Resource Adequacy Trends of the Energy Transition: Experience from North America

PRESENTED BY

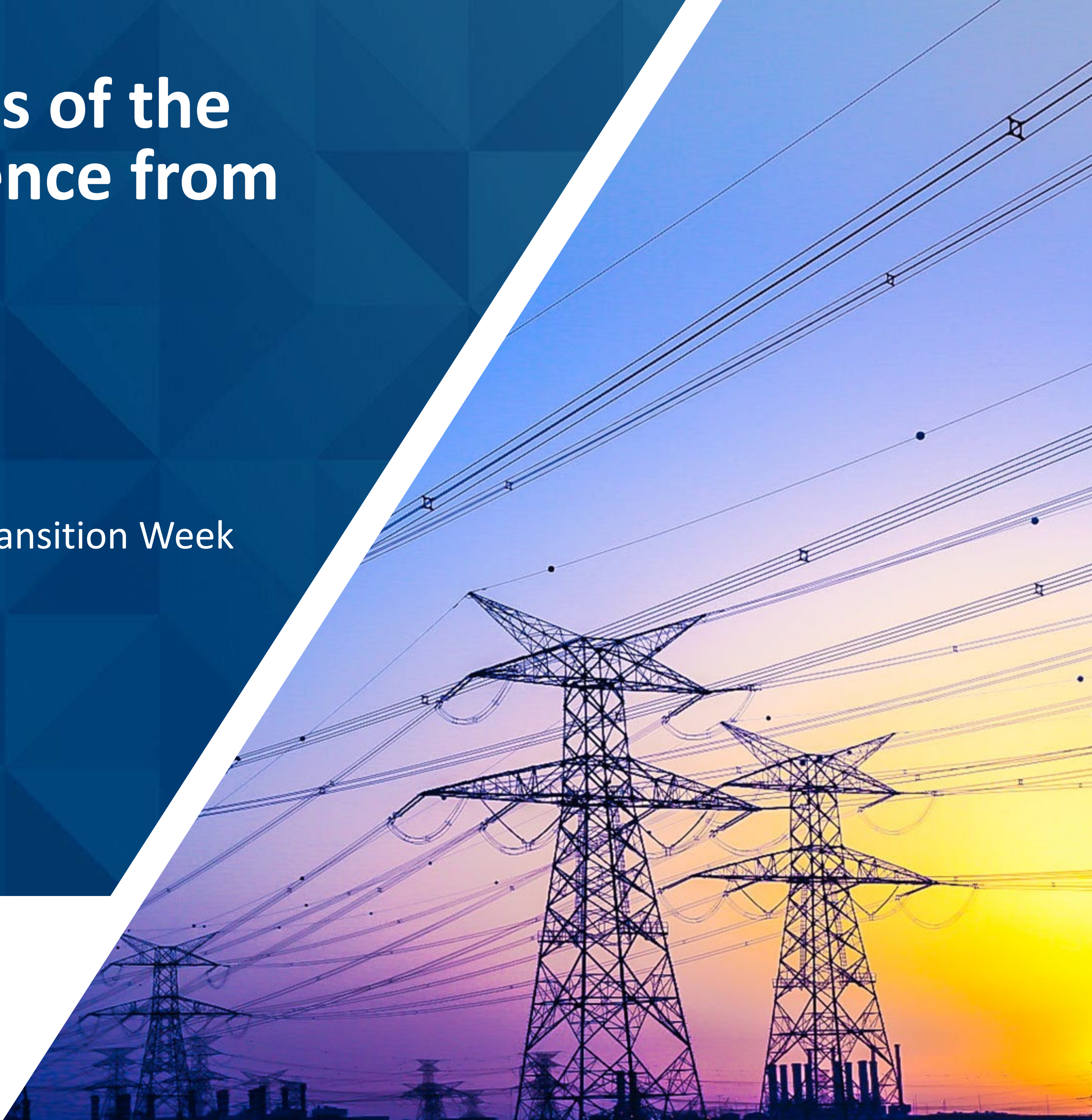
Dr. Andrew W. Thompson

PRESENTED FOR

NTNU Energy Transition Week 2024

MARCH 14, 2024

Brattle



Overview

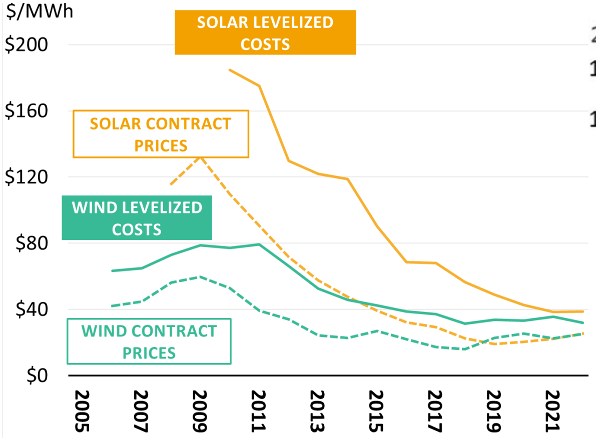
1. Trends and Drivers of the Energy Transition
2. Bulk System Reliability in Tomorrow's Grid

Trends and Drivers of the Energy Transition

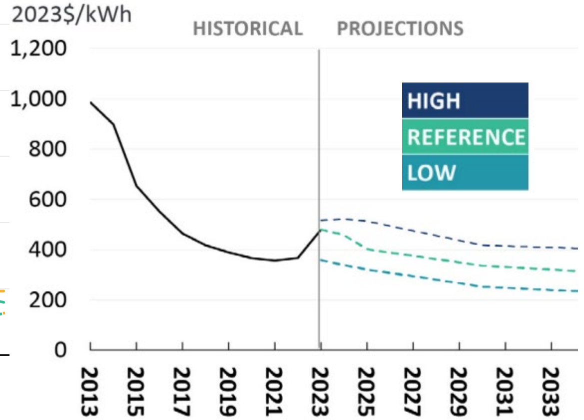
Changes in Generation Mix

Wind, Solar, and Battery Costs Falling

Wind and Solar Costs

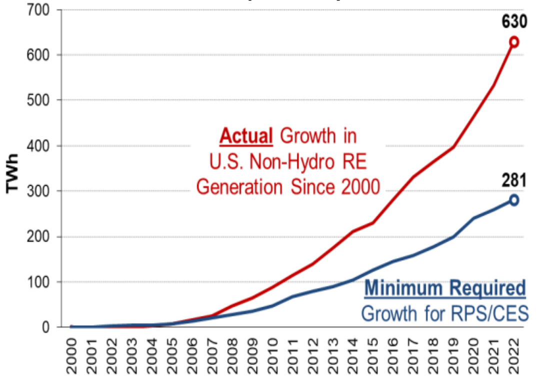


Battery Installed Capital Cost

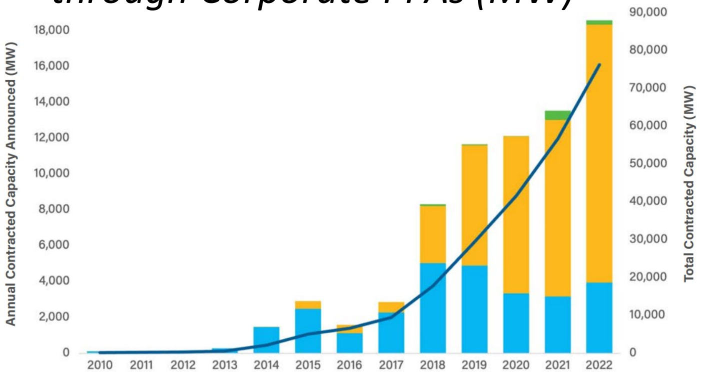


Customer Preferences for Clean Energy Increasing

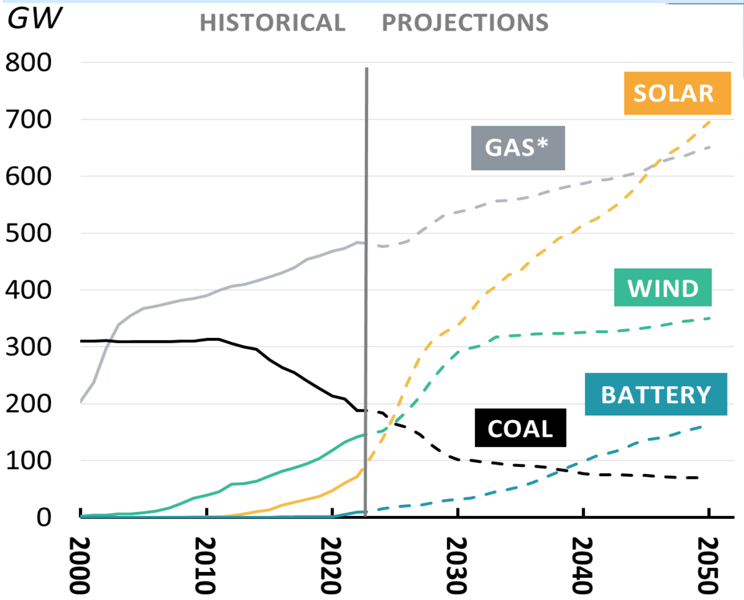
Clean Energy Production (TWh)



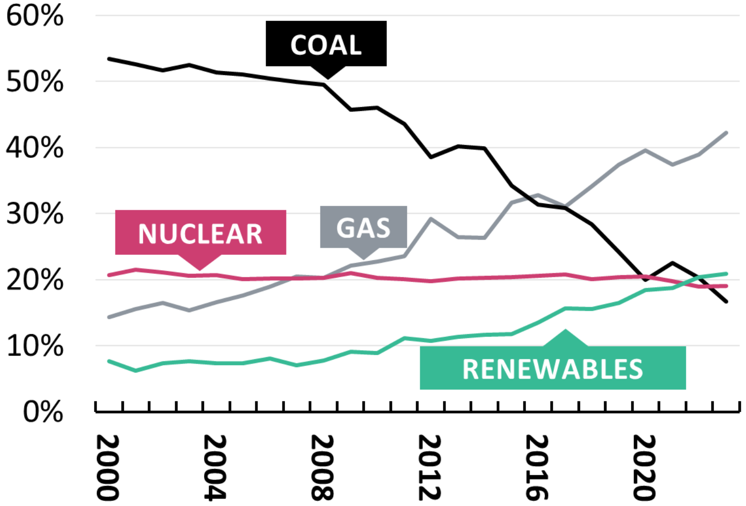
Clean Capacity Purchased through Corporate PPAs (MW)



Clean Capacity Rising (past/future)



Coal Share of Output Falling (past)

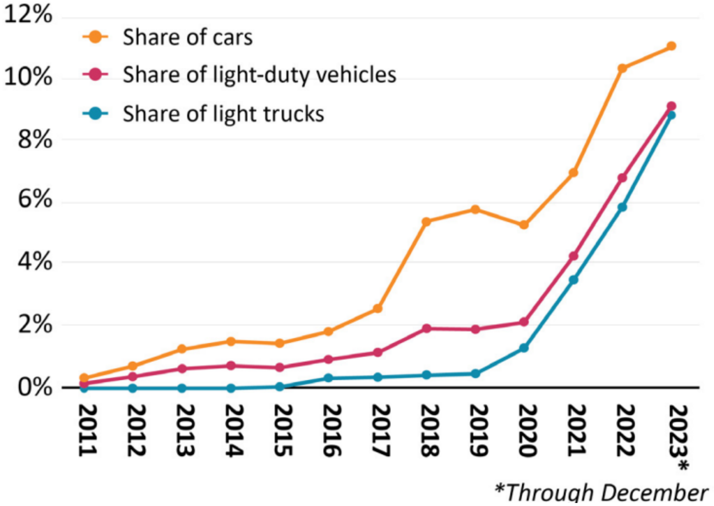


Sources: Celebi et.al, Bulk System Reliability for Tomorrow's Grid, December 20, 2023; American Clean Power, 2022 Corporate Buyers Report, 2022.

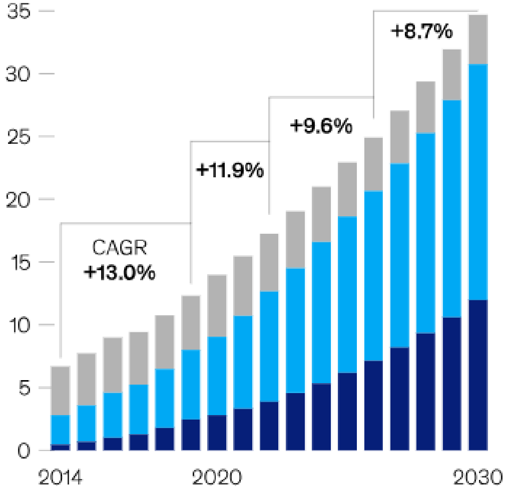
Increasing Demand

Electric Vehicles, New Demand Centers, and Electrification of Buildings All Increasing

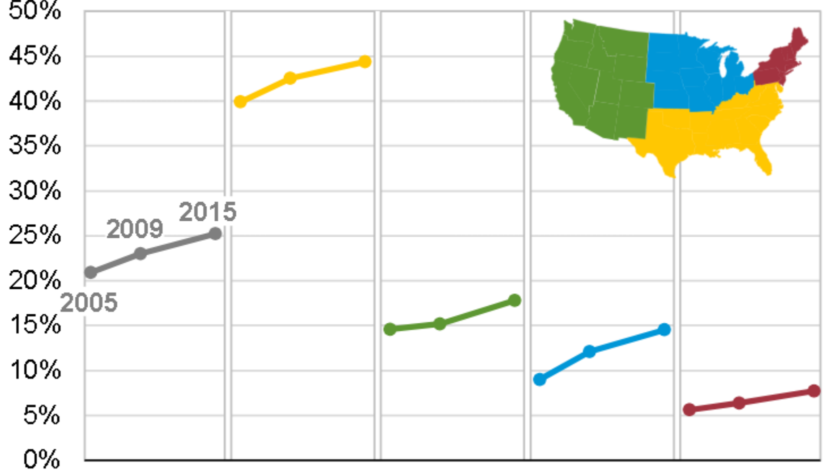
Electric Vehicle Sales Share of All Vehicles



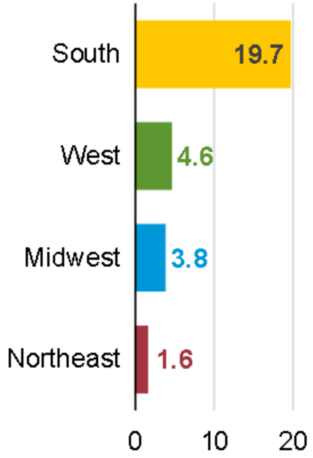
Data Center Power Consumption (GW)



All Electric Homes Share of Total

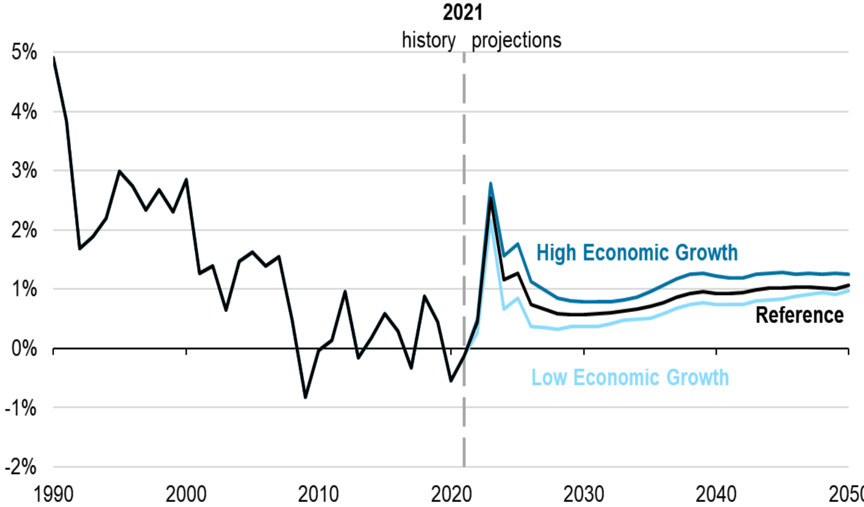


Total Electric Homes as of 2015 (millions)

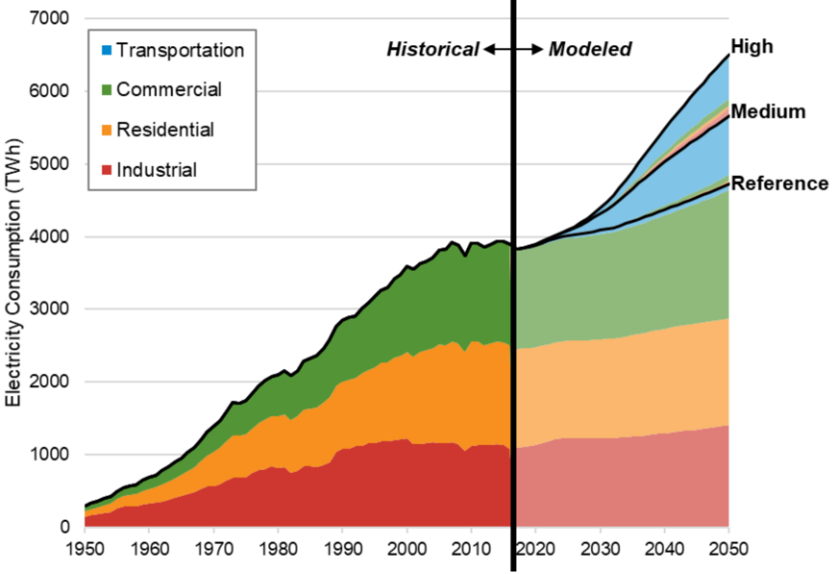


Increase in Electricity Demand After Decades of Decreasing Demand Growth

U.S. EIA Electricity Demand



U.S. NREL Electrification Scenarios

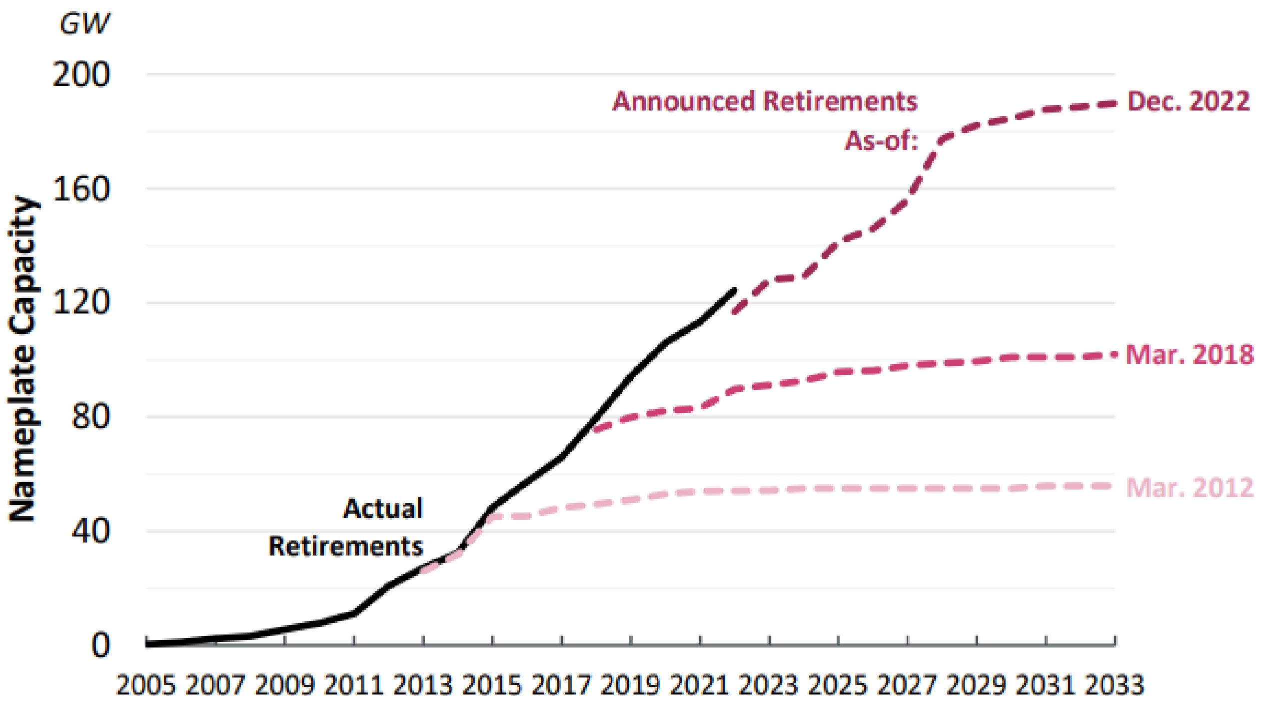


Sources: Celebi et.al, Bulk System Reliability for Tomorrow's Grid, December 20, 2023; U.S. Energy Information Administration, Today in Energy, May 2019.

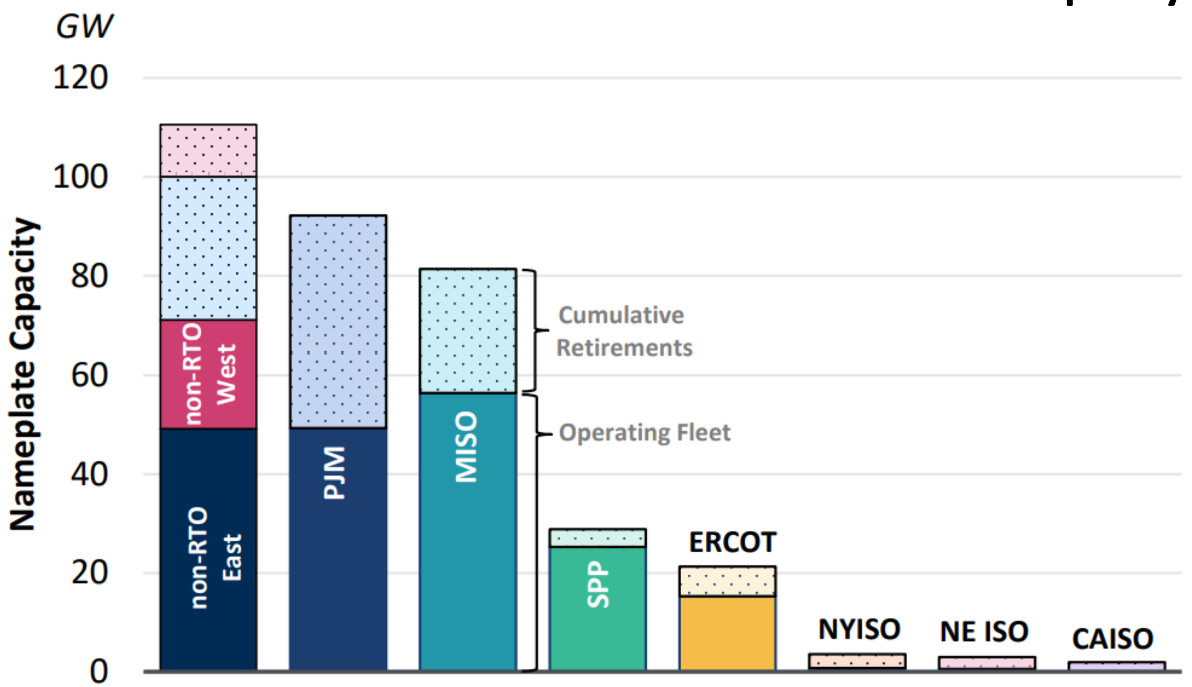
Coal plants have been bulk of capacity retirements

Over 120 GW of coal has retired since 2005 with an additional 68 GW announced and planned for retirement through 2030

Announced vs. Actual Coal Plant Retirements



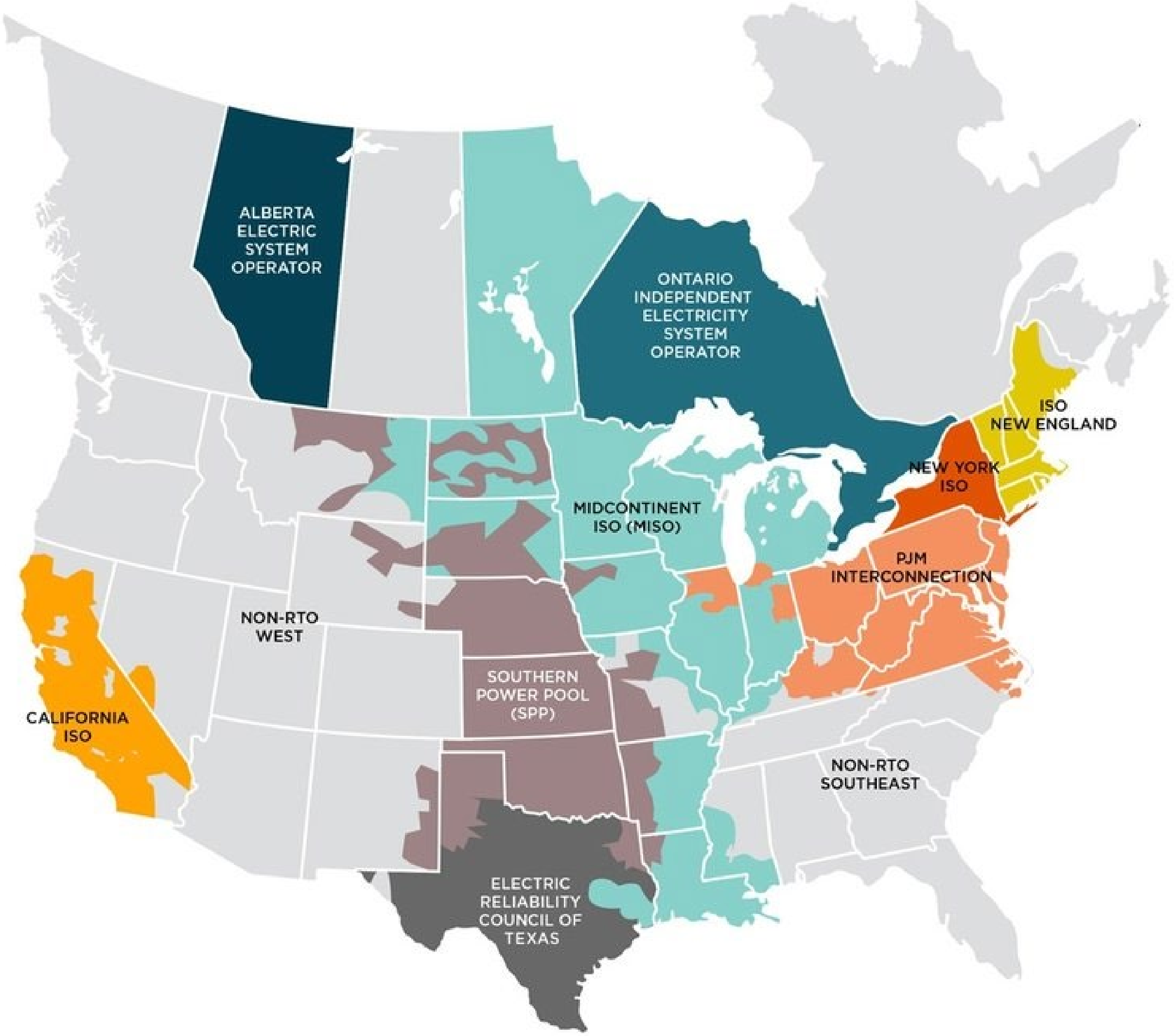
Coal Retirement Locations and Current Capacity



Source: Celebi et. al, A Review of Coal-Fired Electricity Generation in the U.S., April 27, 2023.

Bulk System Reliability in Tomorrow's Grid

North American Organized Wholesale Markets



Regional Transmission Organizations (RTO)
Independent System Operators (ISO)

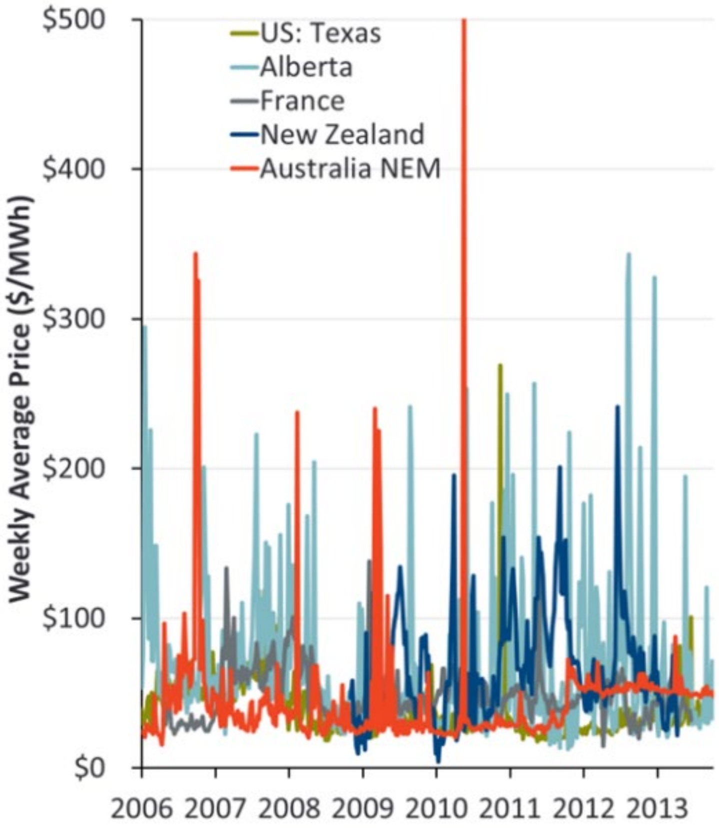
Resource adequacy is achieved in several different ways in North America

Market-Based Options

Vertically Integrated/ Planned	Energy-Only Market	Capacity Market
Vertically integrated utilities or a government entity does resource planning to build or contract new resources	Energy prices (plus "scarcity price" during tight hours) is primary mechanism to attract new investments	Organized market for "capacity" product is primary mechanism to attract new investments
MISO, California, SPP, Ontario	ERCOT, Alberta	PJM, ISO-NE, NYISO

Energy-only and capacity markets both use competitive prices to attract new supply investments

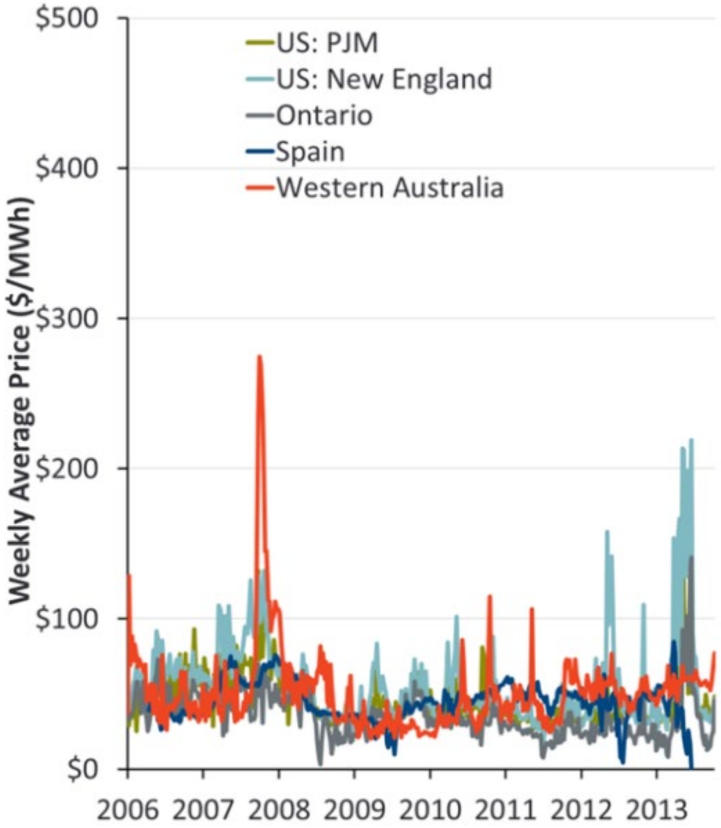
Energy Only Markets



Investments attracted through occasional high price spikes if reserve margins fall

No capacity payments

Capacity Markets or Capacity Mechanisms

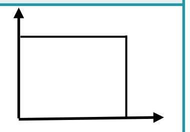
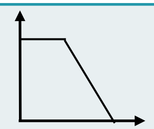
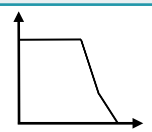
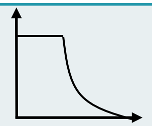


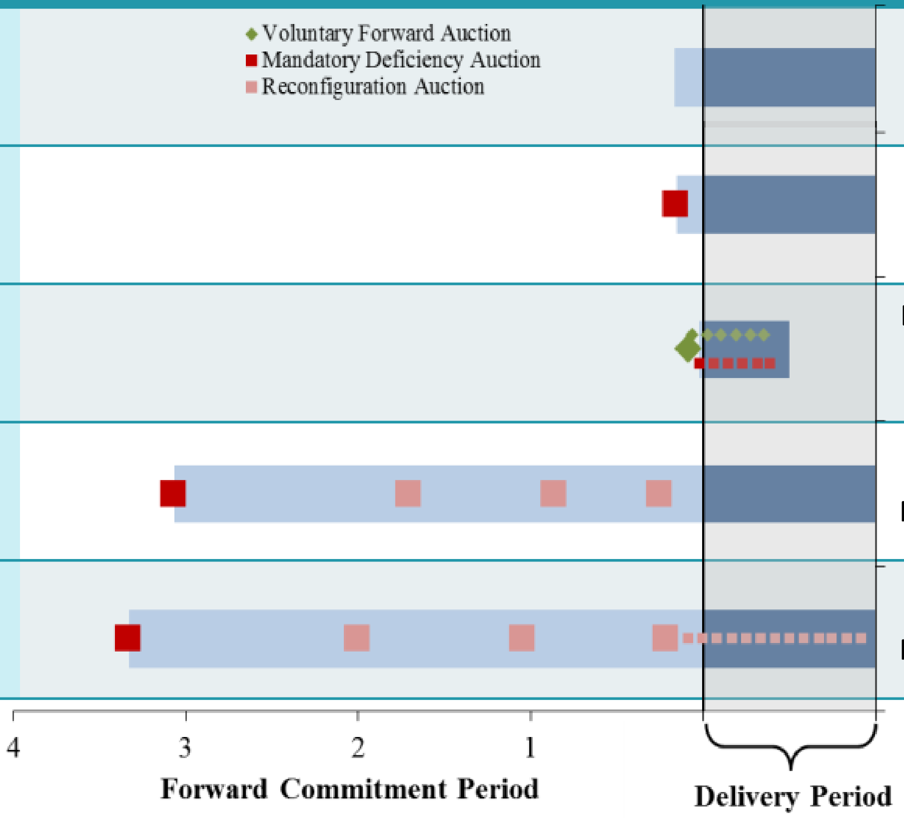
Energy prices are more stable and lower on average

Investments attracted through capacity market payments

See Spees & Newell discussion of alternative resource adequacy constructs.

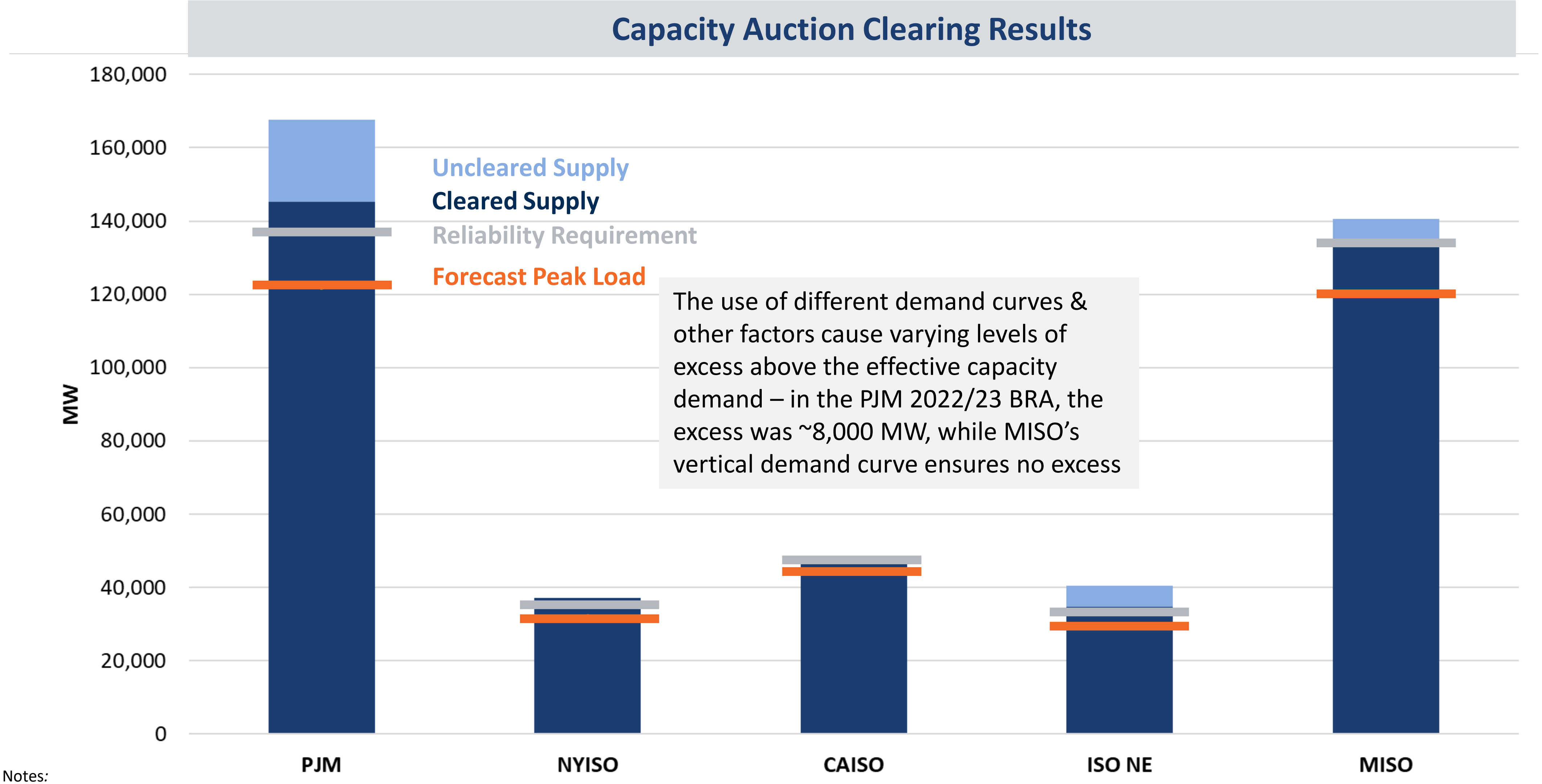
Summary of Capacity Markets and Resource Adequacy Constructs

	Forward Period	Procurement	Delivery Period	Investment Model	Retail Choice?	Net CONE Reference Technology	Demand Curve
CAISO		Bilateral	Monthly	Reserve Margin	Limited	n/a	n/a
MISO		Bilateral + Mandatory Auction	Annual (Soon: Seasonal)	Capacity Market	Limited	CT	
NYISO		Bilateral + Voluntary & Mandatory Auctions	Monthly	Capacity Market	Yes	CT	
PJM		Bilateral + Mandatory Auctions	Annual	Capacity Market	Yes	CT	
ISO-NE		Bilateral + Mandatory Auctions	Seasonal	Capacity Market	Yes	CT (CC until 2017)	



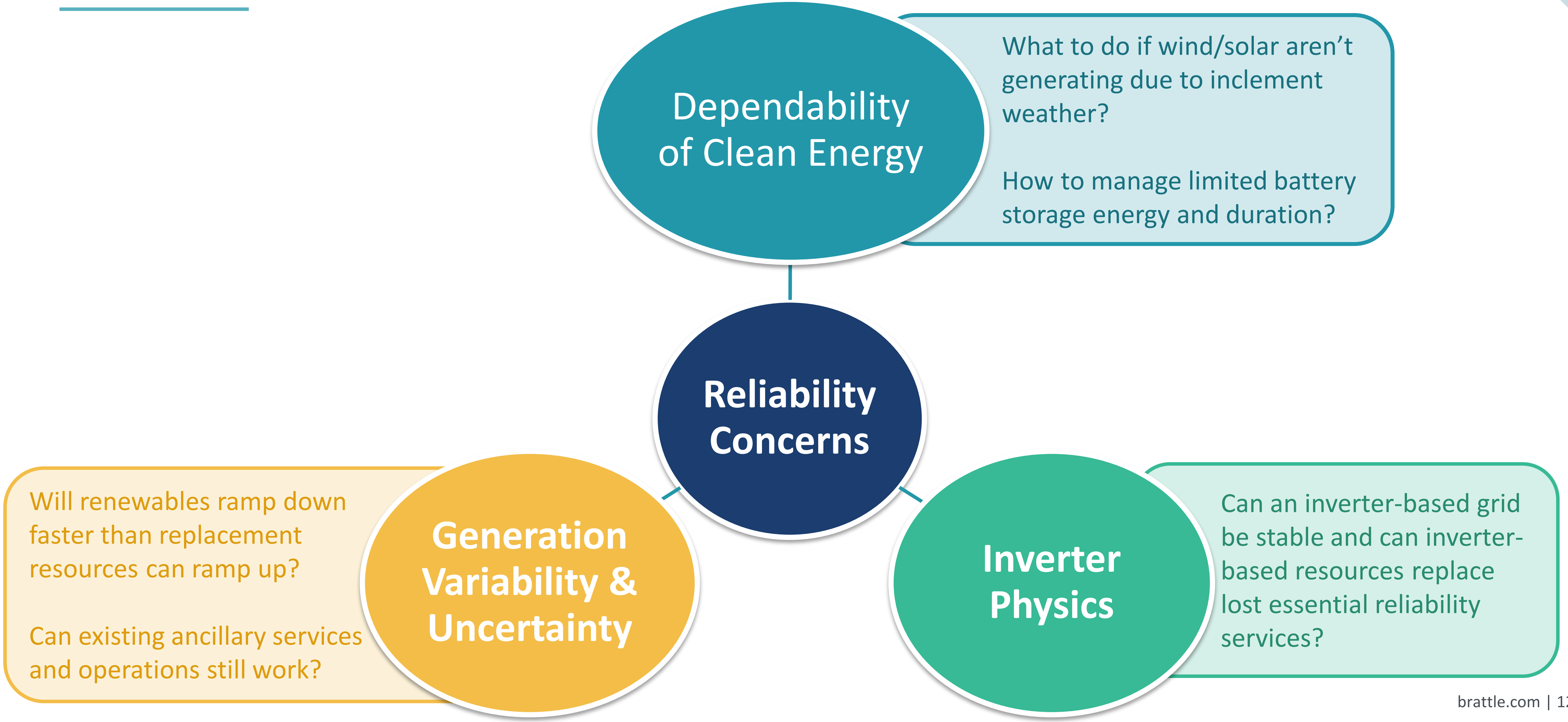
Sources and Notes: MISO does not calculate Net CONE, though they do calculate CONE. MISO, 2019 Annual CONE Filing, 2019, p. 4, PJM, FERC Order ER-19-1050—4, ORDER DENYING REHEARSING, 2020, p. 7; ISO NE: 161 FERC Order 61,035, ORDER ACCEPTING FILING, 2017, p. 7; ISO NE and NYISO, 175 FERC Order 61,172, ORDER ACCEPTING, IN PART, TARIFF REVISIONS, SUBJECT TO CONDITION AND DIRECTING COMPLIANCE FILING, 2021, p. 7 , p. 63.

Summary of Recent Capacity Market Clearing Results



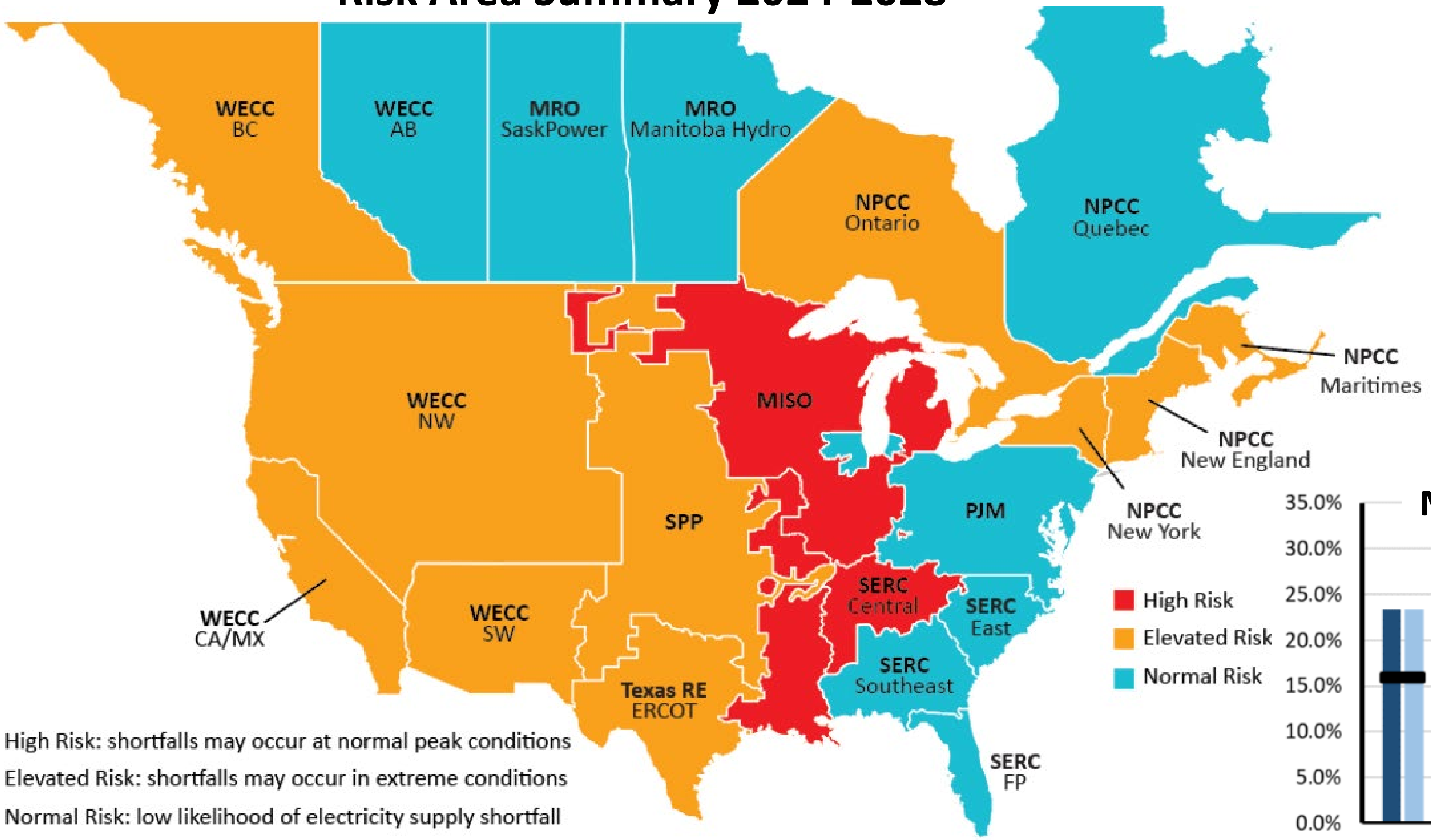
Sources and Notes:
PJM 2022/23 BRA data from 2022-23 BRA Report and 2022-23 BRA Planning Parameters; NYISO August 2021 data from ICAP Market Report and NYISO Installed Capacity and Load Maintenance Survey; CAISO 2019 data from 2019 Annual Report on Market Issues and Performance; ISO NE FCA 15 (DY 2024/25) data from FCA Results and ISO NE Nov 10, 2020 ICR for FCA 15 FERC Filing; MISO 2021/22 PRA data from 2021/22 PRA Results.

Motivation for Reforms (in the words of one U.S. policymaker): "Does the clean transition mean we just have to have blackouts?"



Are firm capacity requirements outpacing replacements?

NERC 2023 Long-term Reliability Assessment: Risk Area Summary 2024-2028



High Risk: "anticipated" 2028 planning reserve margins may fall below targets (not counting prospective generation additions not yet under construction or the RA value of non-firm resources and imports without firm contracts)

Sources: North American Electric Reliability Corporation (NERC), 2023 Long-Term Reliability Assessment, December 2023.

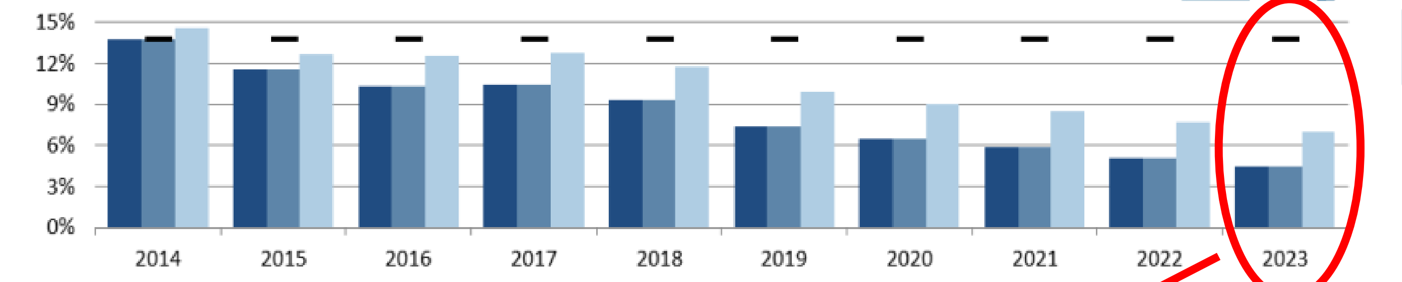
Market responses have effectively attracted new capacity

Can’t underestimate the challenge, but we’ve been there before!

- A decade ago: significant resource adequacy concerns over mercury regulation of coal plants
- Market response prevented doomsday projections from being realized
- Example: **PJM capacity market easily replaced over 47 GW of retiring plants** with range of replacement resources (DR, imports, gas) between 2012-2022

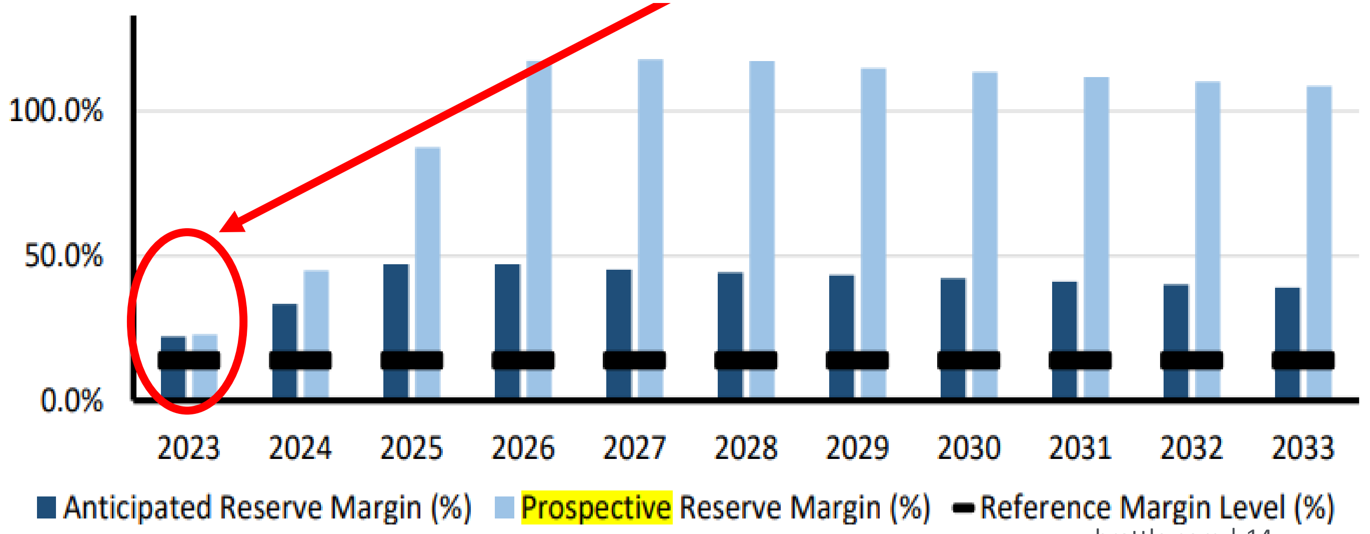
Also note NERC projections often not realized

NERC **2013** Long-term Assessment for ERCOT



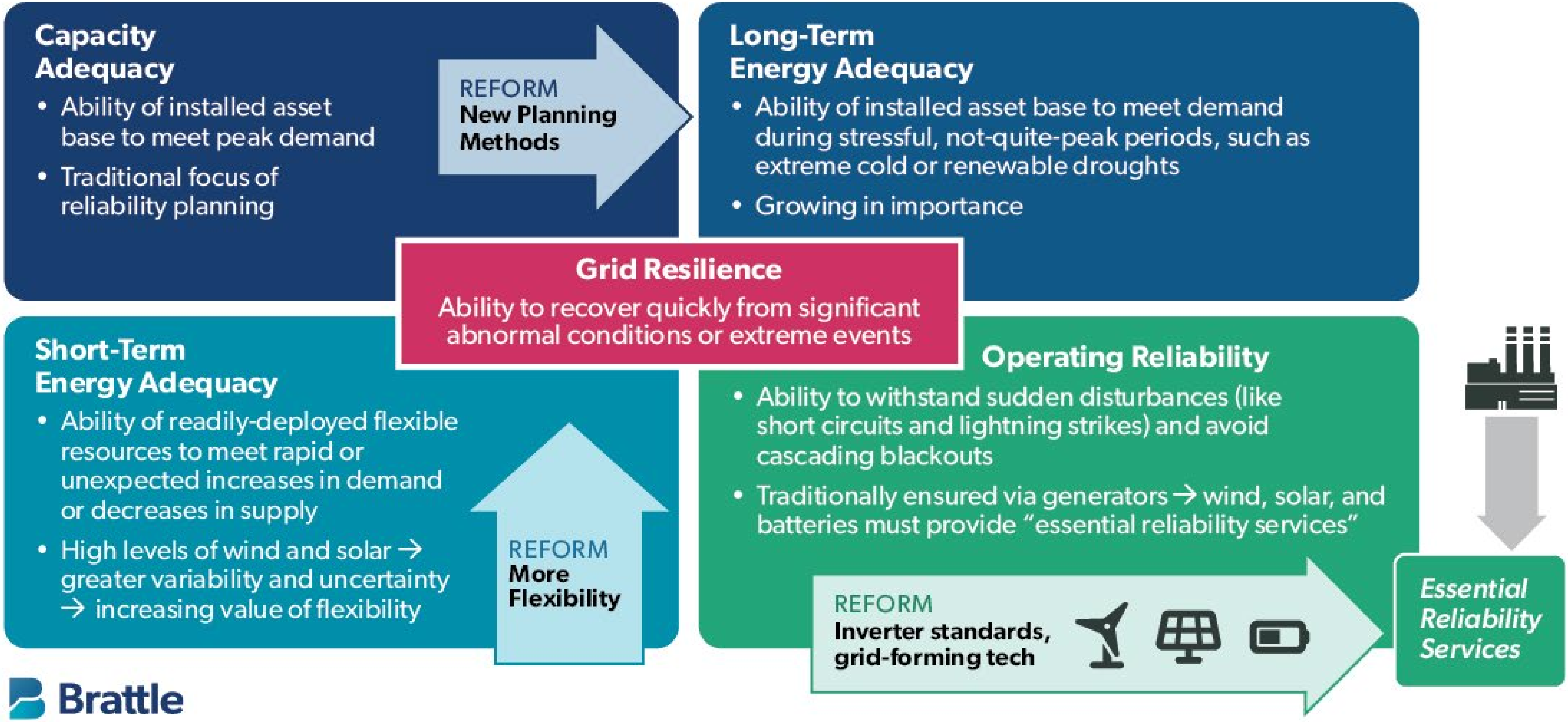
TRE-ERCOT-Summer		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
ANTICIPATED		13.74%	11.59%	10.34%	10.46%	9.34%	7.36%	6.44%	5.91%	5.11%	4.43%
PROSPECTIVE		13.74%	11.59%	10.34%	10.46%	9.34%	7.36%	6.44%	5.91%	5.11%	4.43%
ADJUSTED POTENTIAL		14.58%	12.71%	12.53%	12.71%	11.75%	9.9[illegible]%	9.04%	8.49%	7.67%	6.97%
NERC REFERENCE	-	**13.75%**	**13.75%**	**13.75%**	**13.75%**	**13.75%**	**13.75%**	**13.75%**	**13.75%**	**13.75%**	**13.75%**

NERC **2023** Long-term Assessment for ERCOT



Sources: NERC, 2013 Long-term Reliability Assessment, December 2013 and NERC, 2023 Long-Term Reliability Assessment, December 2023.

Reliability Characteristics and Needed Reforms



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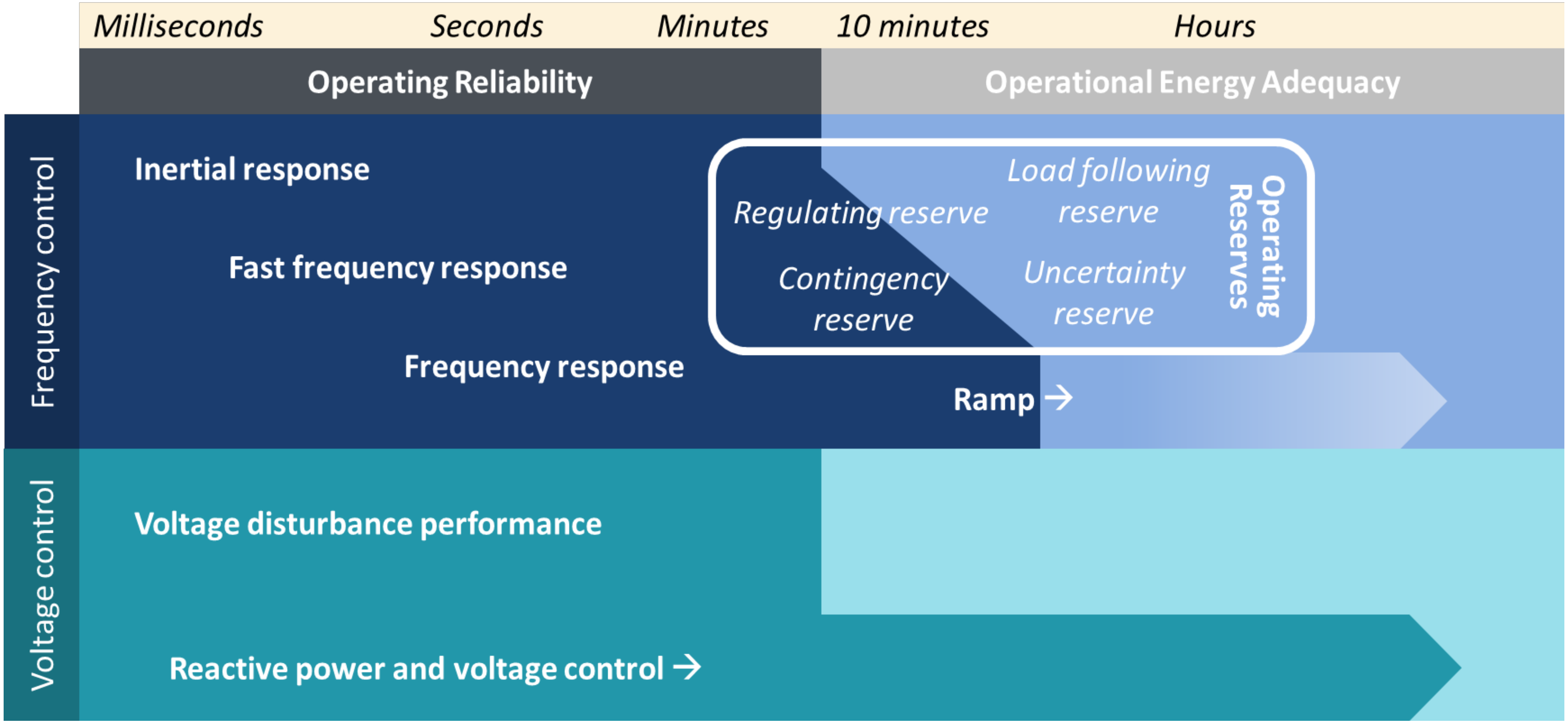
Source: Celebi et.al, Bulk System Reliability for Tomorrow's Grid, December 20, 2023.

Inverter-based resources are capable of providing all Essential Reliability Services to varying degrees

Reliability Aspects and Timescales for Essential Reliability Services



Source: Celebi et.al, Bulk System Reliability for Tomorrow's Grid, December 20, 2023.

Increasing market expansion for short-term energy adequacy

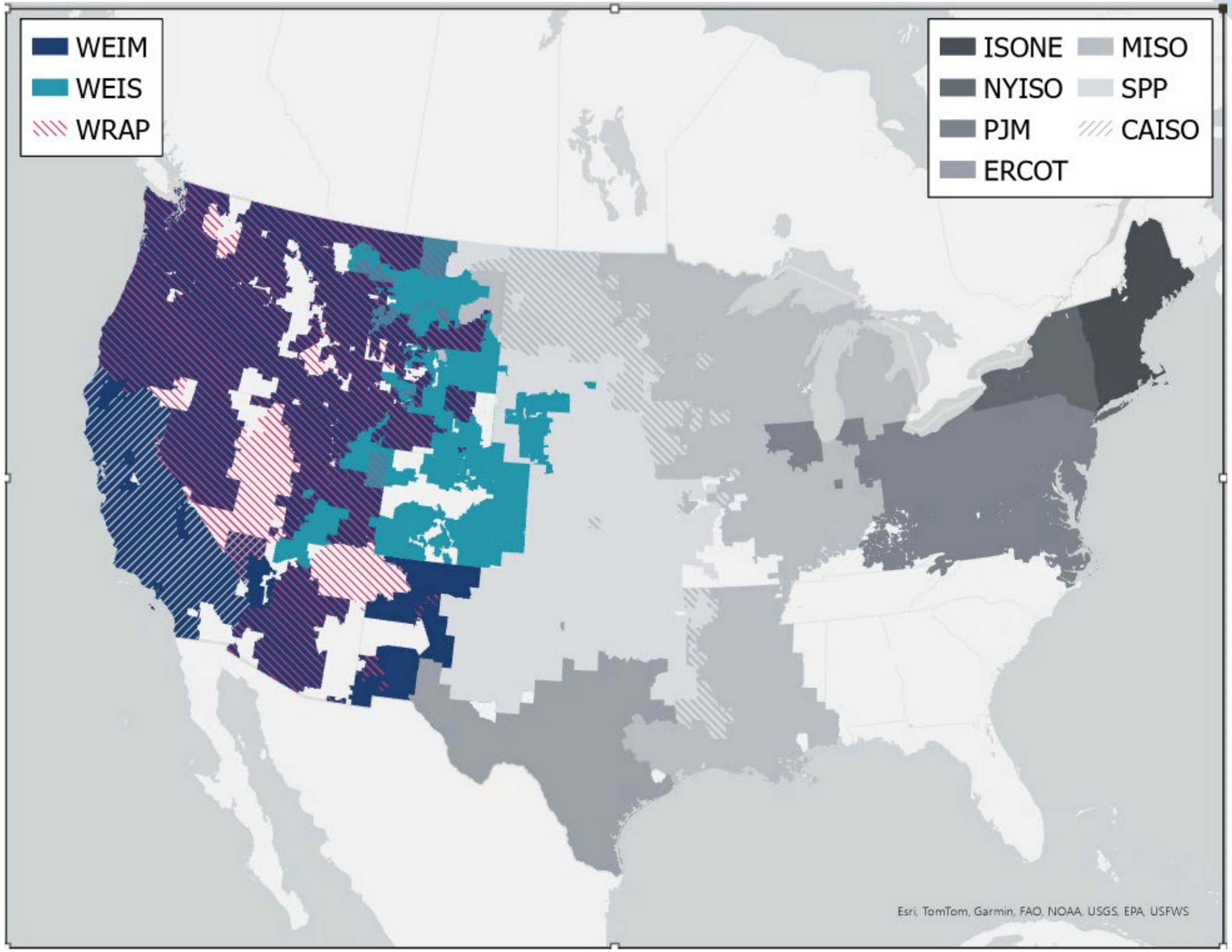
Increasing inter-regional trade boosts intraday flexibility

- Geographic weather and electricity demand diversity reduces impact of wind/solar variability across a wide area
- More seamless power sharing better leverages flexible capability of existing fleet

CAISO (driving EDAM and WEIM) is motivated to seek flexibility for renewables integration. Members explicitly list renewable integration alongside efficiency benefits.

SPP has Markets+ and WEIS. Note SPP set record 90% instantaneous load from wind/solar in 2022.

Map of New Interstate Pooled Markets in the West



Source: Celebi et.al, Bulk System Reliability for Tomorrow's Grid, December 20, 2023.

Thank You!

Additional Slides

About the speaker

Dr. Andrew W. Thompson

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Dr. Andrew W. Thompson, an Associate at The Brattle Group, is an energy economist with a background in electrical engineering and expertise in wholesale electricity market design, regulatory economics, and policy analysis of network industries, particularly in the energy sector.

He supports clients in several international jurisdictions, which include electricity system operators, energy regulators, governments, clean energy advocacy groups, market participants, institutional investors, and utilities in PJM, CAISO, ERCOT, NYISO, ISO-NE, Non-ISO/RTO United States, Ontario, Alberta, Great Britain, Spain, Colombia, Saudi Arabia, Australia, and New Zealand.

Dr. Thompson has published thought leadership on the evolving hydrogen economy, the regulation of the energy sector, energy policy to integrate emerging resources (renewables, battery storage, long-duration energy storage, distributed energy resources, and flexible load), and the economic implications of lithium-ion battery degradation for energy storage and electric vehicle technologies.

He received a Ph.D. in Economics from the Université Paris-Saclay (France), an MS in Energy Economics from the Pontificia Universidad Comillas (Spain), an MSc. in Engineering and Policy Analysis from TU Delft (The Netherlands), and a BSc. in Electrical and Computer Engineering from Rowan University (USA).

Additional Reading

- Johannes P. Pfeifenberger, Are Firm Capacity Requirements Outpacing Replacements?, January 24, 2024
- Celebi, Levitt, Thompson, Sreenanth, Bulk System Reliability for Tomorrow's Grid, December 20, 2023
- Newell, Spees, Levitt, Higham, MISO Reliability Attributes "Solution Space", October 4, 2023
- Celebi and Lam, A Review of Coal-Fired Electricity Generation in the U.S., April 27, 2023
- Newell, Spees, and Higham, Capacity Resource Accreditation for New England's Clean Energy Transition, June 2, 2022
- Spees and Newell, Efficiently Managing Net Load Variability in High-Renewable Systems: Designing Ramping Products to Attract and Leverage Flexible Resources, February 2, 2022

Cataloging Reforms

TABLE 2: EXISTING TOOLS WILL SHIFT IN IMPORTANCE, EVOLVE, AND ITERATE TO MATCH EVOLVING SYSTEM NEEDS AND STRENGTHS

	Shifting Challenges	Shifting Solutions
Capacity adequacy and Long-Term Energy Adequacy	• More variability in potential scarcity conditions • Increased demand for electricity with electrification of other sectors	• Shift to year-round adequacy evaluations (e.g., via new metrics) and away from peak-hour reserve margin metric • Improved precision of probabilistic reliability models, longer weather histories • Potential to incorporate non-probabilistic scenario-based planning of extreme weather for resilience
Operational Energy Adequacy	• More variability and uncertainty • Potential to unlock new sources of flexibility among customer-side resources, batteries, and curtailed renewables	• Greater importance on operational scheduling and dispatch tools, including forecasting • New ancillary services for ramp and other flexibility services to operate and retain or attract flexible resources • Improved pricing of flexibility services in ISOs/RTOs
Operating Reliability	• Faster dynamics and more responsive resources • More computer-mediated transient responses and need to manage configurations, programming, and models • Resources can provide services all the time at lower cost	• Greater role for stability • Requirements for grid-forming inverters • Potentially more synchronous condensers • More HVDC for long-haul access to remote, low-cost resources and stability improvement

Source: Celebi et.al, Bulk System Reliability for Tomorrow's Grid, December 20, 2023.

TABLE 3: ISOS/RTOS PURSUING RELIABILITY ENHANCEMENTS SUITED TO RENEWABLE DEPLOYMENT

		ERCOT	CAISO	MISO	PJM
	[A] Inverter –based resource integration studies & transition efforts	Impact of Growth in Wind and Solar on Net Load; Inverter-Based Resource Working Group	Reliability Standards to Address Inverter-Based Resources	RIIA, Reliability Attributes effort	Energy Transition series; 2014 Renewable Integration Study series
Long-Term Adequacy Model	[B] Includes all hours of year	N/A	Hourly ELCC for clean resource long-term adequacy values	Hourly ELCC for clean resource long-term adequacy values	Proposed comprehensive hourly construct
Long-Term Adequacy Model	[C] Accounts for extreme weather over decades	N/A	Yes for clean resources	Yes for clean resources	Proposed for all resources and overall capacity requirement
Long-Term Adequacy Model	[D] Accounts for extreme weather effects on availability	N/A	No, except for ELCC	No, except for ELCC	Proposed for all resources and overall capacity requirement
Operational Energy Adequacy	[E] Increased procurement of uncertainty reserves	Day-ahead non-spin reserve and online reserves	Day-ahead spinning and non-spinning reserves	No*	Synchronized, Primary, Secondary Reserves
Operational Energy Adequacy	[F] New types of uncertainty reserves	ERCOT Contingency Reserve Service, Dispatchable Reliability Reserve Service (pending)	Flexible Ramping Product, Imbalance Reserve (proposed)	Short-Term Reserve, Ramp Capability Product	Secondary Reserves
Operational Energy Adequacy	[G] 5-minute energy settlements	Yes	Yes	Yes	Yes
Operational Energy Adequacy	[H] Improved day-ahead resource schedule optimization	No	Storage optimization, other day-ahead enhancements	No	No
Operating Reliability	[I] Ensuring voltage control	Yes	Yes	Yes	Yes
Operating Reliability	[J] Ensuring frequency response	Require, monitor, & procure	Require, monitor, & procure	Require & monitor	Require & monitor
Operating Reliability	[K] Ensuring other Essential Reliability Services	Monitor system-wide inertial response, monitor & procure voltage disturbance performance	N/A	N/A	N/A

	ERCOT 2012	ERCOT 2022	CAISO 2012	CAISO 2022	MISO 2012	MISO 2022	PJM 2012	PJM 2022
[L] Percent energy from wind & solar	9%	31%	6%	26%	7%	16%	2%	5%

Source: Celebi et.al, Bulk System Reliability for Tomorrow's Grid, December 20, 2023.

Grid-support from Modern Inverter-Based Resources

Inverter-based resources (IBRs) can create grid reliability challenges that need to be addressed through improved interconnection standards

However, in addition to preventing reliability problems, new IBR standards should be designed to enable grid-supporting capabilities of modern inverter technologies!

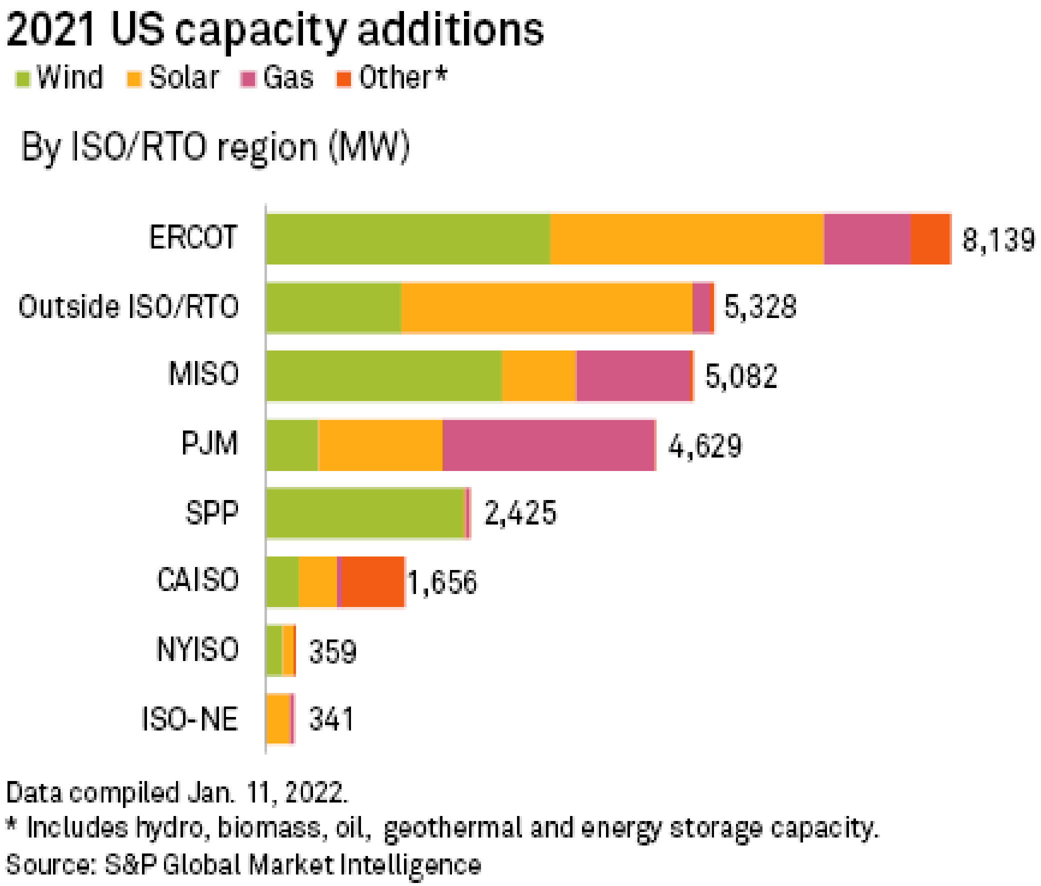
Examples:

- CAISO 2017 and 2020 pilot programs of wind and solar plants providing essential reliability services
  - Successfully provided: spinning reserves, load following, ramping, inertia, frequency response, regulation, droop response, variability smoothing, power quality, and reactive power, voltage, power factor controls
- Inertial and frequency response from wind, solar, batteries, STATCOMs, and HVDC lines
  - Quebec: Inertia provided by all wind generators
  - South Australia: 50% of inertia supplied by batteries (grid-forming inverters with “virtual machine” modes)
  - ERCOT: Primary frequency response provided by all wind and solar plants
  - UK and ENTSO-e: grid code providing for inertial and frequency response from VSC-based HVDC lines

See: 2023 HVDC report, Section V.15 (“Frequency and Inertial Response from HVDC Lines and Inverter-Based Resources”)

Significant Differences in Generation Interconnection Processes

Some RTOs are able to interconnect disproportionately more generation, and have been able to do so more quickly.



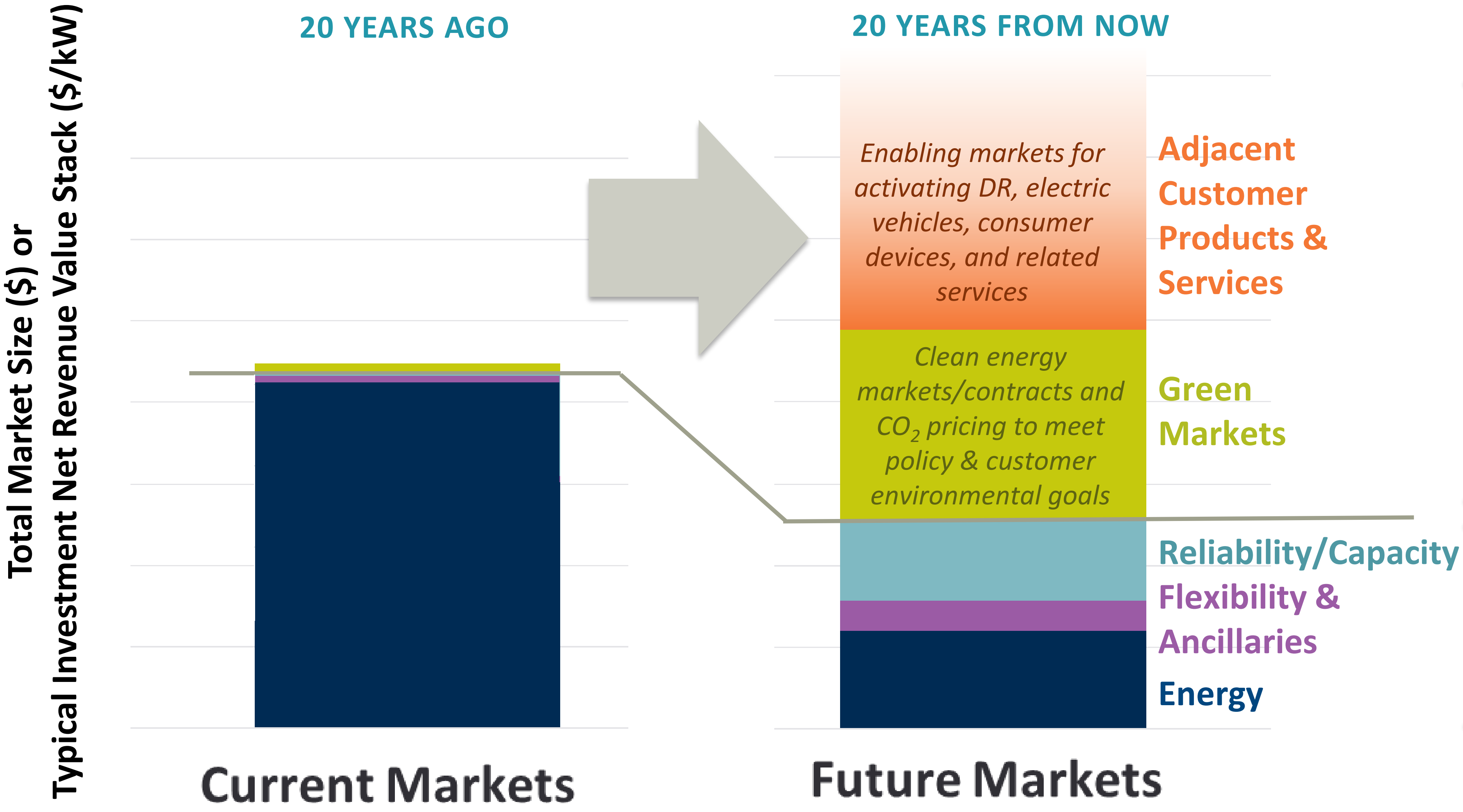
RTO Size	Capacity in Queue
80 GW	135 GW
200 GW	330 GW
150 GW	155 GW
180 GW	245 GW
95 GW	100 GW
52 GW	160 GW
42 GW	75 GW
32 GW	30 GW

Planning regions with the most ambitious state clean energy standards (i.e., east and west coast states) are lagging behind regions such as Texas and the Midwest:

- ERCOT: added 10% of system capacity in 2021
- NYISO and ISO-NE: only 1%
- All others: 2-4%

See also: Generation, Storage, and Hybrid Capacity in Interconnection Queues | Electricity Markets and Policy Group (lbl.gov)

What Might Revenues from “Future Markets” Look Like?



New Markets
Are needed to achieve environmental goals & mobilize customers with a wider array of tech-enabled services

Traditional Markets
Timeless principles of reliability at least cost. But must evolve to rely increasingly on “non-traditional” resources and better definitions of reliability needs

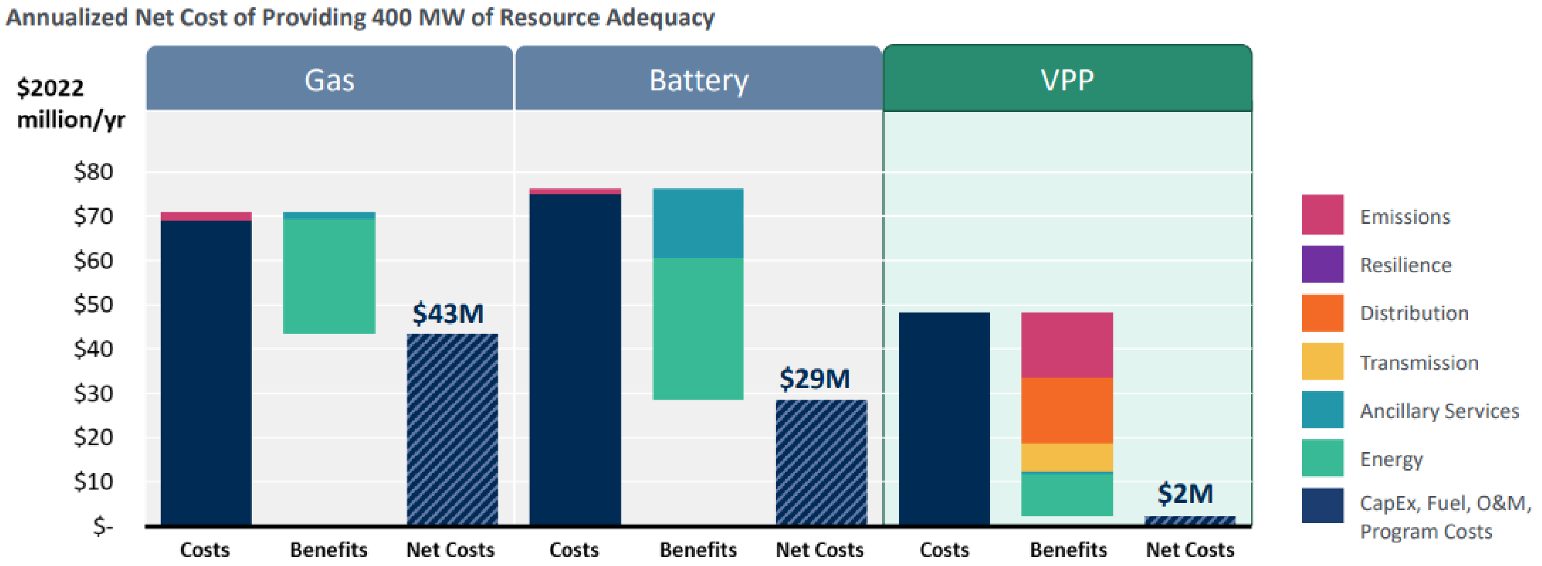
Major resources…. Dispatchable thermal plants, inelastic demand

Renewables, storage, EVs, DR, DER, hydro, interties, prosumers, thermal batteries

Demand Flexibility and Virtual Power Plants (VPPs)

Electrification is quickly increasing electricity demand and system peak loads … and offers substantial opportunities to more cost-effectively meet system needs

- Most electrification demand is flexible
  - Examples: Electric Vehicle (including V2G), building HVAC, thermal storage, solar+storage
- Many electrification loads and distributed energy resources (DERs) are highly controllable
  - RMI: 60 GW of dispatchable VPPs can be developed by 2030 to provide RA and flexibility/operational reliability
  - VPPs offer resource adequacy at (1) significantly lower cost and (2) without delays in generation interconnection



Source: Hledik and Peters, Real Reliability: The Value of Virtual Power (Brattle, May 2023)

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- Nuclear
- Renewable & Alternative Energy

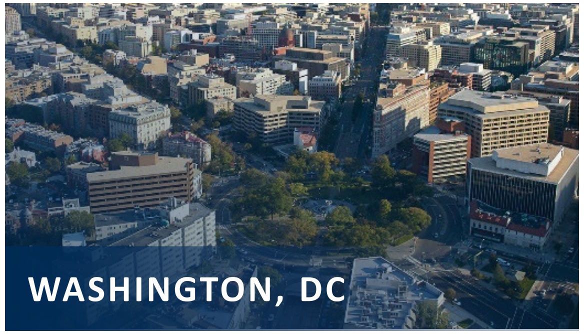
LITIGATION

- Accounting
- Analysis of Market Manipulation
- Antitrust/Competition
- Bankruptcy & Restructuring
- Big Data & Document Analytics
- Commercial Damages
- Environmental Litigation & Regulation
- Intellectual Property
- International Arbitration
- International Trade
- Labor & Employment
- Mergers & Acquisitions Litigation
- Product Liability
- Securities & Finance
- Tax Controversy & Transfer Pricing
- Valuation
- White Collar Investigations & Litigation

INDUSTRIES

- Electric Power
- Financial Institutions
- Infrastructure
- Natural Gas & Petroleum
- Pharmaceuticals & Medical Devices
- Telecommunications, Internet, and Media
- Transportation
- Water

A Global Firm



Clarity in the face of complexity

Brattle