone with all 30% and prior transmission solutions included.

https://cdn.misoenergy.org/RIIA%20Summary%20Report520051.pdf

Different types of storage operate differently





https://www.esig.energy/download/keynote-presentation-100-clean-by-2050-what-does-it-look-like-christopher-clack/#

Debra Lew
Debbie@esig.energy
(303) 819-3470

Break

NERC-EPRI-NATF Planning and Modeling Virtual Seminar

November 3, 2021

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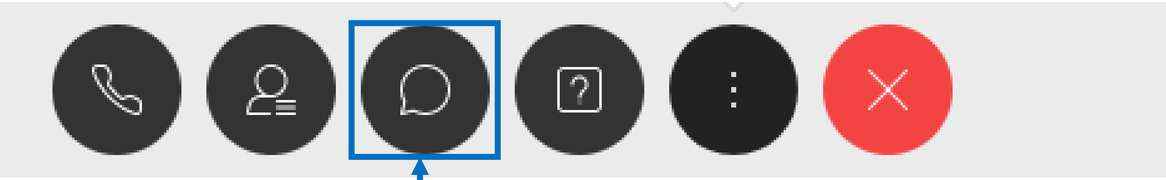
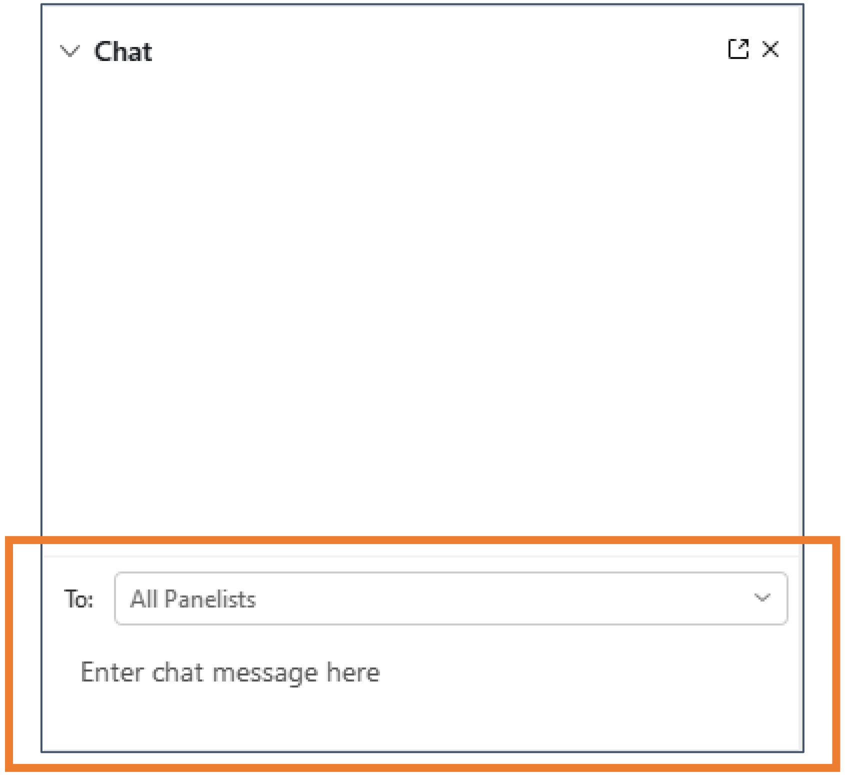
Using the chat feature:

Chat Feature

OR



Chat Feature



North American Transmission FORUM

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

EPRI

Planning Experiences for Integrating Changing Resource Mix

Industry SMEs

NERC-EPRI-NATF Planning and Modeling Virtual Seminar

November 3, 2021

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Transmission Expansion Planning for Integrating Variable Energy Resources – a Paradigm Change

Hari Singh – Public Service Co. of Colorado

NATF-NERC-EPRI 2021 Planning & Modeling Virtual Seminar
November 3rd, 2021

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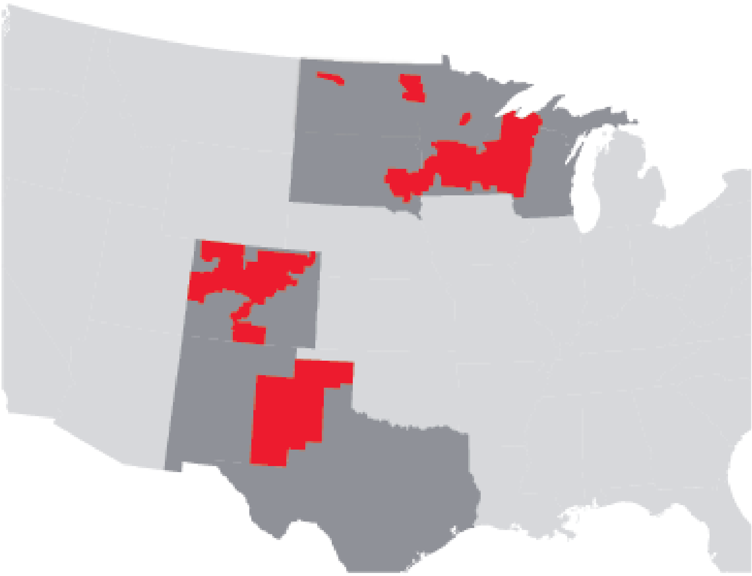
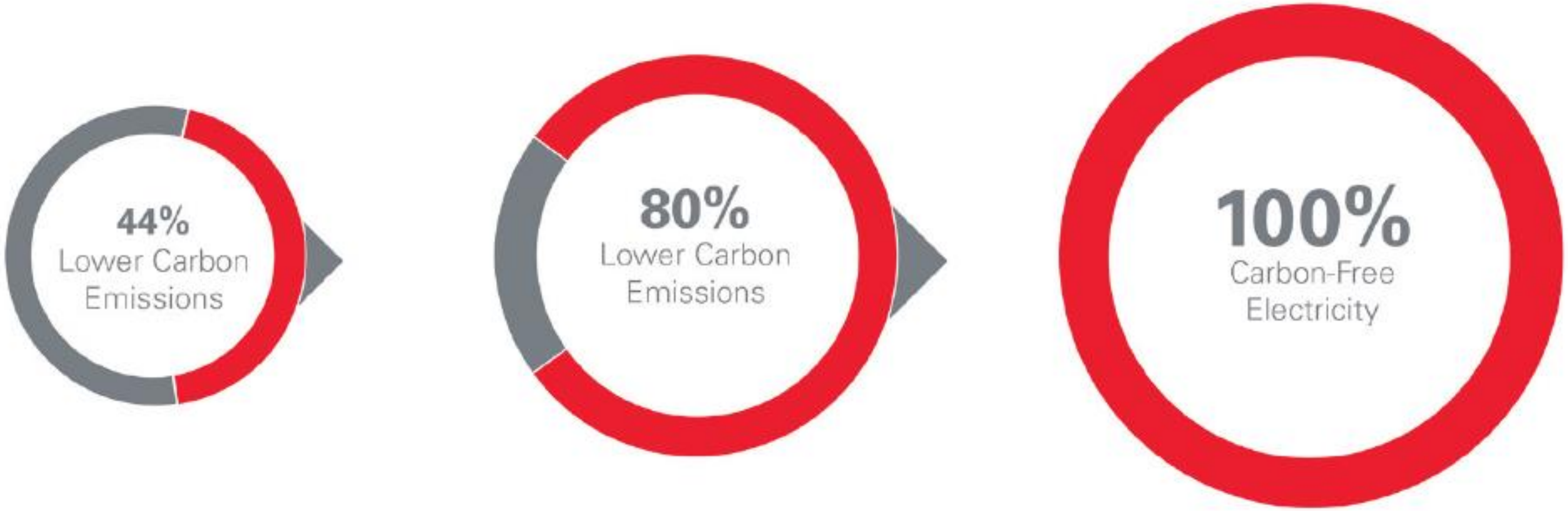
2019 Results | 2030 Goal | 2050 Vision

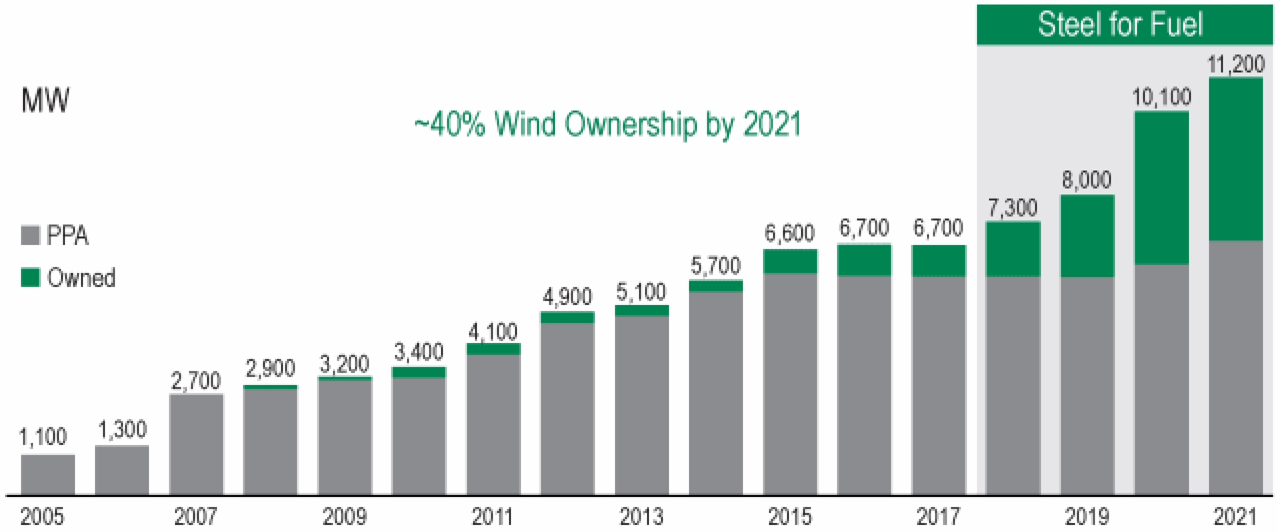




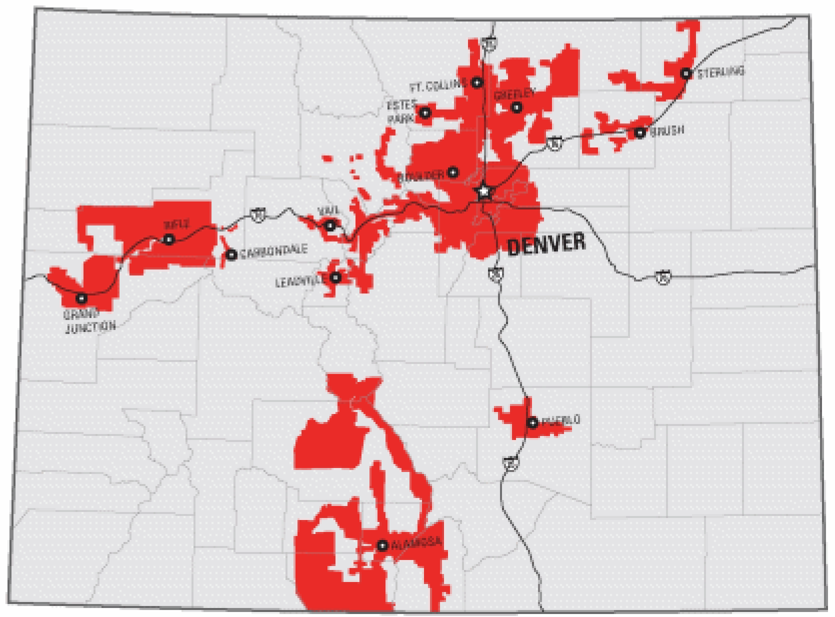
Company-wide emissions reductions from the electricity serving our customers, compared to 2005

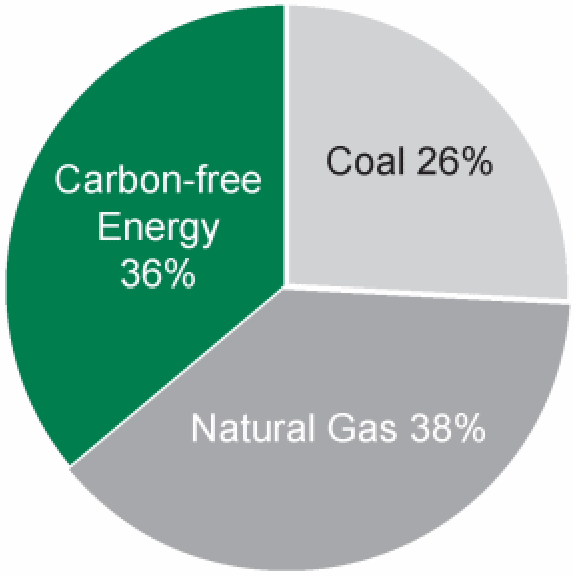
Electric customers	3.7 million
Natural gas customers	2.1 million
Total assets	$54 billion
Electric generating capacity	20,140 MW
Natural gas storage capacity	53.4 Bcf
Electric transmission lines (conductor miles)	110,353 miles
Electric distribution lines (conductor miles)	208,586 miles
Natural gas transmission lines	2,172 miles
Natural gas distribution lines	35,936 miles

Changing Composition of Wind Capacity



Public Service Company of Colorado (PSCo)





Capacity — Wind capacity:

Utility Subsidiary	2020
NSP System	3,348 MW
PSCo	4,085 MW
SPS	2,535 MW

	System Peak Demand (in MW)			
	2020		2019	
NSP System	8,571	July 8	8,774	July 19
PSCo	6,899	Aug. 17	7,111	July 19
SPS	4,195	July 14	4,261	Aug. 5

Existing Capacity Resources = ~7,400 MW (Total Installed Capacity = ~12 GW)

Resource Need for 80x30 Goal (2025-2030) = 5600 MW Name-plate Capacity

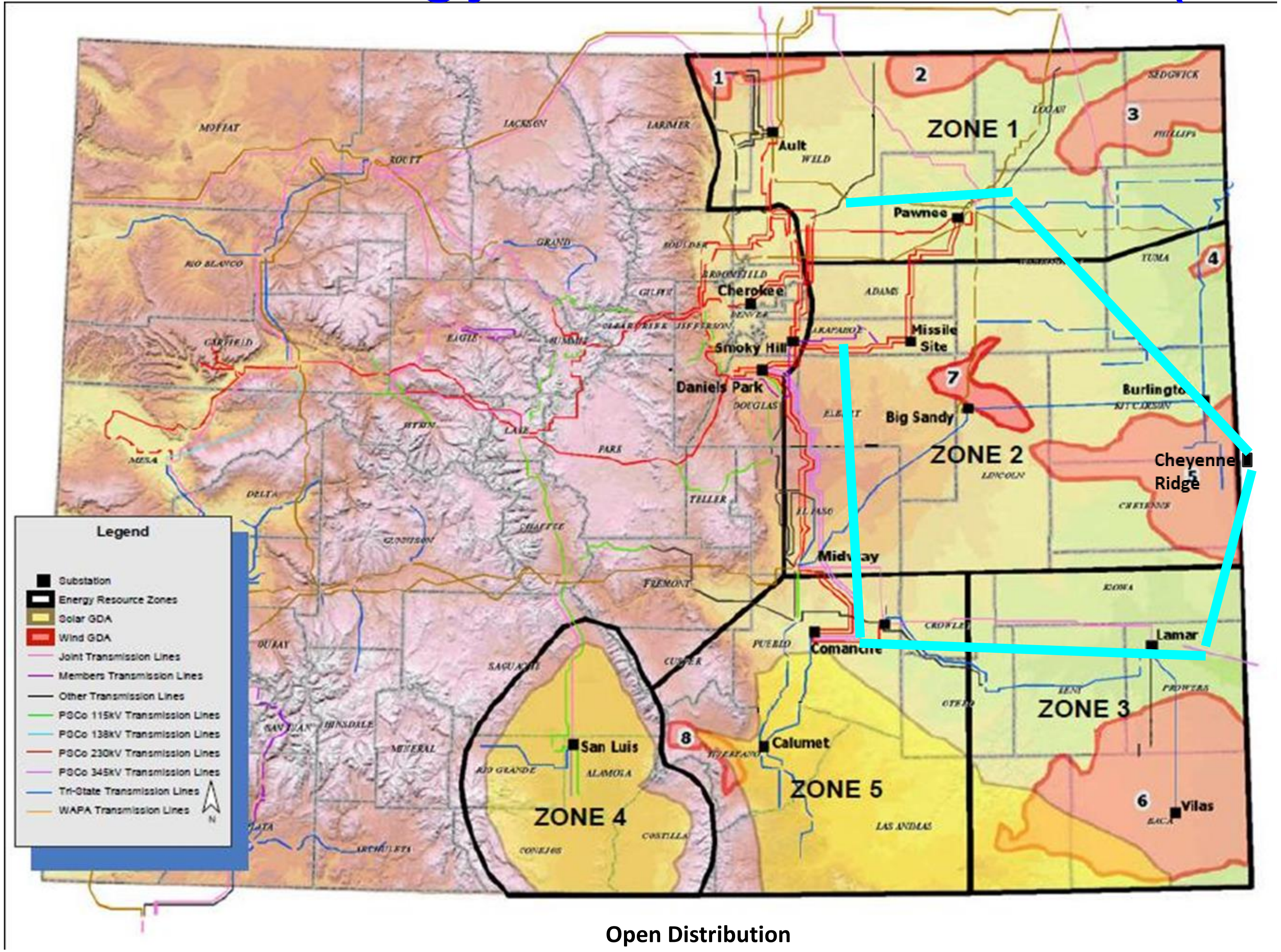
Wind = 2600 MW Solar = 1300 MW Total VER Resources = **3900 MW**

Storage = 400 MW Dispatchable Capacity Resources = 1300 MW

Coal Plant Retirements (2022-2030) = 975 MW (Approved = 742 Proposed = 233)

Colorado's Energy Resource Zones (ERZ)

Xcel Energy



Open Distribution

How much is adequate transmission capacity?

Capacity Resources (coal, gas, hydro)

- ➢ Base-load, Peaker or Intermediate
- Maximum Generation = Aggregate of Generators Name-plate (Rated) MW

Generation Outlet T-Lines Capacity
≥ Maximum Generation MW

- ▪ Predictable & limited number of generation dispatch scenarios sufficient for transmission adequacy planning (typically peak load hour)

Energy Resources (wind, solar, storage)

- ➢ Spatial & Temporal Variability
- Maximum Generation = High-likelihood Coincident MW Output (probabilistic)

Generation Outlet T-Lines Capacity
≥ Maximum Generation MW

- ▪ Coincident MW Output Duration Curve – requires 8760 hours of VER Output MW based on TMY* wind & solar data

VER Output Curtailment is inevitable – should be managed to acceptable level

*** Typical Meteorological Year**

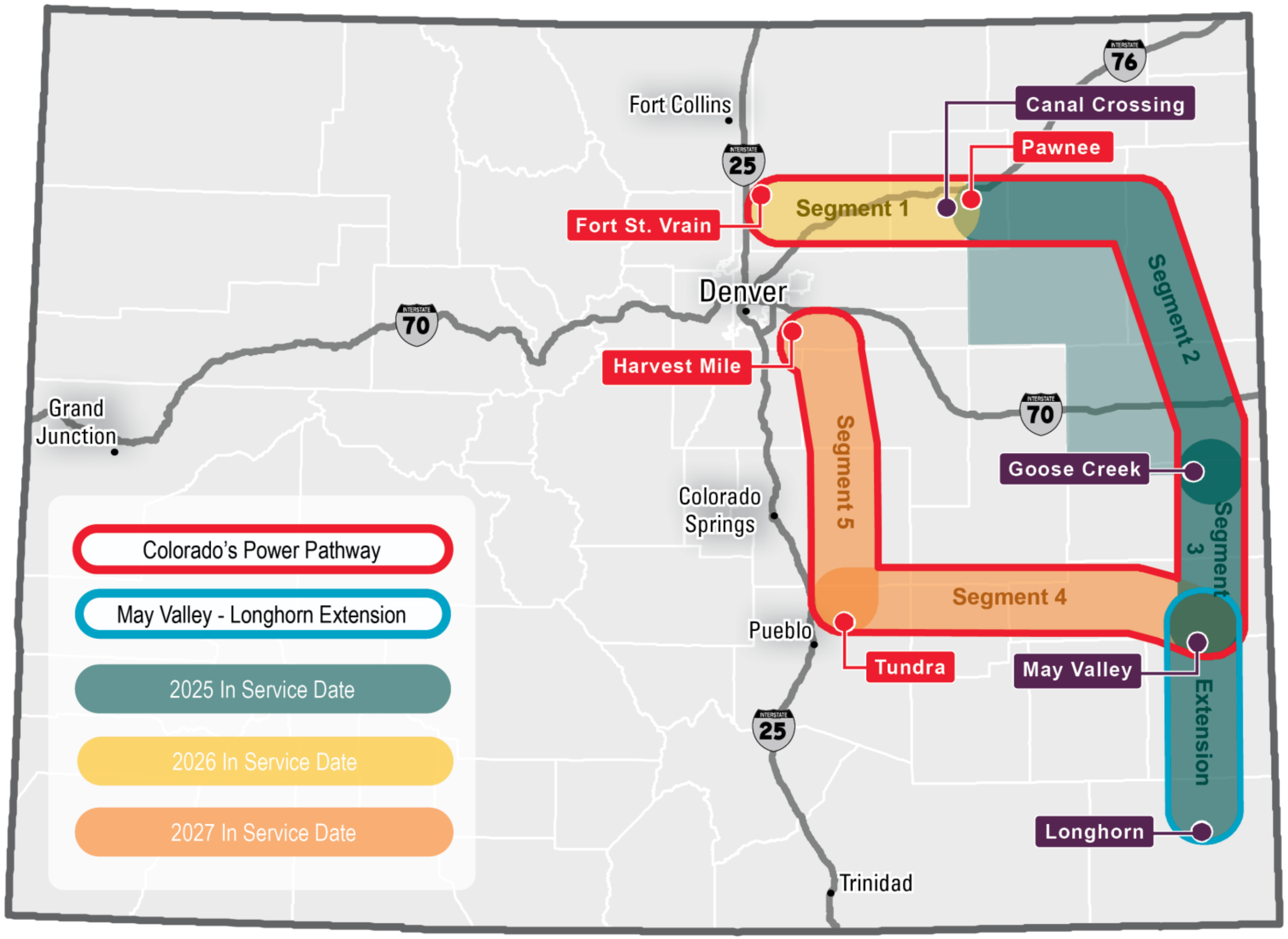
VER Temporal Variability - Example

6000 MW Name-Plate Generation	Coincident Generation Output during Spring/Fall Off-Peak Load Hours 1300-2100 Hours in March/October				
	HE1300	HE1500	HE1700	HE1900	HE2100
Solar = 2400 MW	90% (2160)	60% (1440)	30% (720)	10% (240)	0%
Wind = 3600 MW	40% (1440)	60% (2160)	100%	100%	100%
Coincident Output	3600 MW	3600 MW	4320 MW	3840 MW	3600 MW
MW Curtailment for 3600 MW Xmsn Capability	0	0	720	240	0
Likelihood of Coincident Output Exceed (% Annual Hours)	3.4%	2.2%	<1.1%	<1.7%	1.7%

Transmission Expansion Plan for 80x30

Colorado's Power Pathway

- 345kV double-circuit T-lines
- 560 line-miles
- 3 new & 4 expanded stations
- Segment 1 = 75 mi
- Segment 2 = 160 mi
- Segment 3 = 65 mi
- Segment 4 = 140 mi
- Segment 5 = 120 mi
- MV-L Extension = 90 mi



Transmission Expansion Plan for 80x30

Xcel Energy®

Colorado's Power Pathway

- Injection Capability = Coincident Gen Output = 3000-3300 MW (depends on MW size & extent of co-location of wind & solar resources)
- Provides adequate transmission capacity for 2025-2030 VER acquisition targets in Electric Resource Plan towards corporate 80x30 goal

  Wind = 2600 MW Solar = 1300 MW Total = 3900 MW name-plate

- 3000 MW Coincident Output = ~77% of name-plate MW
- More Spatial & Temporal Diversity → Injection Capability adequate for higher name-plate MW → Integration of >3900 MW name-plate capacity, i.e. more "headroom" available on planned transmission

Takeaways – Xmsn Planning for VER Integration

- Evaluating transmission capacity need/adequacy for integration of dispatch-limited VER resources (wind & solar) must consider their inherent spatial and temporal variability
- *Coincident Generation Output* metric accounts for both – serves as Injection Capability target for Transmission Planning
- Building transmission for injection capability equal to name-plate MW of dispatch-limited VER resources will most likely result in significant under-utilization of transmission capacity for majority of 8760 hours
- Curtailment of VER output will become increasingly unavoidable when installed name-plate capacity approaches/exceeds the system load (especially in export constrained transmission system)

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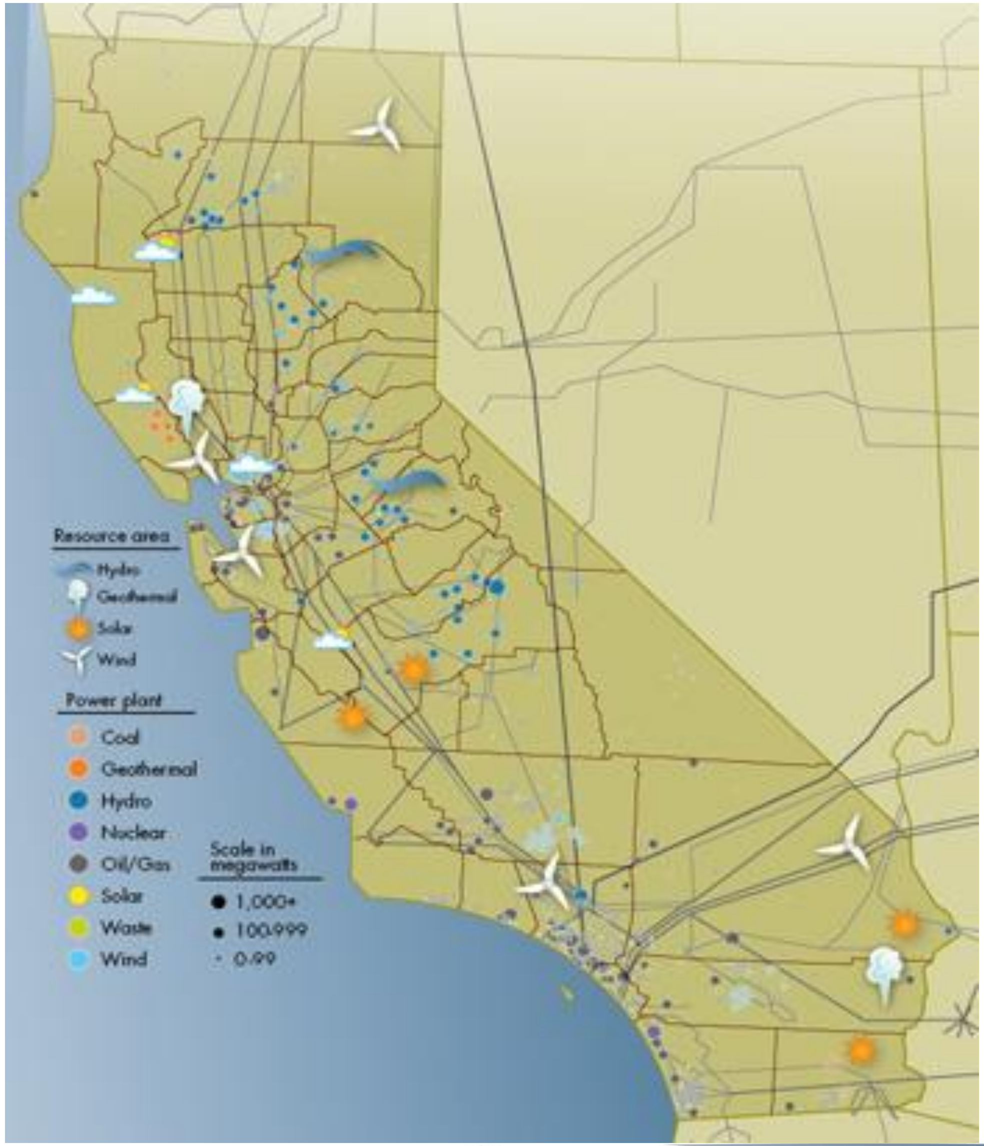
Transmission Planning Perspectives: Interconnection, Modeling, and Studies

Irina Green, California ISO

California ISO Generation Interconnection Queue

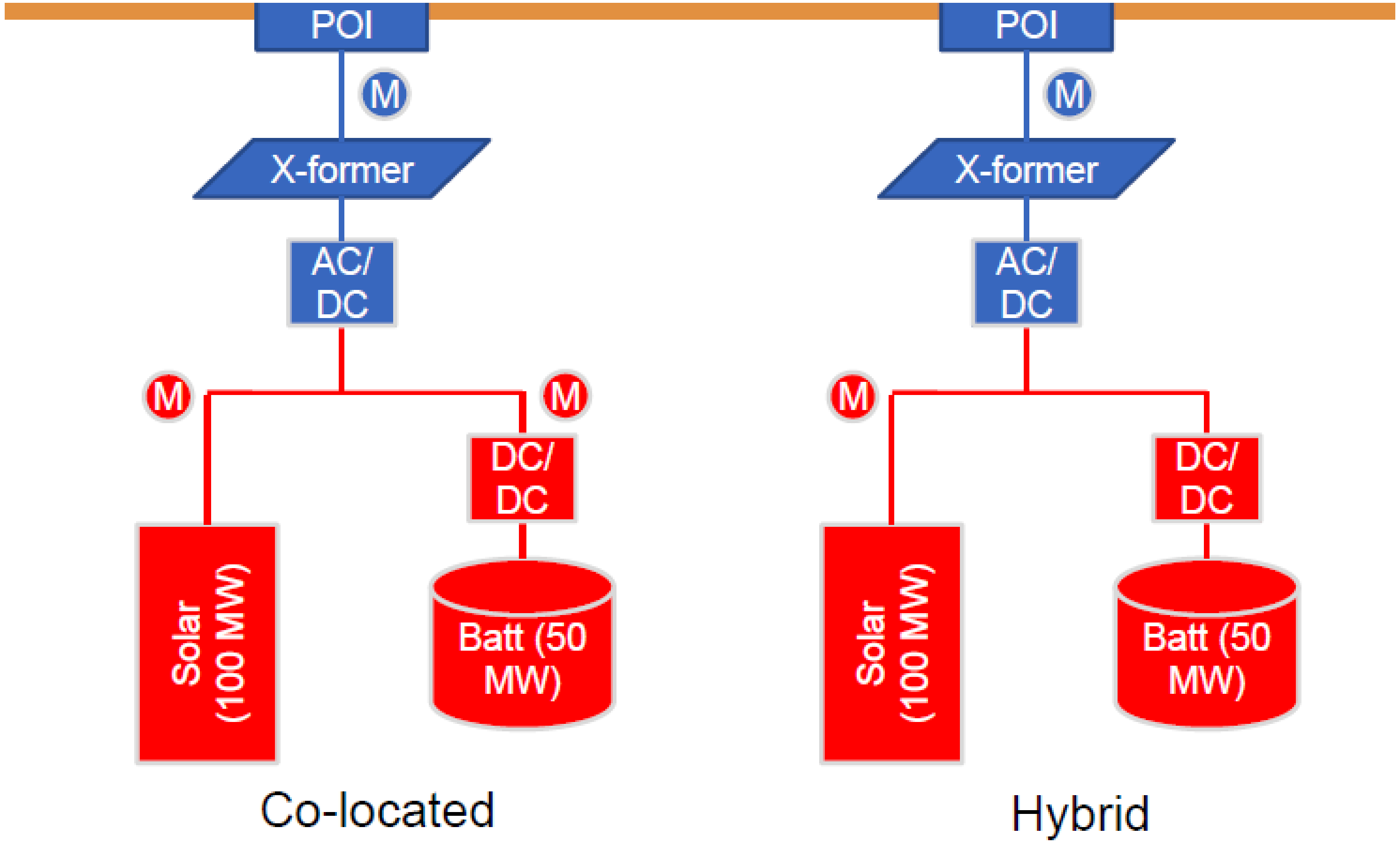
- 609 generation projects in the queue for total capacity of 164,788 MW
- Solar (both PV and thermal) 169 projects, 39,733 MW
- Wind 35 projects, 12,745 MW
- Storage 393 projects, 110,993 MW
- Latest Cluster #14, started April 2021
  - 339 projects, 101,560 MW



Hybrid and Co-Located Plants: Two Models for Facilities with Multiple Gen Types

- Co-located Resources – Multiple Resource IDs behind a single point of interconnection
  - Each resource is modeled and submits bids to the ISO independently
  - ISO will model state of charge, VER forecasts, heat rates independently as appropriate
- Hybrid – Single Resource IDs, with multiple mixed-fuel components behind a single point of interconnection
  - ISO receives one bid curve from the hybrid resource which should include any internal optimization
  - Hybrid resource should always be able to respond to any dispatch instruction from the ISO

Potential Metering for Co-located and Hybrids



Co-located batteries may charge from the co-located plant (solar) or from the grid. Hybrid – only from the plant with which it is connected

Interconnection Considerations

- Size the interconnection request: installed MW capacity, contractual MW limit and MWh
  - Installed MW capacity typically doubles the contractual MW limit in a hybrid IBR plant
  - Duration of sustained MW injection matters; not only for operational flexibility but also for resource adequacy credits
- If hybrid, choose between ac-coupled or dc-coupled
  - Cost, flexibility, RA credits, etc.
- Choose the source of charging and maximum charging power
  - Source of charging has financial impacts on the IBR, such as tax credits

Modification Considerations

- Change ac or dc-coupled, MWh, source of charging down the road
  - Understand utility’s policy and process for making modification and the impacts on the IBR
- Add BESS to an existing plant
  - Adding BESS behind-the-meter, i.e. without increasing MW at point of interconnection, could be done expeditiously (surplus interconnection service in FERC Order 845)
- Replace batteries as performance degrades
  - Understand utility’s retention policy for interconnection and resource adequacy counting

Interconnection Requirements

- Generally follow the same technical requirement for asynchronous generators (and synchronous generators if applicable)
  - Voltage ride-through capability
  - Frequency ride-through capability
  - Power factor design criteria
  - SCADA capability
  - Transient data recording equipment for facilities above 20 MW
  - Automatic voltage regulation
  - Primary frequency response capability
- The requirement applies to both charging and discharging mode

Modeling Requirement

- Positive sequence model
  - Generic model or user-written model
  - Generic RES model capability is being enhanced; industry education is still needed, especially for hybrid IBR plants
  - Model is required upon submission of interconnection request, updated whenever there is a change before commercial operation
  - As-built model and test reports are required after commercial operation; periodic updates or updates upon changes
- EMT model
  - Many utilities now require EMT model for IBR plants due to SSCI and weak grid issues
  - Similar technical requirement has been implemented cross the country; however, when the model is required varies
  - EMT model is often used to benchmark the positive sequence model

•

Modeling Considerations

- Properly model both physical limits and contractual limits
  - Power plant controller model reflects contractual limits
  - Inverter model reflects physical limits
- Power plant controller power flow model is being implemented in all major software platforms
  - Monitor total plant output against the plant Pmax/Pmin, which are contractual limits
  - Coordinate voltage droop control among all generators in the plant
- Power plant controller dynamic model is repc_a or repc_b*
  - Use repc_b if multiple generators in the plant are represented in the power flow model
  - Repc_b is the most “confusing” and misused model

EMT Model Requirement

- EMT models are usually black-box. It is important to provide documentation with setup instructions, control functions, protections, etc.
- Provide model test reports
- Full representation of the plant from generators to the point of interconnection
- Include the full detailed inner control loops of the power electronics
- Represent all plant level controllers
- Represent all protections
- **Be configured to match expected site-specific equipment settings**

Interconnection Studies

- Interconnection studies (same for all generator types):
  - Power flow contingency analysis
  - Voltage stability analysis
  - Transient stability analysis
  - Short circuit analysis
- Different dispatch of BESS and hybrid are studied under various peak conditions, such as summer peak, spring off-peak, e.g.
  - At maximum discharging output: peak and off-peak
  - At maximum charging output: peak and off-peak
  - At capacity counted for resource adequacy: peak

Integrating Storage and Hybrid Resources

Amanda Schiro
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NATF-EPRI-NERC

November 2021

Key Takeaways

Purpose: Overview of MISO's processes related to integrating Hybrid Resources

Key Takeaways:

- MISO tariff updates for defining Hybrid Resources were just approved by FERC
- MISO's first Hybrid Resource is scheduled to begin commercial operation this year!
- 2021 Interconnection Queue continues to see a rise in both hybrid and storage requests

MISO Definition – Hybrid Resource

- A Generator that combines more than one type of Electric Facility for the production and/or storage for later injection of electricity.
- Interconnected to the Transmission System
- Viewed as a single, dispatchable resource within the MISO Market

Interconnection Queue Study Options for Hybrid Resources

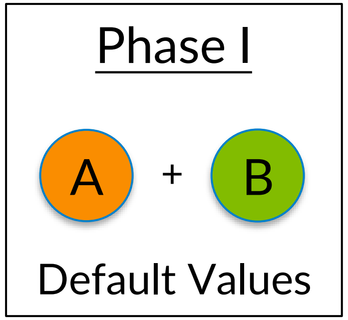
Hybrid	Individual Portion	Modify Existing
• Point of interconnection • Nameplate Capacity for each resource type within the hybrid unit • Interconnection Service request – may be less than combined nameplate capacity • For a hybrid with storage, the method for charging the storage resource – grid or non-battery hybrid resource • One GIA	• Point of interconnection • Nameplate Capacity of each Resource • Interconnection Service request for each resource • Can be staggered across interconnection cycle requests • Option of one or multiple GIAs	• Surplus Interconnection Service - Add new Electric Facility to an existing resource • Existing resource point of interconnection • Nameplate Capacity of each resource by fuel type • Utilizes existing resource Interconnection Service • Administered Separate from DPP

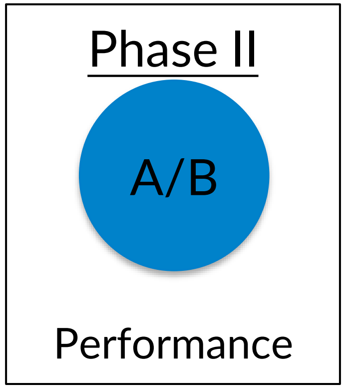
Planning Modeling Requirements

- Outlined in the MOD-032 R1 document
- Include point of interconnection, step-up transformer, and collector system equivalents
- Recommended Machine ID (W, PV or S, ES or E)
- Generator Bus Name must include the MISO Interconnection Queue study number
- Hybrid Resources
  - Each generator type must be modeled separately
  - Dispatch within the case will be determined by the Interconnection Service value

Resource Adequacy accreditation incorporates a two-phased approach for hybrids

- Phase I
  - Sum of parts at default values up to firm Interconnection Service
  - Applicable prior to operational data on the resource
- Phase II
  - Availability-based on peak hour performance
  - Applicable after operational data is collected





Advantages of Storage to the grid

- Carbon-Neutral
- Quick to Build
- Costs continue to decline
- Adaptable
  - Stand-alone or hybrid
  - Multiple Operational Uses
    - Supply and demand management
    - Addressing curtailment
    - Resilience during extreme events

The 2021 MISO interconnection application cohort is a record high, with more storage than wind

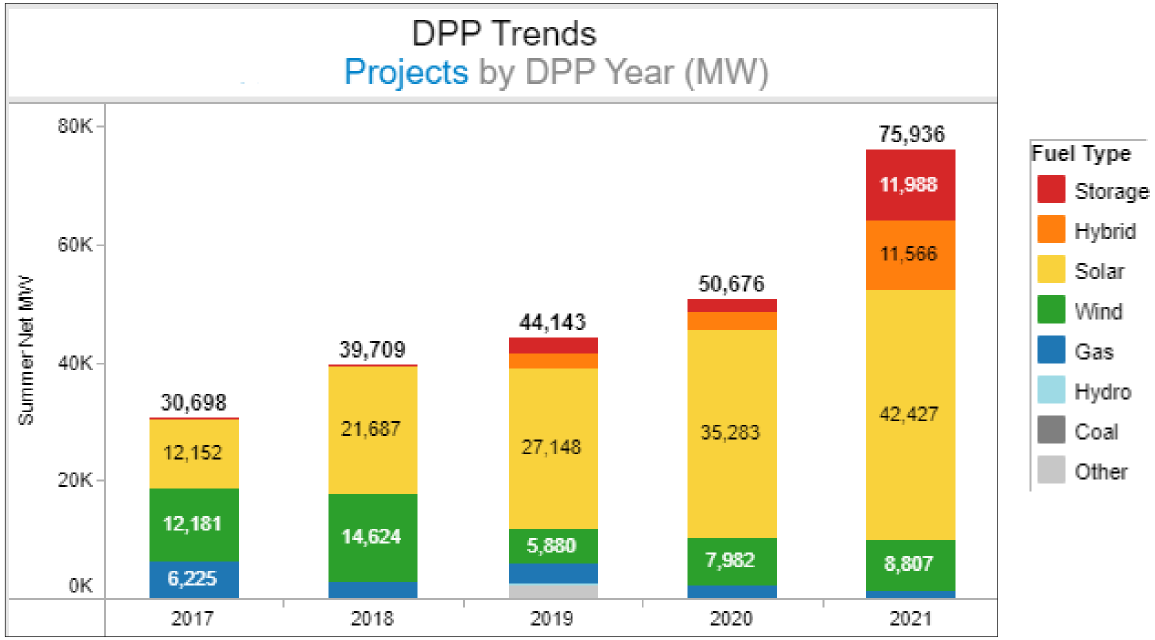
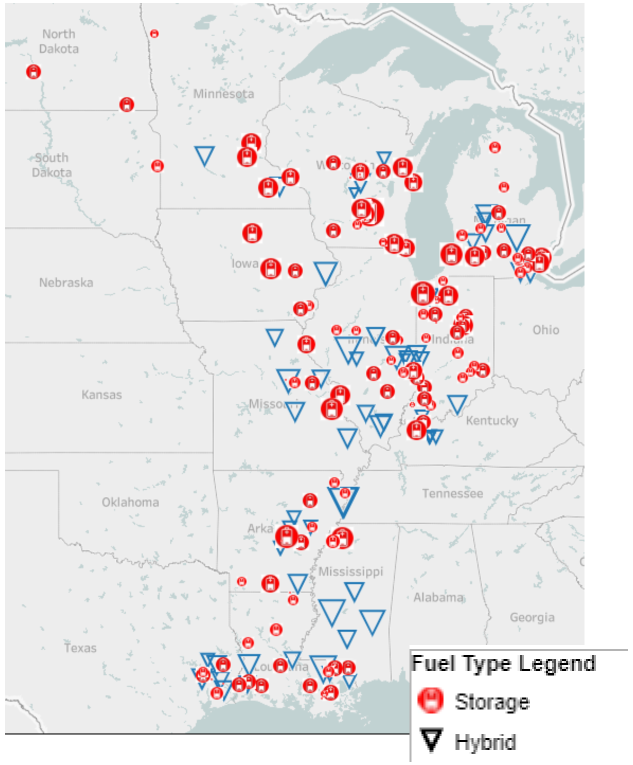


*Chart includes withdrawn projects

Location of 2021 Storage and Hybrid Applications

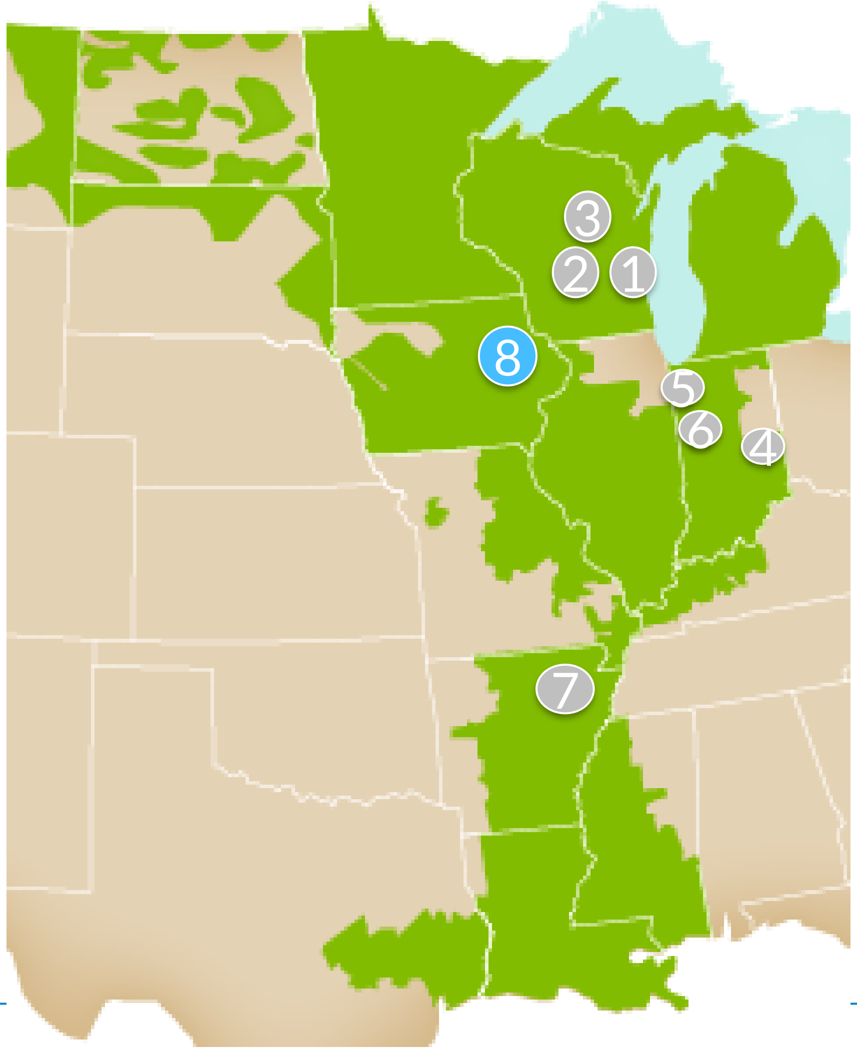


- 2021 applications easily set a record for volume of annual inbound requests
- **Storage applications (12 GW, 131 projects) surpass Wind (9 GW)**
- Storage and hybrid applications distributed throughout the MISO footprint
- Next step: Understand what storage technologies are represented in the queue, improve tracking

MISO Announcement 9.15.2021

Open Distribution

MISO utilities have publicly announced proposals for 3 GW of hybrid resources in-service within the next 3 years.



Hybrid total 2968MW; storage total 585MW

1. **WEC Paris Project**
   200MW Solar + 110MW Storage
2. **WEC Darien Project**
   250MW Solar + 75MW Storage
3. **WEC Koshkonong Project**
   300MW Solar + 165MW Storage
4. **NIPSCO Greensboro Project**
   100MW Solar + 30MW Storage
5. **NIPSCO Dunns Bridge II Project**
   435MW Solar + 75MW Storage
6. **NIPSCO Cavalry Project**
   200MW Solar + 60MW Storage
7. **Entergy Searcy Project**
   100MW Solar + 10MW Storage
8. **NextEra Duane Arnold Project**
   690MW Solar + 60MW Storage

[1] Greensboro, Dunns Bridge II, Cavalry and Searcy have been approved by their state utility commissions; the balance of the projects are under review

MISO

We still have a lot to learn!

- Learn from the operational experience associated with the upcoming implementation
- Should current transmission planning processes be modified to optimize the use of hybrid resources?
- Technologies continue to advance – are we collecting the correct information?

Southern Company

Planning and Operations Considerations for Integrating Solar amid a Changing Resource Mix

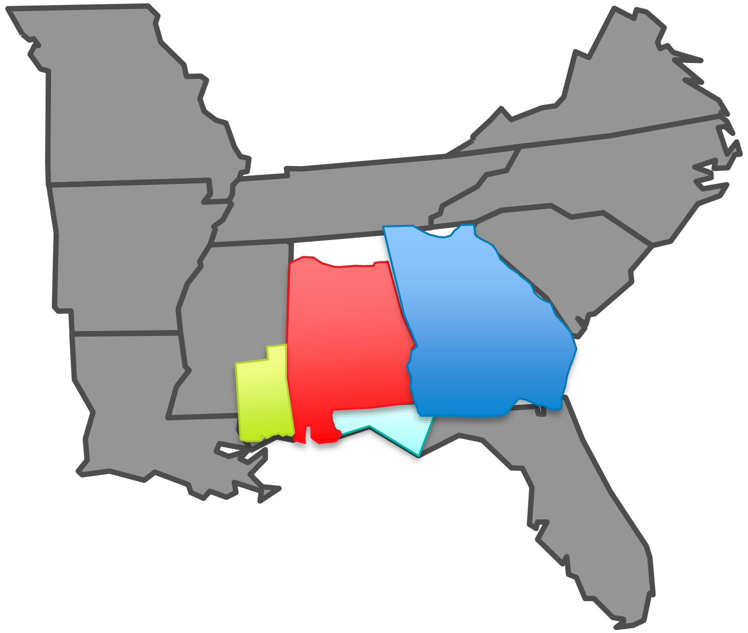
Cindy Hotchkiss
November 3, 2021

Open Distribution

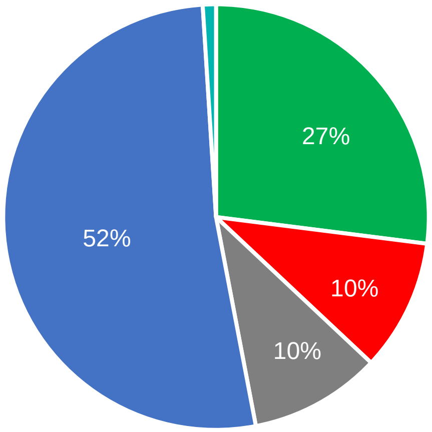
Southern Company System and Resource Mix Overview

SBAA:
~27,000 miles transmission
500 < Transmission Substations
3,700 < Distribution Substations
70 Tie Lines to Neighboring Systems

Alabama Power
Georgia Power
Mississippi Power

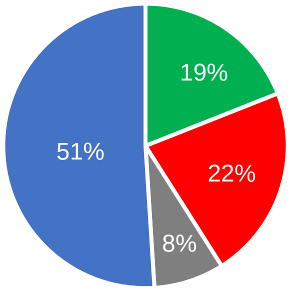


2030 Projected Capacity Mix



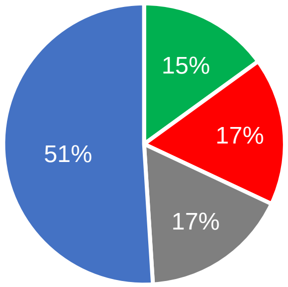
■ Renewables ■ Coal ■ Nuclear ■ Gas/Oil ■ Energy Storage

2020 Capacity Mix



■ Renewables ■ Coal ■ Nuclear ■ Gas/Oil

2020 Total Energy Mix



■ Renewables and Other ■ Coal ■ Nuclear ■ Gas

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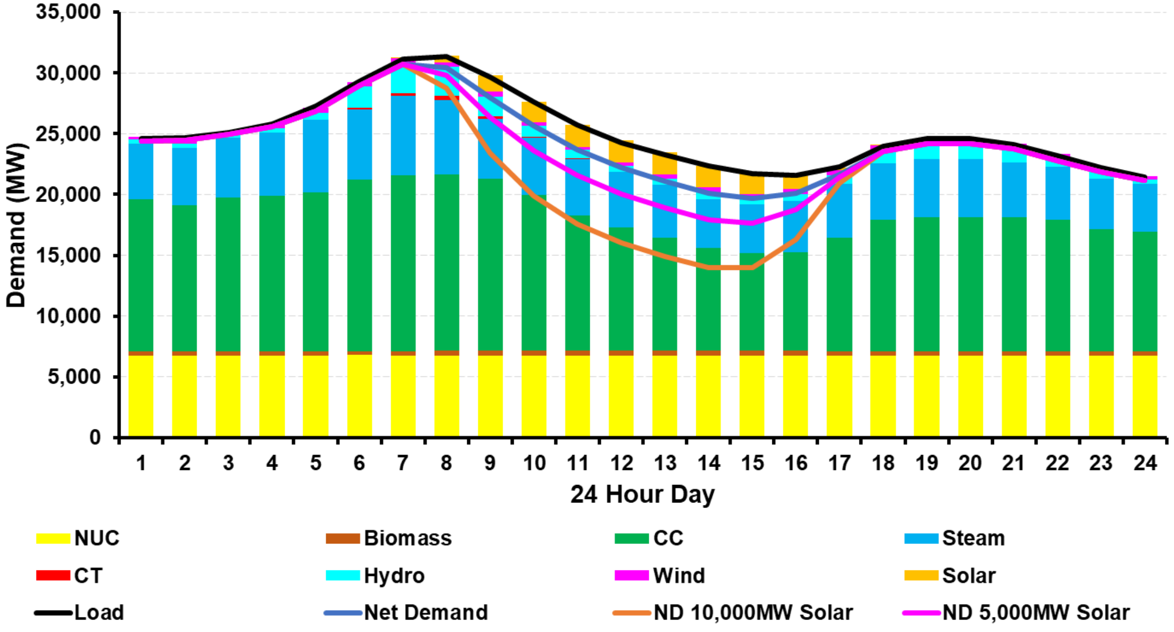
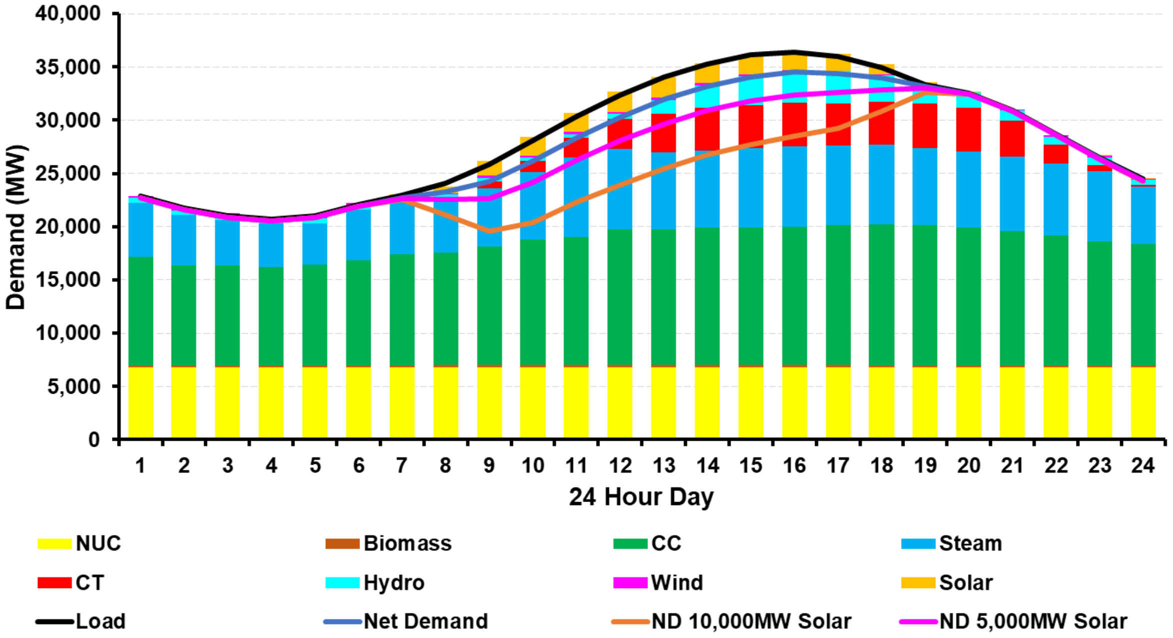
Effects of Increasing Solar Penetrations





- Additional solar and baseload resources, such as nuclear, will require the system to be committed differently to prevent excess generation as the fossil fleet is pushed below their low limits
- In these examples, the net demand curve for 10,000MW of solar requires steam units offline at H9
- Because these units cannot be cycled for short durations, it is apparent that dispatch will change for the CC and CT fleet as solar penetration levels increase

3 Key Principles for Operations and Planning

Visibility

Predictability

Dispatchability

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Question and Answer

Moderator: **Gayle Nansel -** Western Area Power Administration

Hari Singh
Xcel Energy

Amanda Schiro
MISO

Irena Green
California ISO

Cindy Hotchkiss
Southern Company

Agenda

Day Two – Emerging Technologies

Session 2 – Resilience Planning		
Time (ET)	Topic	Presenters
1:00 p.m.	**Welcome**	NATF – Andy Balascak
1:05 p.m.	**Integrating Security into the Planning-Design Process**	EPRI – John Stewart
1:35 p.m.	**Extreme Climate Events & Transmission Resiliency**	EPRI – Anish Gaikwad & Dr. Delavane Diaz
2:05 p.m.	**Audience Interaction**	EPRI – Anish Gaikwad & Mobolaji Bello
2:25 p.m.	**Break**	
Session 3 – Technology Impacting the Utility Industry		
2:40 p.m.	**EMT Studies for Transmission Planning**	Eversource – Janny Dong, Goodarz Ghanavati, Meiyan Li Electranix – Andrew Isaacs
3:20 p.m.	**Transportation Electrification & System Planning**	EPRI – Jared Green INL – Tim Pennington
4:00 p.m.	**Day Two Wrap-up and Closing Comments**	NATF – Andy Balascak

Wrap Up

Reminder: Register for Day 2!

November 4 at 1:00PM (Eastern Time)