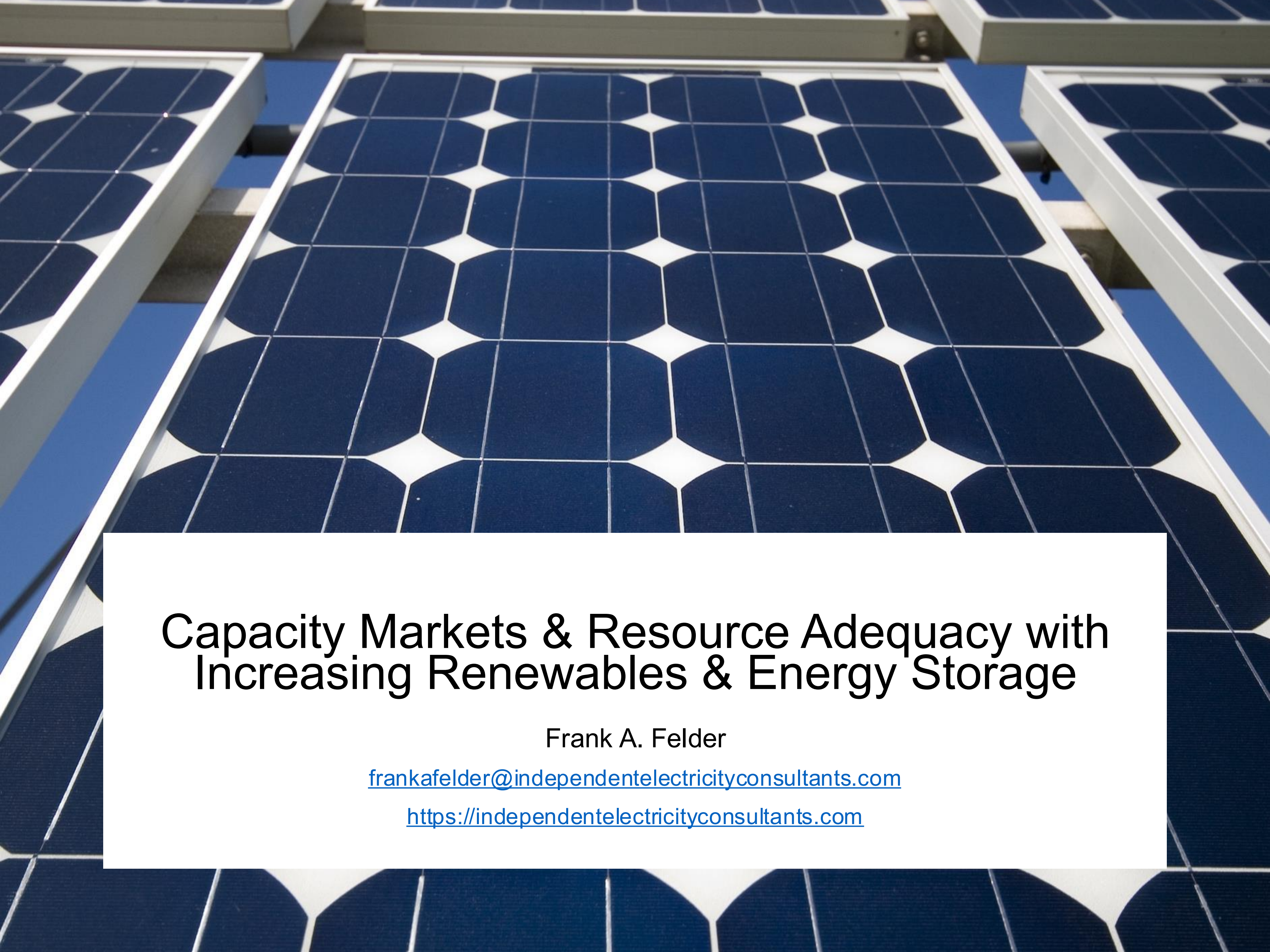

Capacity Markets & Resource Adequacy with Increasing Renewables & Energy Storage

Frank A. Felder

frankafelder@independentelectricityconsultants.com

https://independentelectricityconsultants.com

UPCOMING TRAINING

Half-day, Morning Sessions

- Sept. 17: Fundamentals of Power System Optimization – Virtual only

- Dec. 2: Introduction to the Electricity Sector
- Dec. 3: Power System Fundamentals
- Dec. 9: Electricity Markets
- Dec. 10: Regulatory and Business Context

- Dec. 2: Trump Electricity Policy Update, 2 pm
- Dec. 9: Quiz Bowl, 4 pm

Gatineau & Virtual

Training schedule and slides available at
https://www.independentelectricityconsultants.com/training-presentations

https://www.independentelectricityconsultants.com/training-presentations

U.S. Capacity Markets & Resource Adequacy with Increasing Renewables & Energy Storage

Tuesday, July 22, 2025, 9:30am - 12:30pm U.S. Eastern Time
Virtual Only

Resource adequacy is a fundamental component of power system reliability. It also serves as the modeling foundation for wholesale capacity markets. Severe weather and intermittent PV solar and wind resources, and the expansion of energy storage are challenging this modeling foundation and therefore definition and operation of capacity markets. This webinar explains how capacity markets work, how resource adequacy modeling is conducted, and how the changes in the power sector are affecting both. Business and public policy implications are also considered.

Course Material

Fundamentals of Power System Optimization, Energy Storage and Data Centers

Tuesday, September 16, 2025, 9:30am - 12:30pm U.S. Eastern Time
Virtual Only

The power system and wholesale electricity markets are organized around a sequence of optimization problems starting with economic dispatch, unity commitment, resource adequacy/capacity markets, and transmission planning. This webinar introduces optimization as a tool and way of thinking and how it is applied in electricity markets. Financial trading and business implications are discussed.

Course Material

In-Depth Introduction to Electricity Markets

Gatineau & Virtual

Tuesday, December 2, 2025
9:30am - 12:30pm - Introduction to the Electricity Sector
2:00pm - 3:00pm - Trump Administration Electricity Policy Update

Wednesday, December 3, 2025
9:30am - 12:30pm - Power System Fundamentals for Understanding Electricity Markets

Tuesday, December 9, 2025
9:30am - 12:30pm - Electricity Market Bids, Offers, Trades, & Prices

Wednesday, December 10, 2025
9:30am - 12:30pm - Political, Regulatory, & Business Contest
2:00pm - 3:00pm - Regulatory Olympics: Brookfield Team Competition

In-depth Introduction to Electricity Markets covers the engineering, economic, regulatory and business aspects of U.S. wholesale and retail electricity markets in an integrated and comprehensive manner. It stresses understanding key concepts in an intuitive and accessible manner supported with numerical calculations and data. Sessions are independent & can be attended separately.

QUIZ BOWL – TUESDAY, DECEMBER 9, 4 PM, GATINEAU

Rules:

- Teams of 1-4 people (at least 1 person in Gatineau)
- Two Rounds
    - Round 1 based upon "In-depth Intro to Electricity Markets"
    - Round 2 based upon other short courses on transmission planning, capacity markets, optimization, and market power
- Each round approximately 15 questions, about 20 minutes
- Winning team gets a firm handshake and maybe an inexpensive trophy

Send an email to

frankafelder@independentelectricityconsultants.com

If you are interested in forming a team and participating

MAJOR THEMES

Capacity markets are an important source of revenue in U.S. RTO/ISO markets (except ERCOT)

The analytical basis for capacity markets – resource adequacy – is being re-evaluated due to extreme weather, variable renewables, and energy storage

As a a result, capacity market reforms are being considered that may substantially affect revenues

KEY CONCEPTS

Resource Adequacy

Monte Carlo Simulation

Capacity Accreditation

Capacity Market Mechanics

RTO/ISO Capacity Market Design Choices

Independent and dependent generation failures

Effective Load Carrying Capability

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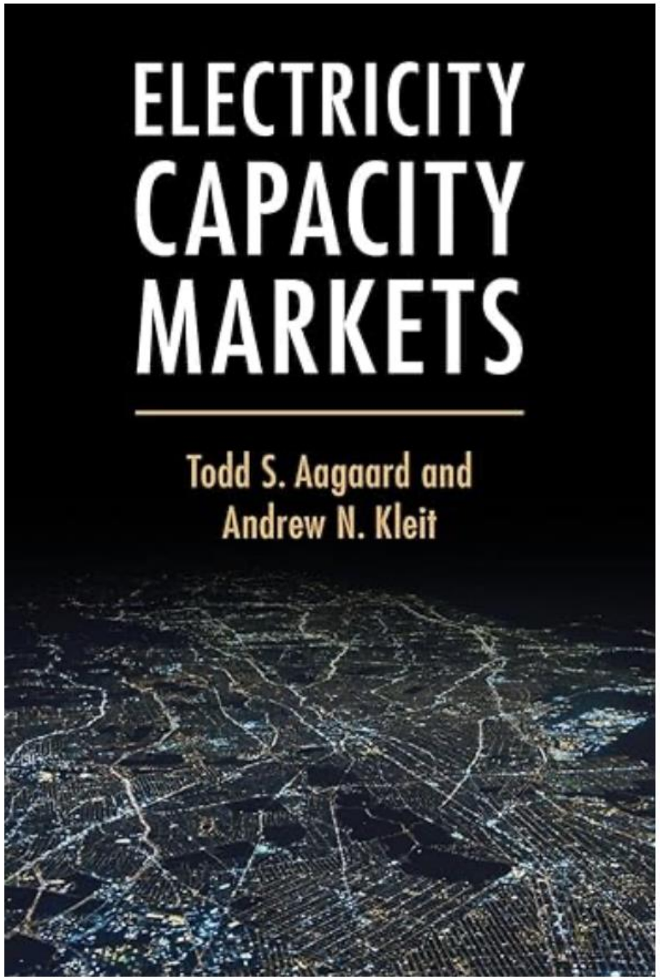


SEMINAR AGENDA

9:30-9:40 Introduction, Logistics, Course Overview

9:40-11:00 Reliability, Resource Adequacy and Capacity

11:00-11:15 Break

11:15-12:00 Capacity Market Fundamentals

12:00-12:25 Emerging Issues with Capacity Markets

12:25 to 12:30 Q&A

Send an email to frankafelder@independentelectricityconsultants.com to request a letter of attendance for professional education requirements

Ask questions or comment at anytime during the session and feel free to contact me at anytime if you would like more information or discussion.

Connect with me on LinkedIn: https://www.linkedin.com/in/frank-felder-8766976/

IN THE NEWS

ENERGYWIRE

DOE plays out worst-case scenarios for US grid

By PETER BEHR | 07/08/2025 06:48 AM EDT

The Department of Energy report is widely viewed as groundwork for the White House to order coal and gas plants slated for closure to run for longer.

https://www.eenews.net/articles/doe-plays-out-worst-case-scenarios-for-us-grid/

DIVE BRIEF

Load growth, plant retirements could drive 100x increase in blackouts by 2030: DOE

The U.S. Department of Energy on Monday published a methodology for assessing grid reliability, but clean energy advocates say it likely exaggerates the risks of blackouts.

Published July 8, 2025

https://www.utilitydive.com/news/load-growth-plant-retirements-blackouts-doe/752408/

IN THE NEWS

Summer Has Long Stressed Electric Grids. Now Winter Does, Too.

Electric utilities, which designed their system to meet peak demand in sizzling weather, are straining to keep up during the cold.

By Ivan Penn NYT
Ivan Penn, who covers the energy industry, reported from Houston and Los Angeles.

Feb. 5, 2024

Rethinking Energy Reliability with Modern Power Systems

As the energy transition to inverter-based resources continues, reliability risk increases and requires additional investment to mitigate threats. But what measures should be put in place, what are the associated costs, and how can the power generation industry budget accordingly?

POWER, June 1, 2023, https://www.powermag.com/rethinking-energy-reliability-with-modern-power-systems/

Climate Crisis Catches Power Companies Unprepared

Utilities are fighting to keep the lights on amid extreme wildfires, heat and flooding fueled by global warming.

By Brad Plumer and Ivan Penn

Published July 29, 2021 Updated Aug. 6, 2021 NYT

UTILITY DIVE

DIVE BRIEF

NIPSCO, Linde to pay $66.7M to settle charges for gaming MISO demand response program

The Federal Energy Regulatory Commission-approved settlement agreement marks the second recent enforcement action involving MISO's demand response program.

Published Jan. 8, 2024

Ethan Howland
Senior Reporter

America's largest power grid is struggling to meet demand from AI

By **Laila Kearney**

July 9, 2025 6:25 AM EDT · Updated July 9, 2025

https://www.reuters.com/sustainability/boards-policy-regulation/americas-largest-power-grid-is-struggling-meet-demand-ai-2025-07-09/

WHY CAPACITY MARKETS ARE IN THE NEWS

- Anticipated substantial increase in variable and intermittent renewable energy (VIRE) (or weather-dependent resources), e.g., solar PV and wind
- Planned retirements of coal power plants due to economic reasons (age)
- Electricity demand load growth
- Long generation-interconnection queues
- Inadequate regional and interregional transmission
- Major recent blackouts and close calls in Texas, California, PJM, Spain/Portugal, and elsewhere

DIVE BRIEF

PJM capacity prices hit record highs, sending build signal to generators

Consumers across the PJM Interconnection footprint will pay $14.7 billion for capacity in the 2025-26 delivery year, up from $2.2 billion in the last auction.

Published July 31, 2024

https://www.utilitydive.com/news/pjm-interconnection-capacity-auction-vistra-constellation/722872/

1. Reliability, Resource Adequacy, and Capacity

ENERGY VS POWER

ENERGY is the amount of power delivered over time measured in Watt-hours (Wh) (analogous to distance traveled)

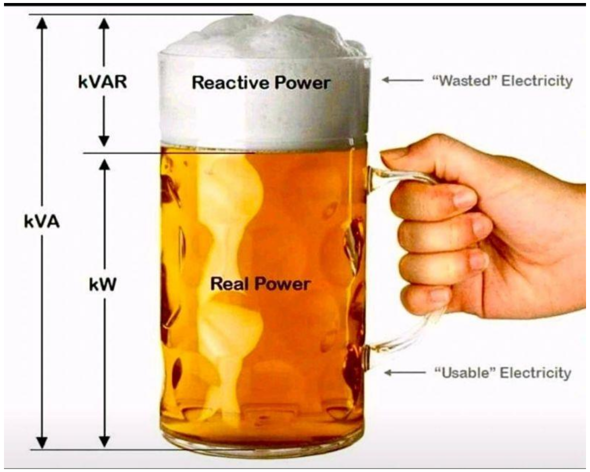
e.g., a 100W light bulb consumes 2,400 Wh (or 2.4 kWh) of energy in 24 hours

POWER is the rate at which energy is used or supplied (analogous to speed)

- Real Power has the units of watts and measures the strength of a supply source
- Reactive Power, measured in vars, is needed by wires and motors to enable energy conversion but provides no useful work

Insufficient reactive power was a contributing factor to the August 2003 blackout

Similar to a golfer who must hit the ball high in the air even though his goal is only to move the ball horizontally



See the FERC Staff Report (2005) *Principles for Efficient and Reliable Reactive Power Supply and Consumption*

CAPACITY AND CAPACITY FACTORS

- Capacity is the ability of a generation unit to produce energy
- Energy is the amount that the unit produces
- Capacity factor is the ratio of the actual energy produced over a period to the energy it could have produced if it ran at full capacity for the same duration

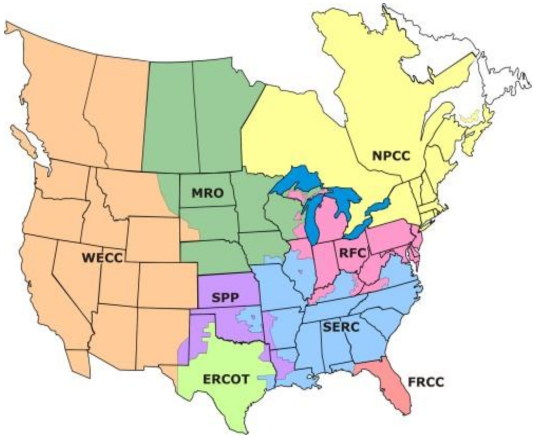
  E.g., a 100 MW unit that produces 500,000 MWh of energy has a capacity factor:

  500,000 MWh/[100 MW * 8760] = 0.57 = 57%
  (Note: 8760 is the number of hours in a non-leap-year year)

- Compare a 1,000 MW nuclear power plant with a 90% capacity factor to a 1,000 MW wind farm with a 30% capacity factor with 1,000 MW of PV solar with a 15% capacity factor
- At the retail level, usage is measured in kW and kWh
- At the wholesale level, usage is measured in MW an MWh

  1,000 kWh = 1 MWh   1,000 kW = 1 MW
  1,000 MWh = 1 GWh   1,000 MW = 1 GW

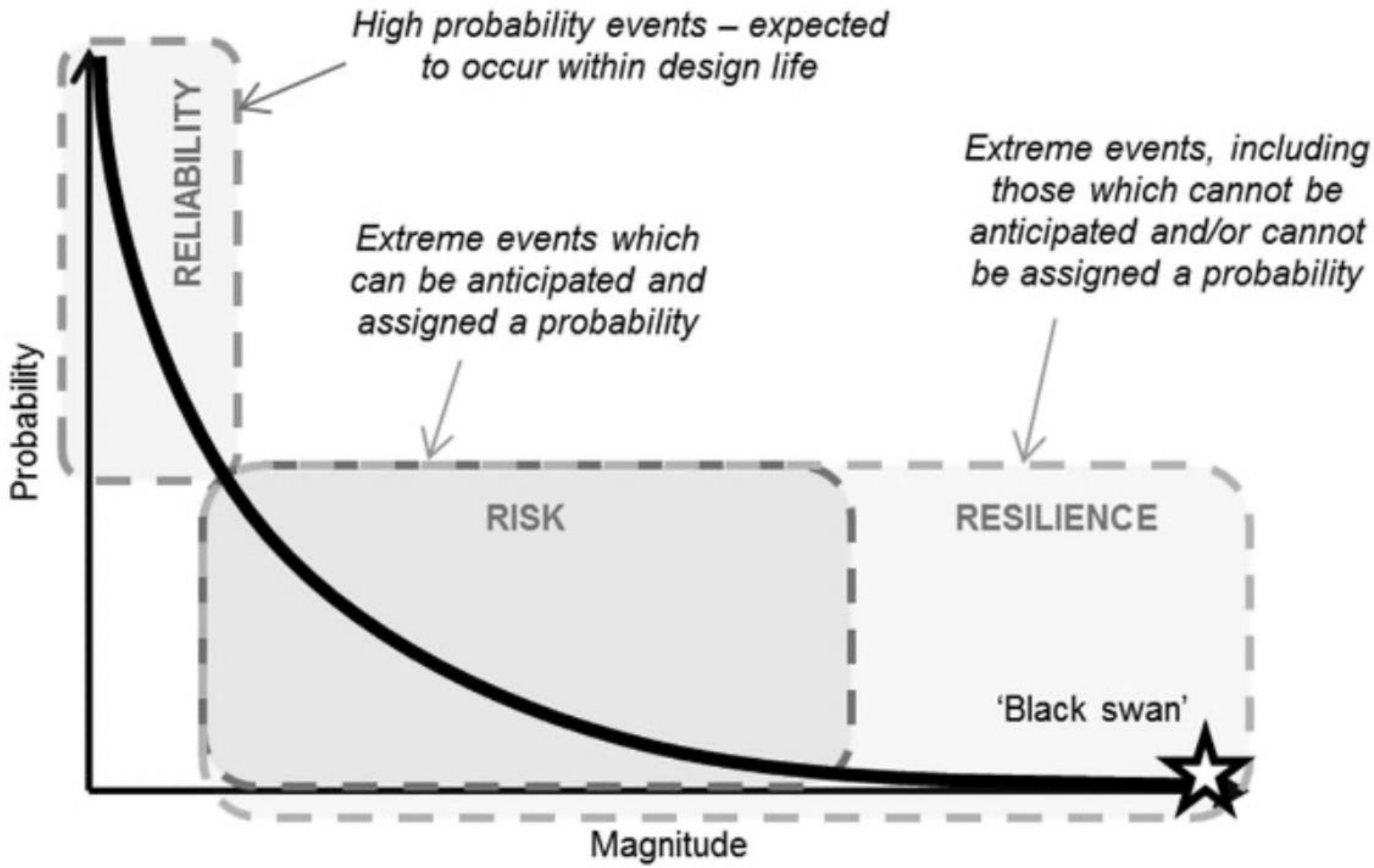
NERC RELIABILITY



Recall that NERC (the North America Electric Reliability Corporation) sets the reliability standards that are adopted by the Federal Energy Regulatory Commission (FERC)

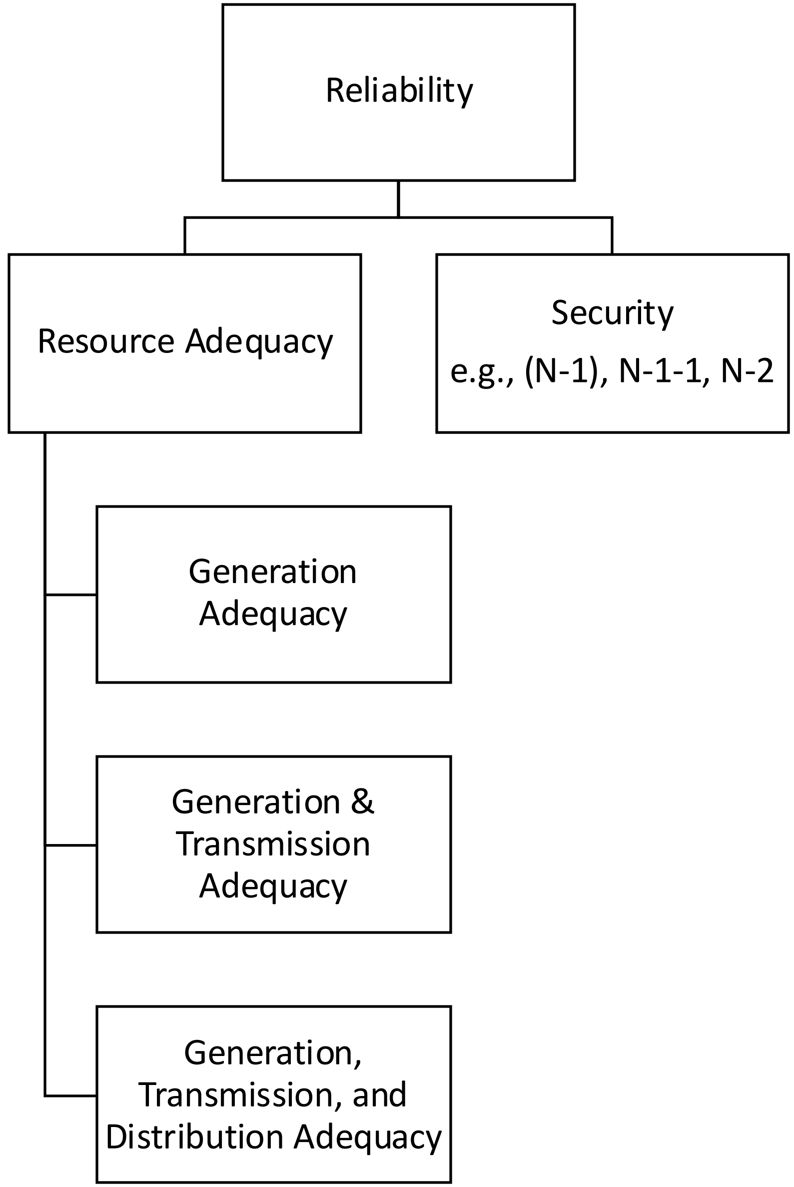
- The bulk electric systems shall be planned and operated to avoid widespread cascading interruptions of electricity supply for the types of contingency events normally encountered on electric systems (i.e., more probable contingencies)
- The bulk electric systems also must demonstrate the ability of its bulk electric system to withstand more severe contingencies
- The frequency of having to disconnect firm load should not exceed one time in ten years (not an explicit NERC requirement)

RELIABILITY & RESILIENCY



https://www.researchgate.net/publication/327950078_Design_and_operation_of_urban_wastewater_systems_considering_reliability_risk_and_resilience/figures?lo=1

BULK POWER SYSTEM RELIABILITY COMPONENTS



HISTORICAL SUMMARY OF RESOURCE ADEQUACY

Hour of peak demand plus sufficient reserve margin determines the amount of needed total generation capacity

Total amount of capacity is determined by loss of load probability/expectation (LOLP/LOLE) study that simulates independent random generation outages that satisfies the one-time-in-ten years or one-day-in-ten-years criteria

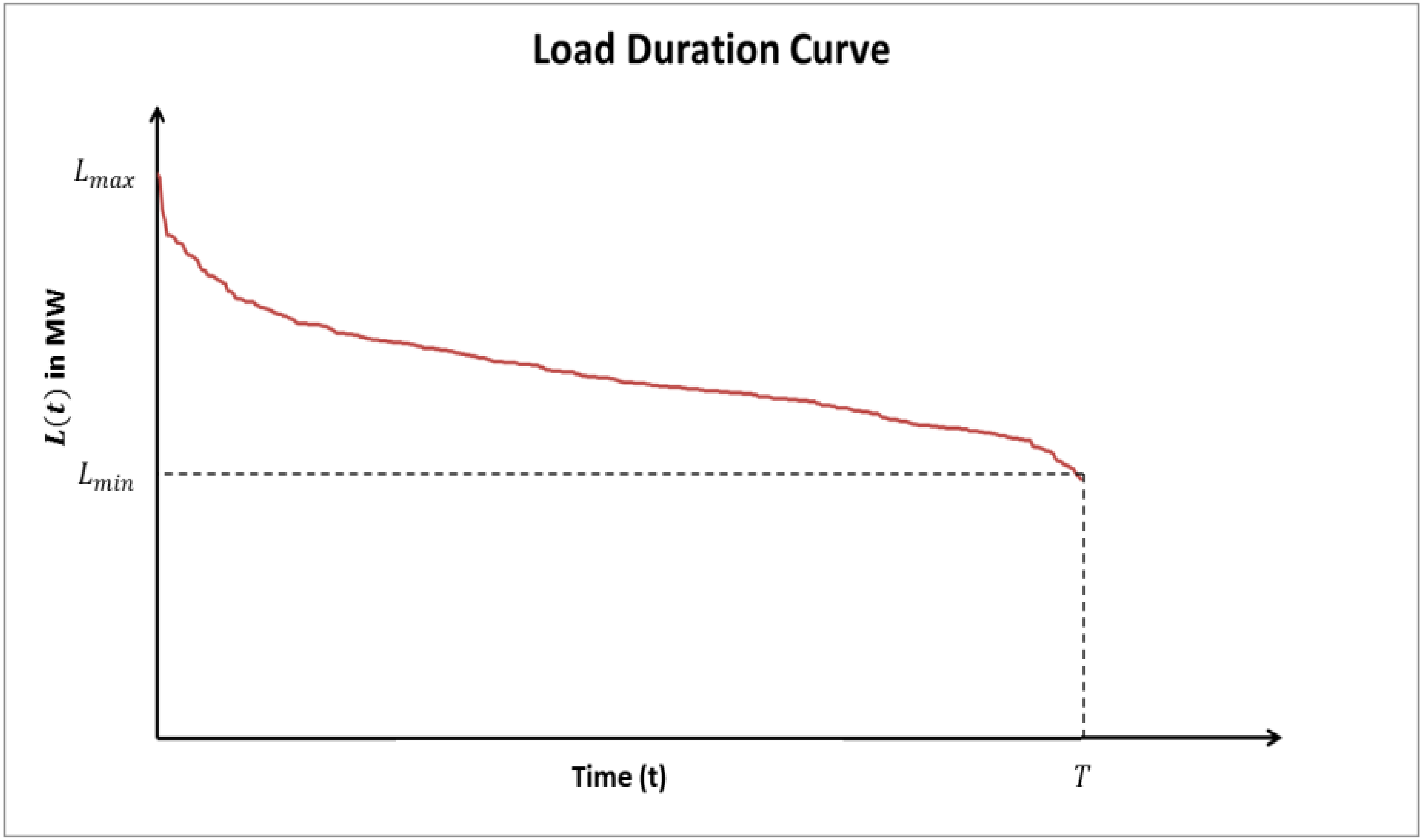
Capacity Margin =

$$\frac{(Total\ Generation\ Capacity\ - Peak\ Load)}{Total\ Generation\ Capacity}$$

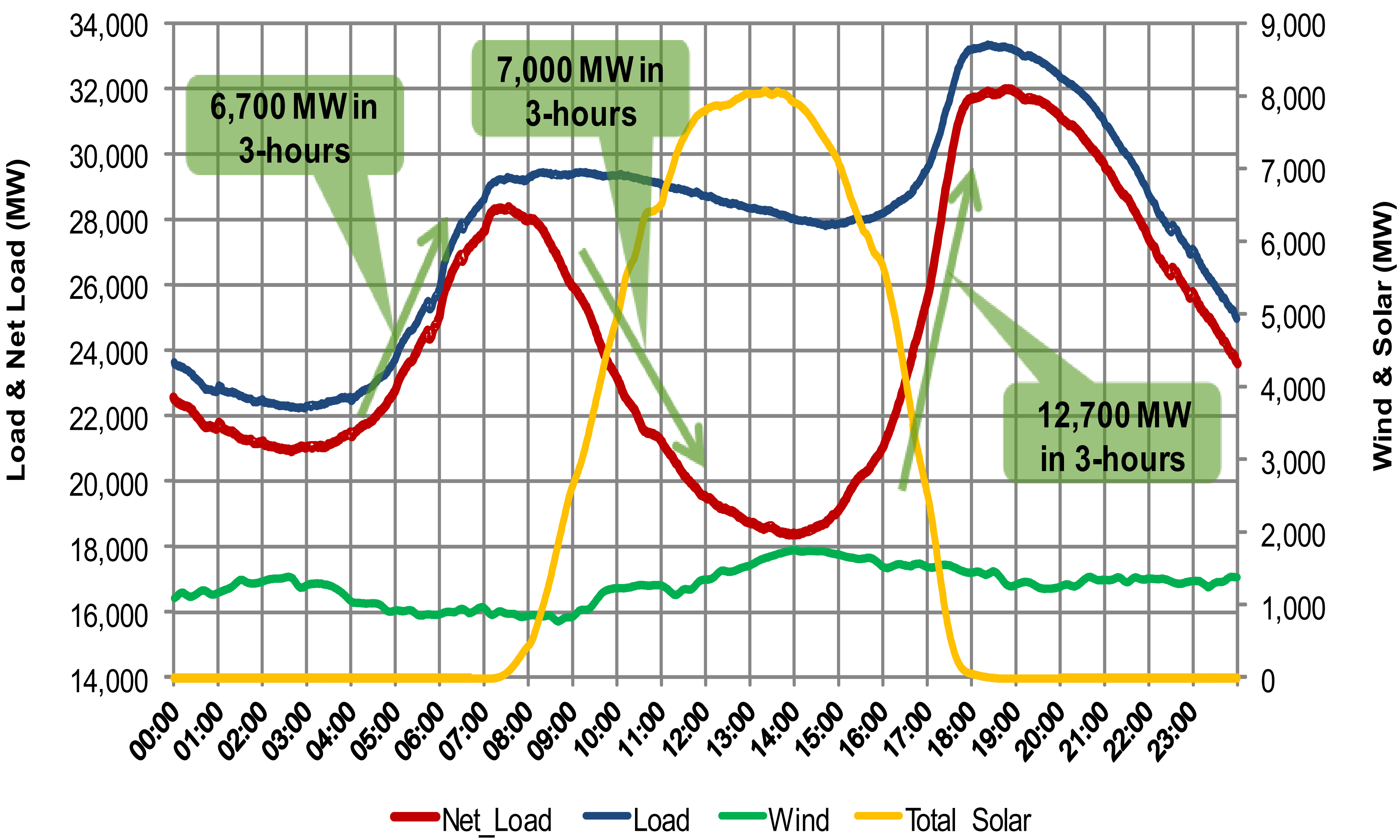
Reserve Margin =

$$\frac{(Total\ Generation\ Capacity\ - Peak\ Load)}{Peak\ Load}$$

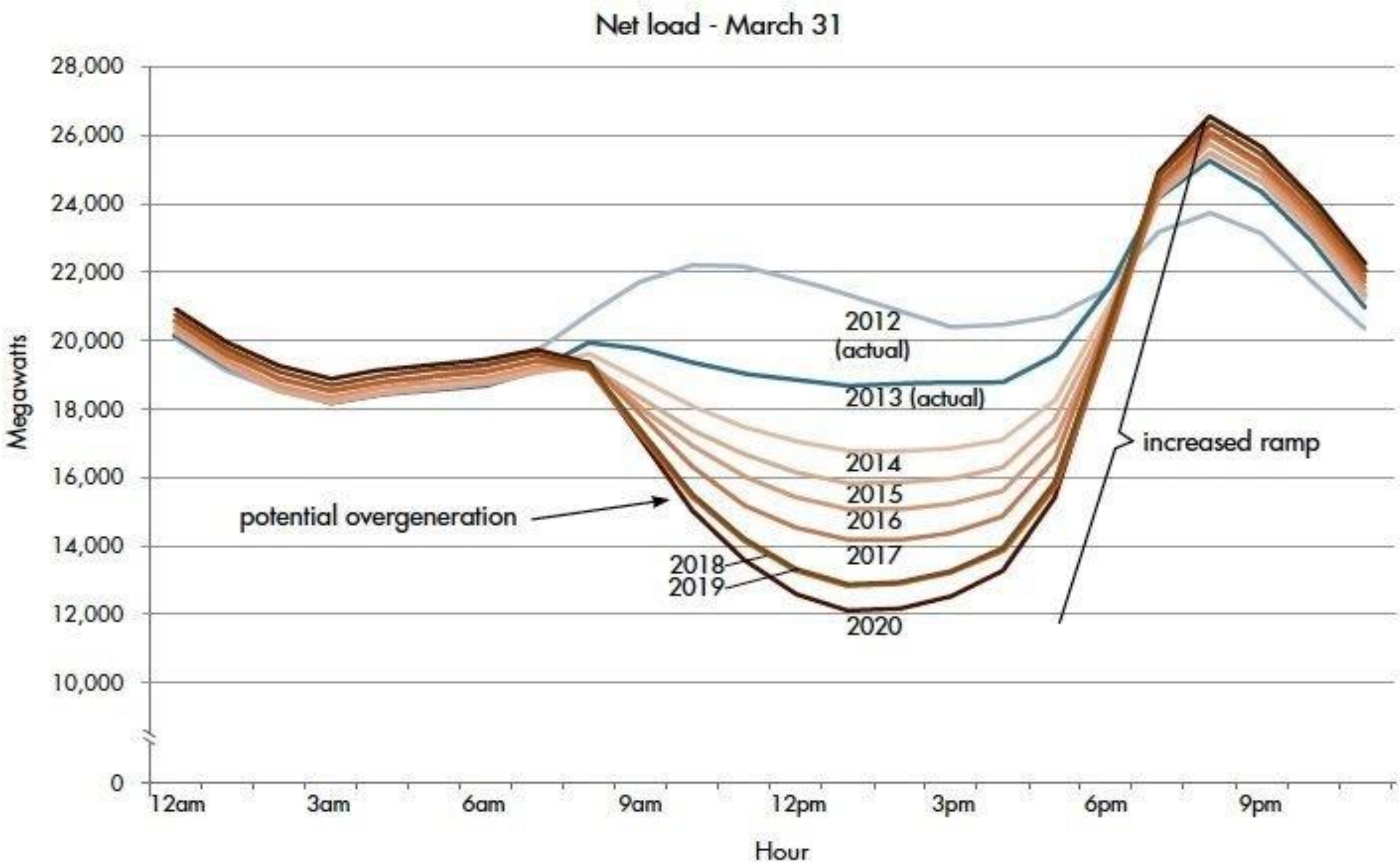
LOAD DURATION CURVE (LDC)



"DUCK DIAGRAM"



“DUCK DIAGRAM” AND NET LOAD



https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

CAPACITY UNITS

Generation capacity is measured in megawatts (MW)

Capacity prices are reported in $/(MW-Day) or $/(kW-Year) or $/(kW-Month)

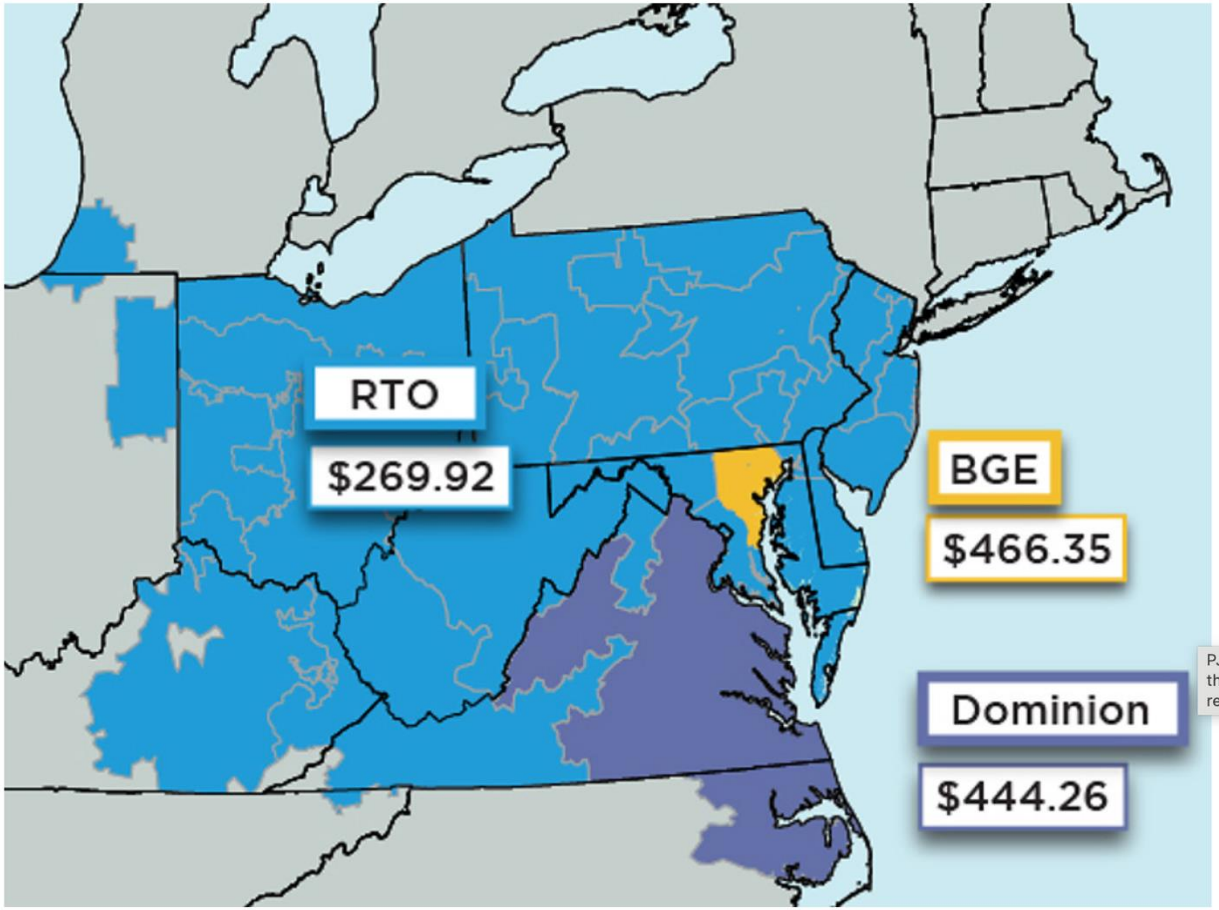
1 $/MW-Day *(365 Days/Year)*(1 MW/1000 kW) = 0.365 $/(kW-Year)

Recall that the units for energy are MWh or kWh and prices are $/MWh or $/kWh

RECENT PJM CAPACITY RESULTS

PJM Capacity Prices Spike 10-fold in 2025/26 Auction

Load Growth, Deactivations, Risk Modeling Changes Cited as Causes



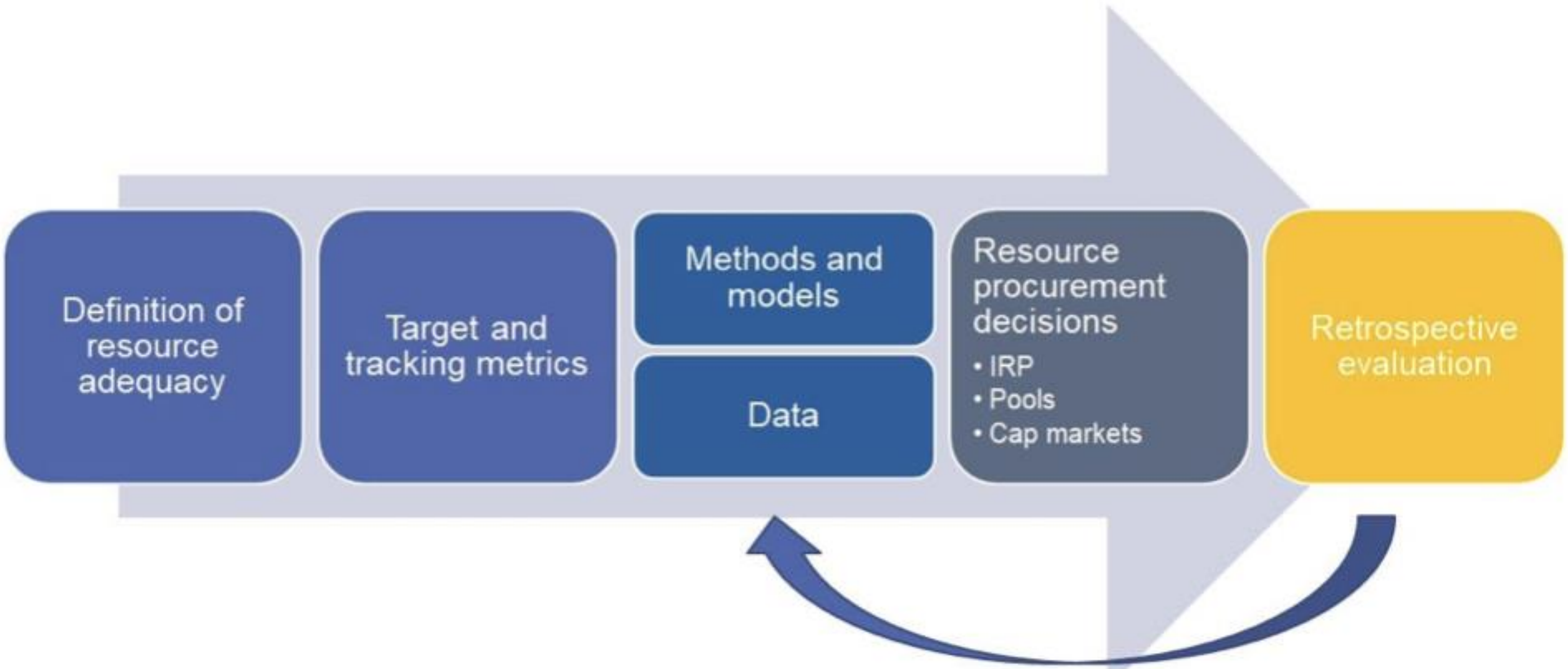
PJM capacity prices increased nearly ten-fold in the 2025/26 Base Residual Auction, with two regions reaching their zonal caps. | *PJM*

Jul 30, 2024 | Devin Leith-Yessian

Prices are in $/MW-day

https://www.rtoinsider.com/84356-pjm-capacity-prices-spike-2025-26-auction/

RESOURCE ADEQUACY PROCESS & ENERGY ADEQUACY



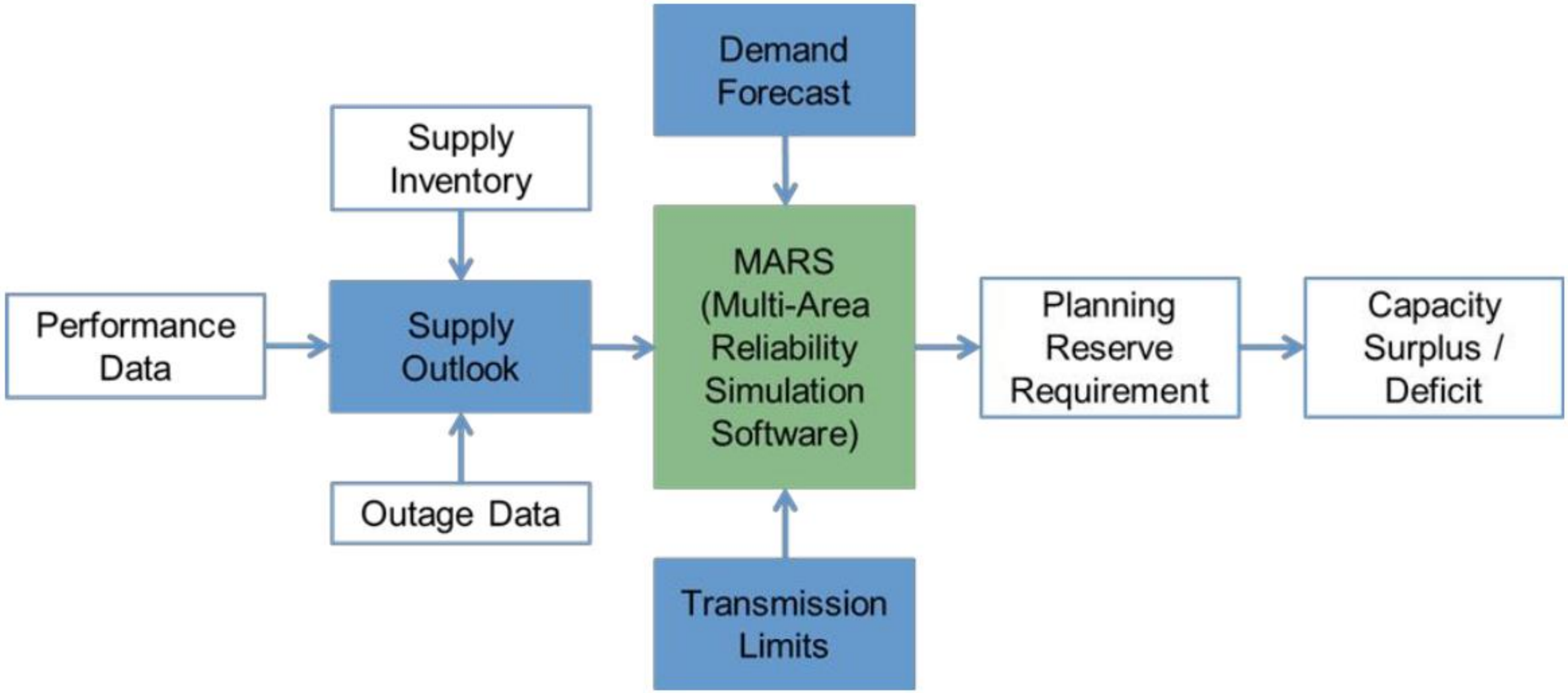
https://live-etabiblio.pantheonsite.io/sites/default/files/ra_project_-_final.pdf

Energy adequacy is ensuring that there is enough energy to meet demand over a given (generally a long) time and accounting for random variations in fuel availability and variable renewable energy production.

https://live-etabiblio.pantheonsite.io/sites/default/files/ra_project_-_final.pdf

RESOURCE ADEQUACY MODELING (ONTARIO IESO)

Figure 2 | Overview of Inputs and Process for MARS Model and Resource Adequacy Assessment



https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Mar2024/Resource-Adequacy-and-Energy-Assessment-Methodology.pdf

Table 5.2 Overview of RTO, ISO and other regional approaches to RA in transmission planning

Entity/Year	Metrics and targets	Models and modeling approach
Midcontinent Independent System Operator (MISO) Regional Resource Assessment 2022	Adopted LOLE target for the MISO region: 0.1 days/year.	MISO's RA analysis begins with a Regional Resource Assessment (RRA) that projects the region's generation portfolio over a 20-year time horizon to meet member plans and state policy objectives. Used a capacity expansion model (Electric Generation Expansion Analysis System) to find the least-cost resource mix that meets renewable and carbon targets under various resource forecasts, examines the flexibility of the regional system, and ensures the build out meets the established LOLE requirement. MISO used Plexos to review the potential impacts of changes in the planning reserve margin requirement and capacity contributions of wind, solar, solar plus storage, and battery and energy storage systems. The analysis requires a set of inputs, including load forecasts and renewable energy production profiles created for different historical years under the pre-defined electrification and weather scenarios (MISO Futures).
ISO New England (ISO-NE) Regional System Plan 2021	Average of 0.1 days/year LOLE	ISO-NE produces a Regional System Plan once every 3 years. This analysis produces a comprehensive ten-year peak and energy forecast and determines whether the region has enough capacity to satisfy the resource adequacy requirements. If the system has shortfalls, it identifies generation and transmission plans to address any identified needs. The forecast of peak and annual electricity consumption was projected using gross energy modeling and gross demand modeling tools (both are regression models constructed using weather, economic, and time variables) with forecast inputs related to the economy and weather. The system-wide and local-area capacity needs were calculated using the General Electric Multi-Area Reliability Simulation Program (GE MARS), which conducts a chronological Monte Carlo simulation to incorporate uncertainties in loads and resources under a wide range of existing and future system conditions
PJM RA Studies	Average of 1 day every 10 years (1 day every 25 years for locational assessments); 2022 PRM of 14.7%	PJM conducts resource adequacy planning studies to determine the capacity resources needed to serve forecasted loads while satisfying reliability criteria. The planning study consists of three components. First, the Generator Availability Data System (GADS), provides information on the availability of generating units over the past five years and identifies the parameters for generation forecasting. Second, load forecasting over the next 15 years at the monthly level generated using multiple regression analysis of the hourly metered

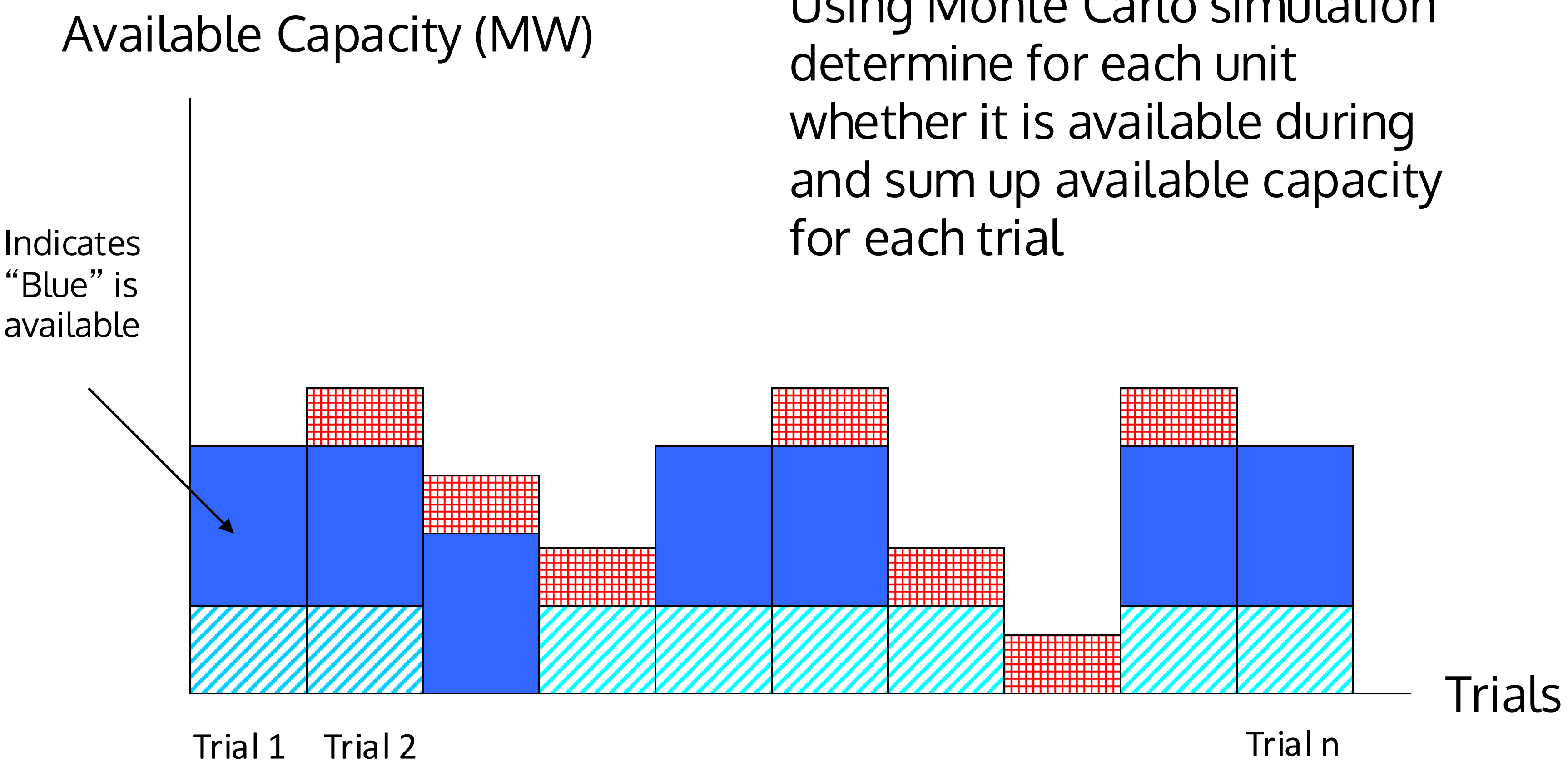
Resource Adequacy Models

- GE-MARS
- PRAS (from NREL)
- SERVM

https://live-etabiblio.pantheonsite.io/sites/default/files/ra_project_-_final.pdf

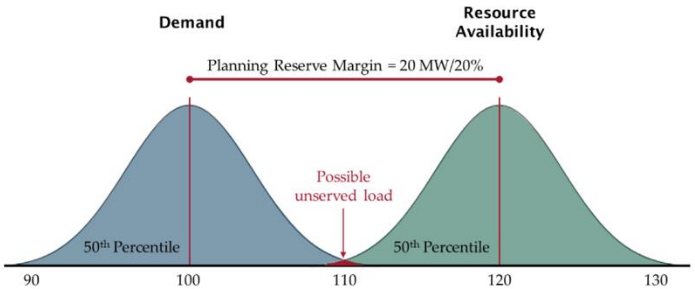
GENERATION CAPACITY ADEQUACY

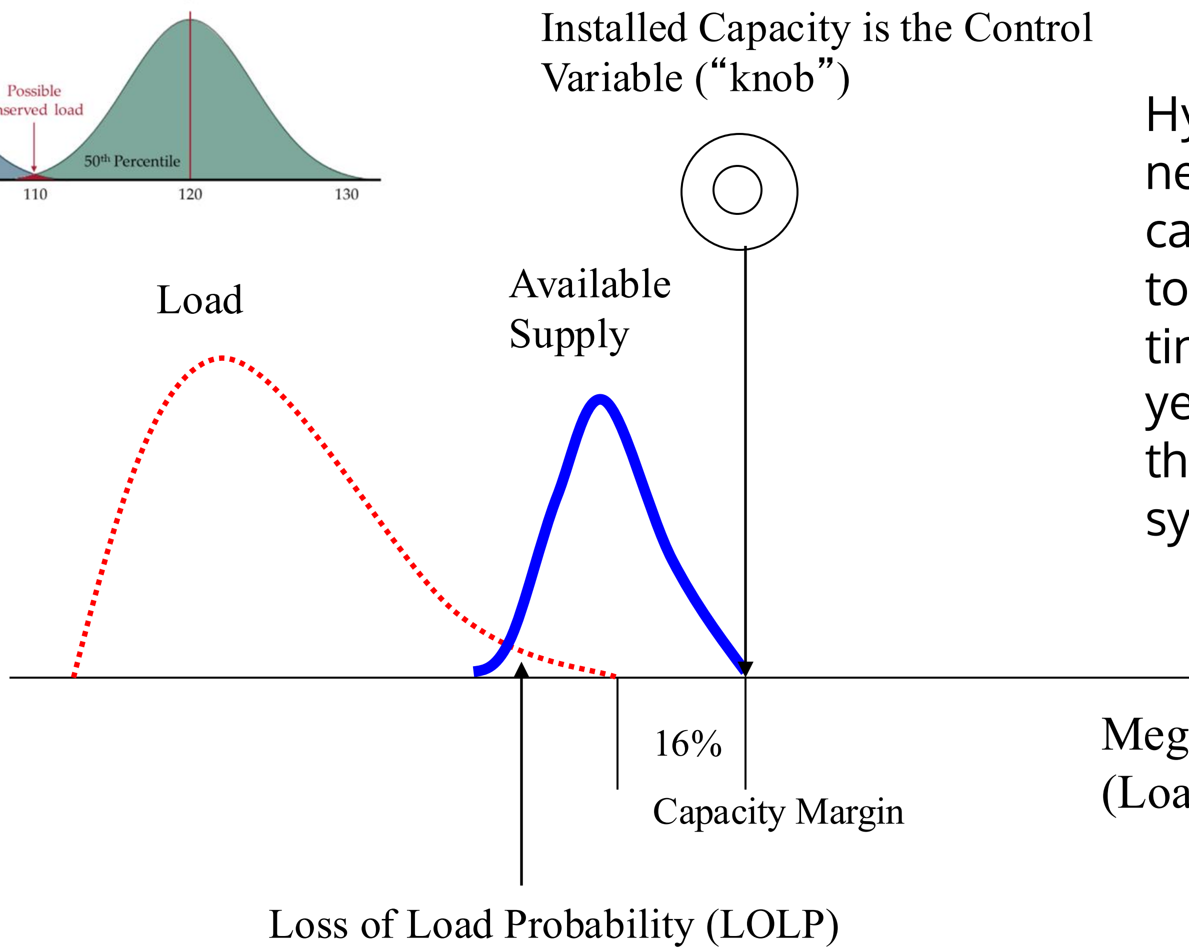
Using Monte Carlo simulation determine for each unit whether it is available during and sum up available capacity for each trial



Important concept: Effective Load Carrying Capability (ELCC)

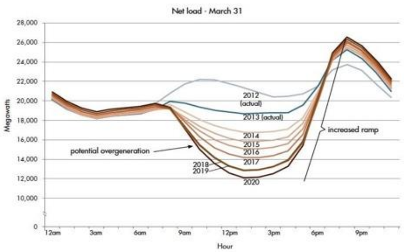
GENERATION CAPACITY ADEQUACY

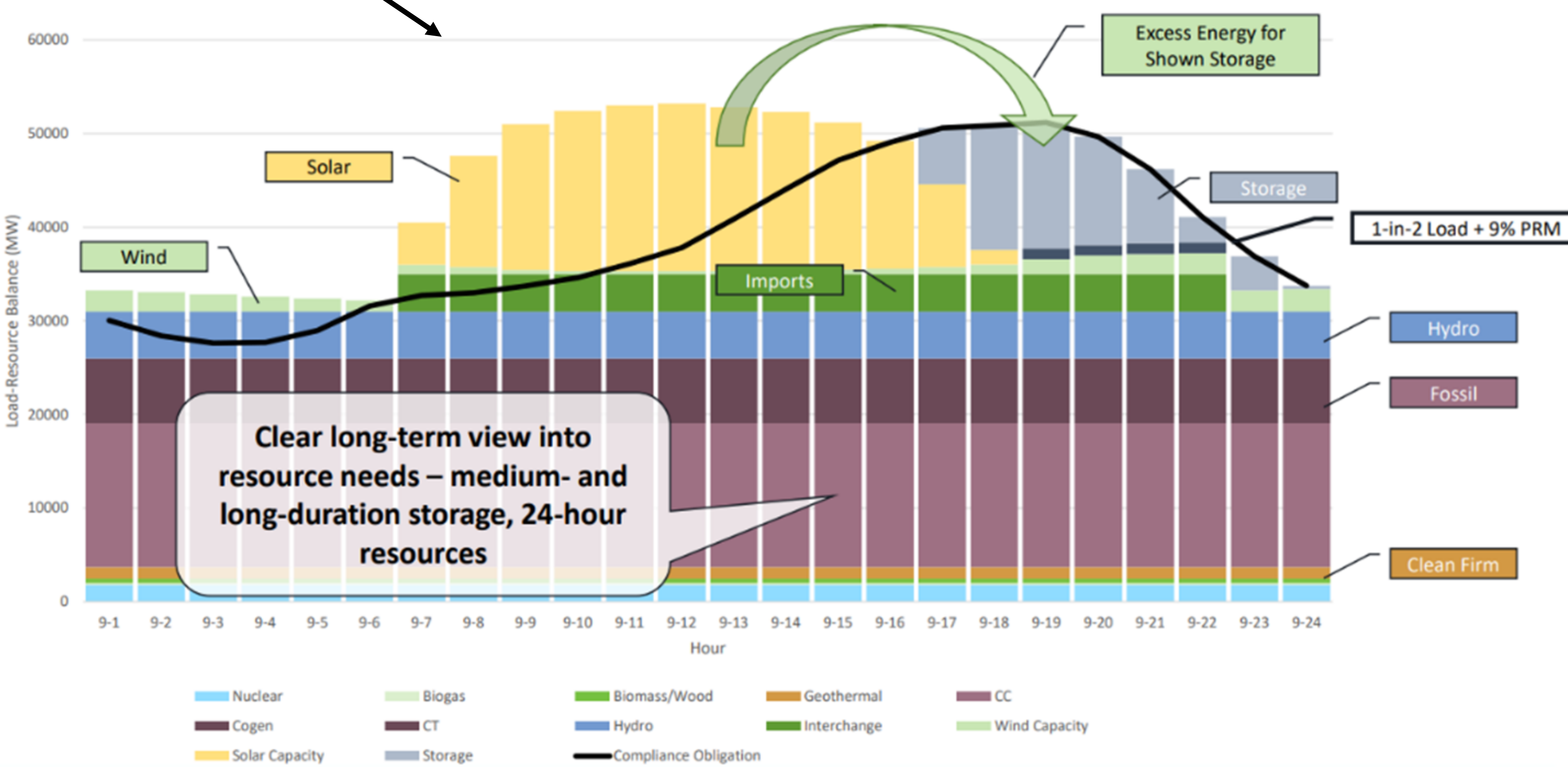




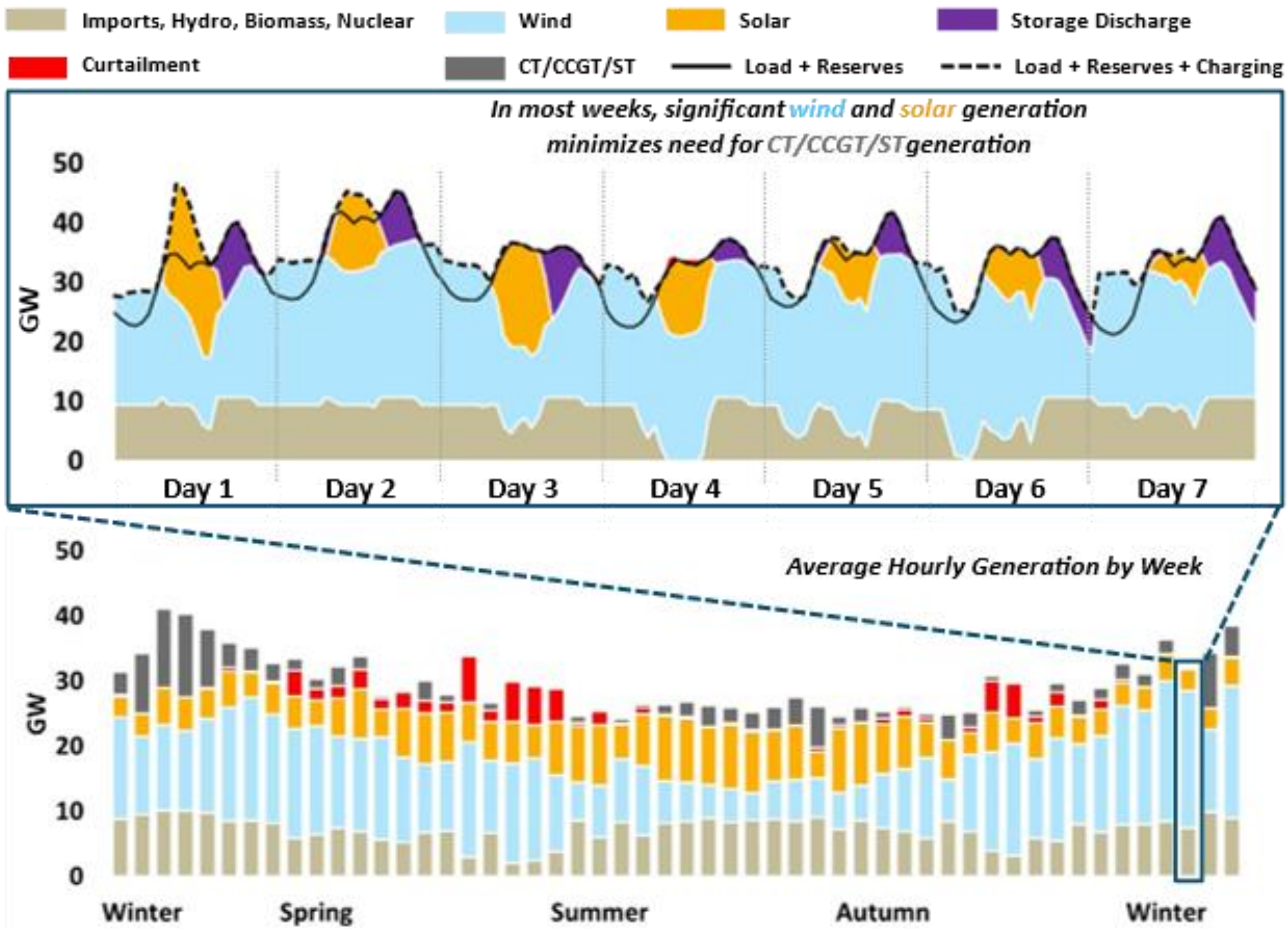
Hydro systems need a lower capacity margin to obtain the 1-time-in-ten-year level than thermal systems

CHRONOLOGICAL RESOURCE ADEQUACY (RA)





CURTAILMENTS



VALUE OF LOST LOAD (VOLL)

Definition

The Value of Lost Load (VOLL) is an indicator of the economic value that consumers place on the energy not served in case of a supply disruption, e.g. an electricity outage (blackout). VOLL is broadly used by industry and regulators for benchmarking the operating conditions of an energy system.

Interpretations

- Literal cost to consumers
- An oversimplification of individual consumer demand curves
- An approximate value used for planning purposes

Ways to Measure VOLL

- Surveys
- Costs of behaviors in response to actual or anticipated power outages
- Macroeconomic studies
- Estimates of cost of lost production

RESOURCE ADEQUACY METRICS

Loss of Load Expectation (LOLE)

The expected number of hours in a year that load loss or generation deficiency occurs

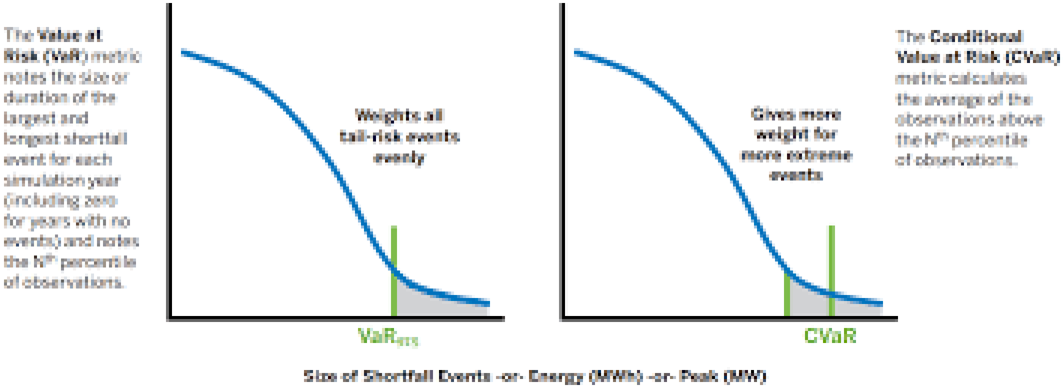
Loss of Load Probability (LOLP)

The probability that a system's load will exceed generation

Unserved Energy

The expected amount of energy not supplied by generation during a period due to insufficient generation

Other metrics that account for risk are being considered



https://cdn.misoenergy.org/20240926%20RA%20Risk%20Metric%20Workshop%20Item%2003%20Stenclik%20ESIG%20New%20Resource%20Adequacy%20Criteria650105.pdf

CAPACITY ACCREDITATION AND TESTING

- Need to test capacity, generally winter and summer, to determine its amount
- Adjusted by effective forced outage rate (EFOR) based upon rolling average of, for example, 18 months
  - UCAP = ICAP*(1-EFOR)
- Typically test the unit when it is scheduled to operate
- Ability to produce energy for multiple hours, e.g., 4 or 6 hours
- Special tests for limited energy resources (e.g., hydro, energy storage, intermittent renewables)

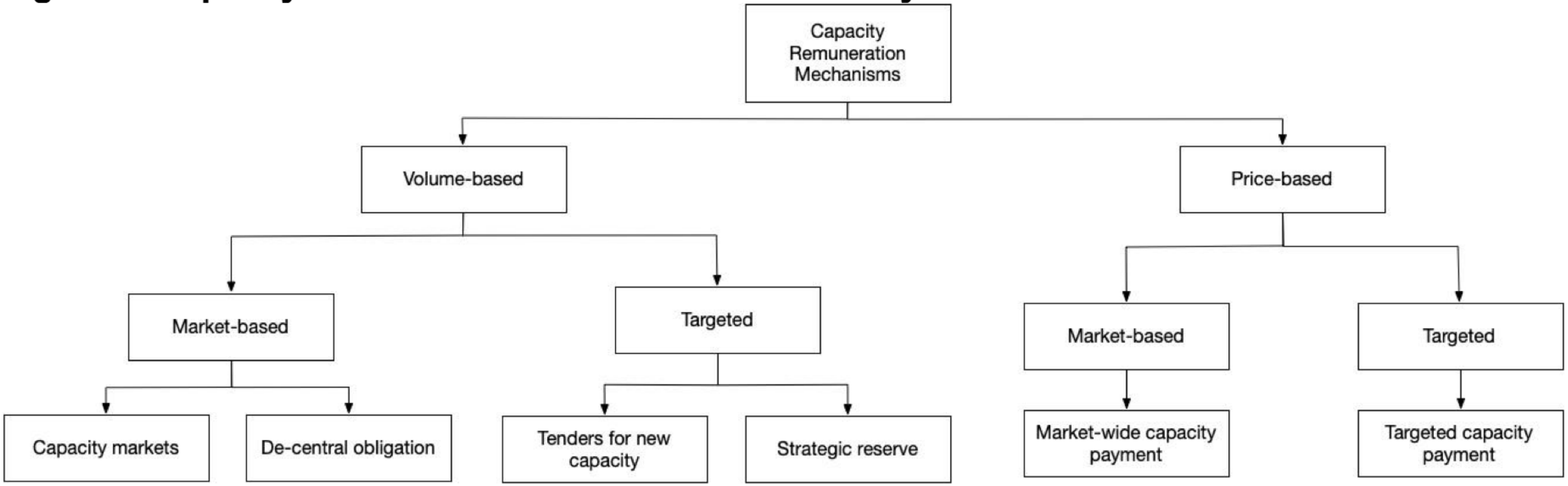
2. Capacity Market Fundamentals

SUMMARY OF MARKET DESIGN CHOICES

Design Element	Comment
Multi-settlement	Needed to align incentives between unit commitment and dispatch
Congestion Pricing (i.e. LMPs)	Needed to reflect transmission constraints
Ancillary Services Markets	At a minimum need opportunity cost pricing
Capacity Markets	Depends on willingness to tolerate extremely high prices and amount of price-responsive demand
Transmission	Avoid having transmission policies undercut wholesale electricity markets
Wholesale Demand Response	A must if there is no retail price responsive demand
Retail Demand Response	Need political will and should consider advanced metering infrastructure (AMI)

TYPES OF CAPACITY MECHANISMS

Figure 1: Capacity remuneration mechanisms taxonomy



Source: adapted from ACER 2018

Apostolopoulo and Poudineh, Reforming Capacity Markets: How to Incorporate the Flexibility of Residential Consumers, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/05/EL55-Reforming-Capacity-Markets_publish.pdf

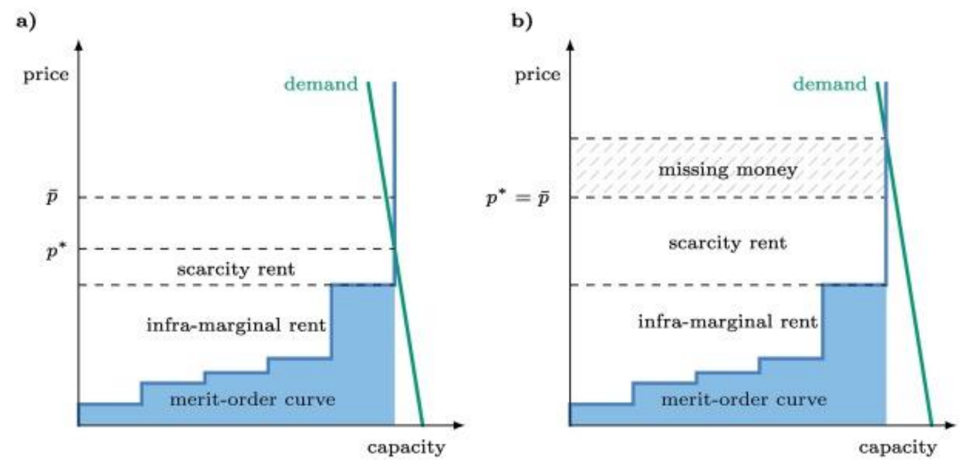
MOTIVATIONS FOR CAPACITY MARKETS

- Historical
- Missing money
- Positive externality
- Public good
- Lack of demand response
- Political economy

MISSING MONEY DUE TO OFFER CAPS

Case No.	Technology	Description	Net Nominal Capacity (kW)	Net Nominal Heat Rate (Btu/kWh)	Capital Cost ($/kW)	Fixed O&M Cost ($/kW-year)	Variable O&M Cost ($/MWh)
1	USC Coal without Carbon Capture – Greenfield	1 x 735 MW Gross	650	8,638	$4,103	$61.60	$6.40
2	USC Coal 95% Carbon Capture	1 x 819 MW Gross	650	12,293	$7,346	$86.70	$13.73
3	Aeroderivative CTs – Simple Cycle	4 x 54 MW Gross	211	9,447	$1,606	$9.56	$5.70
4	CTs – Simple Cycle	1 x H-Class	419	9,142	$836	$6.87	$1.24/ MWh, $23,100/ Start

- Assume 15% annual carrying charge (cost of capital & depreciation)
- If combustion turbine (CT) runs 1 hour per year, its total cost/kWh = $836*0.15 + $6.87 + $0.0124 = $132/kW = $132,000/MWh
- RTO/ISO markets typically have an offer cap of $1,000/MWh or $2,000/MWh



US EIA, January 2024 https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2025.pdf

CAPACITY MARKET BASICS

- Determine the amount of installed capacity for the region using a resource adequacy model
- Assign a portion to Load Serving Entities (LSEs), usually based on a LSE's % of peak load
- LSE's must procure enough ICAP to satisfy their obligation otherwise pay a deficiency penalty

  LSE's can build or buy ICAP or reduce their peak demand

  LSE's that are short ICAP are required to purchase it from the spot ICAP market

"Competitive Electricity Markets and System Reliability: The Case for New England's Proposed Locational Capacity Market" J. Farr and F. Felder, *The Electricity Journal*, Vol. 18, Number 8, October 2005, pp. 22-33.

"Should Electricity Markets Have A Capacity Requirement: If So, How Should It Be Priced?" A. Jaffe and F. Felder, *The Electricity Journal*, December 1996.

ISSUES WITH CAPACITY MARKETS

- Should there only be energy markets (e.g., ERCOT)?
- Should there be a forward capacity market (FCM)?
- If and how should demand response and energy efficiency be compensated?
- How should transmission constraints be handled?
- How should the capacity values of wind, solar, and energy storage be calculated in capacity markets?
- How should capacity markets be modified to account for severe weather?

"Competitive Electricity Markets and System Reliability: The Case for New England's Proposed Locational Capacity Market" J. Farr and F. Felder, *The Electricity Journal*, Vol. 18, Number 8, October 2005, pp. 22-33.

"Should Electricity Markets Have A Capacity Requirement: If So, How Should It Be Priced?" A. Jaffe and F. Felder, *The Electricity Journal*, December 1996.

WHOLESALE MARKET PRICES (PJM)

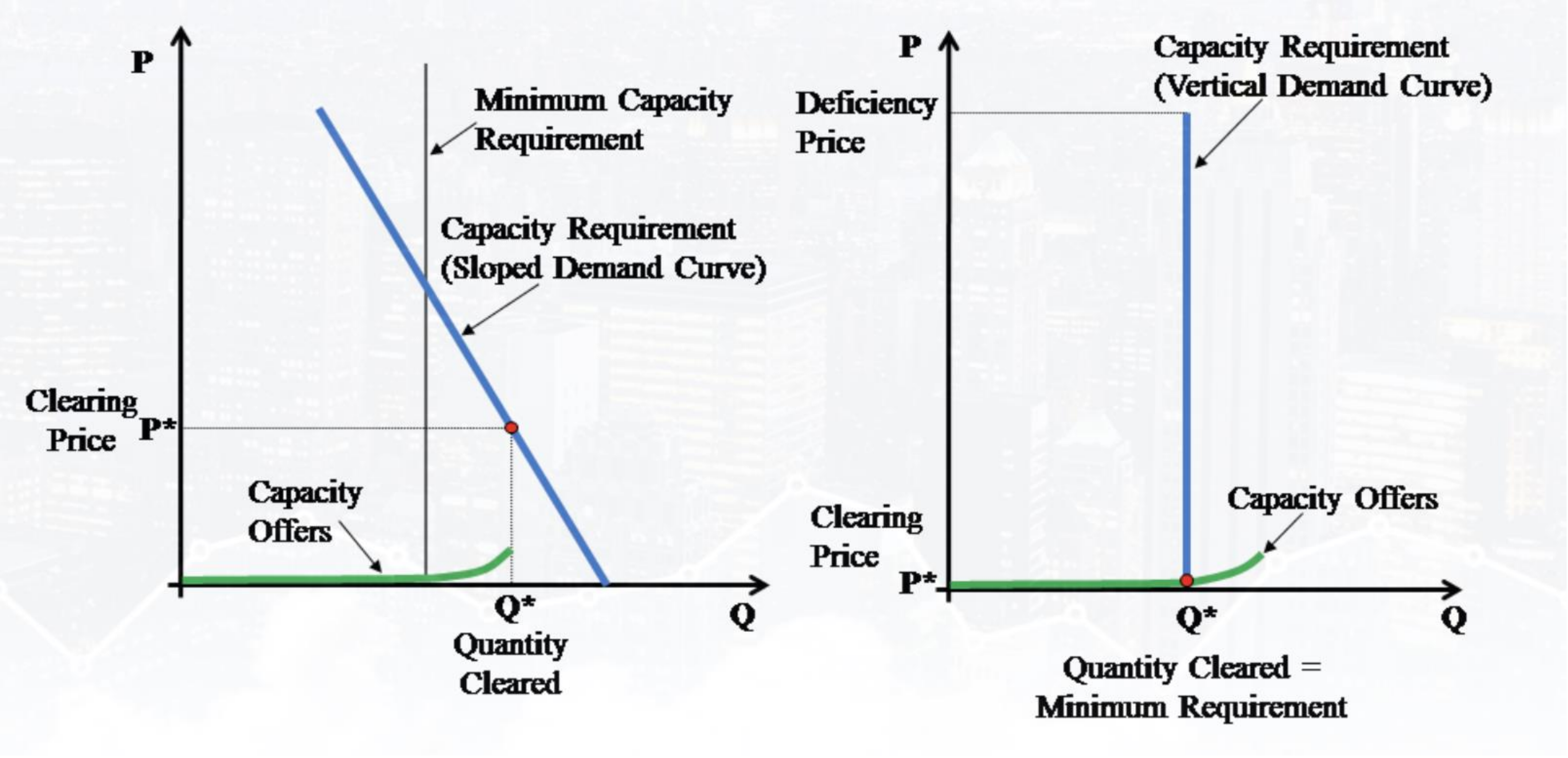
Table 9 Total cost per MWh by category: 2023 and 2024[56 57 58]

Category	2023 $/MWh	2023 ($ Millions)	2023 Percent of Total	2024 $/MWh	2024 ($ Millions)	2024 Percent of Total	Percent Change
Energy	$30.40	$22,956	57.3%	$32.58	$25,549	58.7%	7.2%
Day Ahead Energy	$31.58	$23,847	59.5%	$33.43	$26,215	60.2%	5.8%
Balancing Energy	$0.45	$338	0.8%	$0.57	$444	1.0%	26.6%
ARR Credits	($1.46)	($1,103)	(2.8%)	($1.24)	($971)	(2.2%)	(15.2%)
Self Scheduled FTR Credits	($0.42)	($320)	(0.8%)	($0.53)	($414)	(0.9%)	24.5%
Balancing Congestion	$0.39	$296	0.7%	$0.39	$304	0.7%	(0.9%)
Emergency Energy	$0.00	$0	0.0%	$0.00	$0	0.0%	0.0%
Inadvertent Energy	$0.01	$4	0.0%	$0.01	$9	0.0%	104.8%
Load Response - Energy	$0.01	$6	0.0%	$0.01	$11	0.0%	74.0%
Emergency Load Response	$0.08	$61	0.2%	$0.00	$0	0.0%	(100.0%)
Energy Uplift (Operating Reserves)	$0.21	$156	0.4%	$0.34	$268	0.6%	65.2%
Marginal Loss Surplus Allocation	($0.51)	($385)	(1.0%)	($0.45)	($356)	(0.8%)	(10.9%)
Market to Market Payments	$0.07	$55	0.1%	$0.05	$38	0.1%	(33.3%)
Capacity	$4.63	$3,497	8.7%	$3.65	$2,864	6.6%	(21.1%)
Capacity (Capacity Market and FRR)	$4.53	$3,417	8.5%	$3.56	$2,791	6.4%	(21.3%)
Capacity Part V (RMR)	$0.11	$79	0.2%	$0.08	$65	0.1%	(21.3%)
Load Response - Capacity	$0.00	$0	0.0%	$0.01	$8	0.0%	3,010.6%
Transmission	$16.54	$12,488	31.2%	$17.71	$13,886	31.9%	7.1%
Transmission Service Charges	$14.13	$10,671	26.6%	$15.04	$11,796	27.1%	6.4%
Transmission Enhancement Cost Recovery	$2.32	$1,754	4.4%	$2.57	$2,019	4.6%	10.8%
Transmission Owner (Schedule 1A)	$0.08	$63	0.2%	$0.09	$72	0.2%	10.5%
Transmission Seams Elimination Cost Assignment (SECA)	$0.00	$0	0.0%	$0.00	$0	0.0%	0.0%
Transmission Facility Charges	$0.00	$0	0.0%	$0.00	$0	0.0%	0.0%
Ancillary	$0.89	$670	1.7%	$0.92	$725	1.7%	4.2%
Reactive	$0.52	$389	1.0%	$0.49	$381	0.9%	(5.8%)
Regulation	$0.17	$130	0.3%	$0.23	$183	0.4%	35.7%
Black Start	$0.09	$67	0.2%	$0.09	$74	0.2%	5.7%
Synchronized Reserves	$0.10	$73	0.2%	$0.10	$75	0.2%	(2.1%)
Secondary Reserves	$0.00	$1	0.0%	$0.00	$2	0.0%	76.7%
Non-Synchronized Reserves	$0.01	$9	0.0%	$0.01	$10	0.0%	8.6%
Day Ahead Scheduling Reserve (DASR)	$0.00	$0	0.0%	$0.00	$0	0.0%	0.0%
Administration	$0.62	$465	1.2%	$0.67	$529	1.2%	9.5%
PJM Administrative Fees	$0.57	$428	1.1%	$0.62	$489	1.1%	10.1%
NERC/RFC	$0.04	$31	0.1%	$0.04	$35	0.1%	5.9%
RTO Startup and Expansion	$0.00	$0	0.0%	$0.00	$0	0.0%	0.0%
Other	$0.01	$6	0.0%	$0.01	$5	0.0%	(11.6%)
Total Price	$53.08	$40,076	100.0%	$55.54	$43,554	100.0%	4.6%
Total Day Ahead Load	748,619			775,838			3.6%
Total Balancing Load	(6,433)			(8,345)			29.7%
Total Real Time Load	755,053			784,182			3.9%
Total Cost ($ Billions)	$40.08			$43.55			8.7%

PJM State of the Market, 2025, Table 1-9, Monitoring Analytics

https://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2024/2024-som-pjm-vol1.pdf

NEED FOR DEMAND CURVE IN CAPACITY MARKETS



https://www.potomaceconomics.com/capacity/why-do-capacity-markets-exist

DEMAND CURVE AND COST OF NEW ENTRY (CONE)

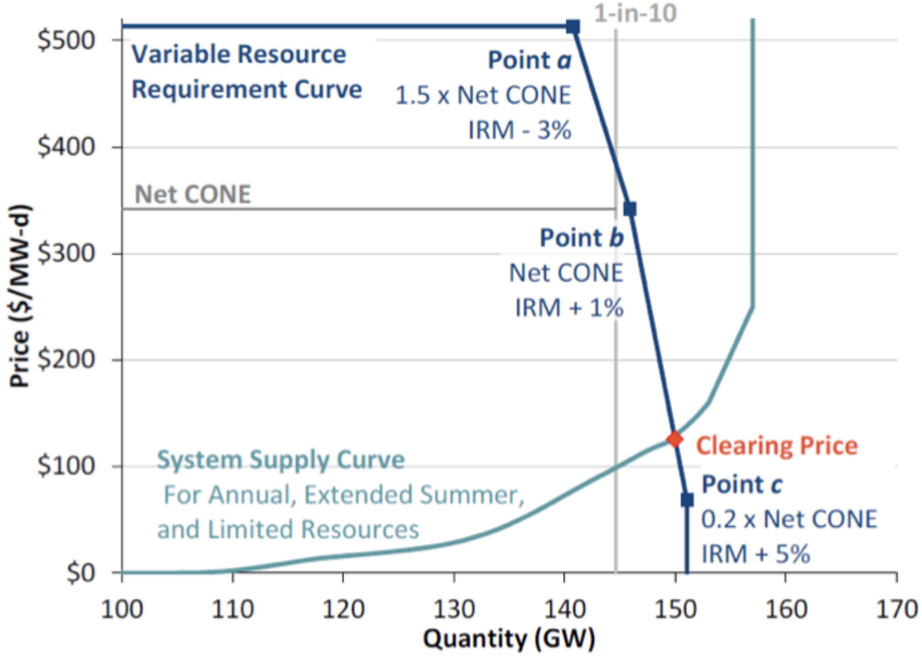


Figure 1. VRR demand curve for PJM used in 2011 for 2014/15 Base Residual Auction

IRM = installed RM; VRR curve reflects the system VRR curve in the 2014/15 PJM Planning Parameters. The supply curve reflects all supply offers for Annual, Extended Summer, and Limited Resources, stacked in order of offer price and smoothed for illustrative purposes.

Source: Figure and notes from Pfeifenberger et al. (2014).

https://www.nrel.gov/docs/fy16osti/65491.pdf

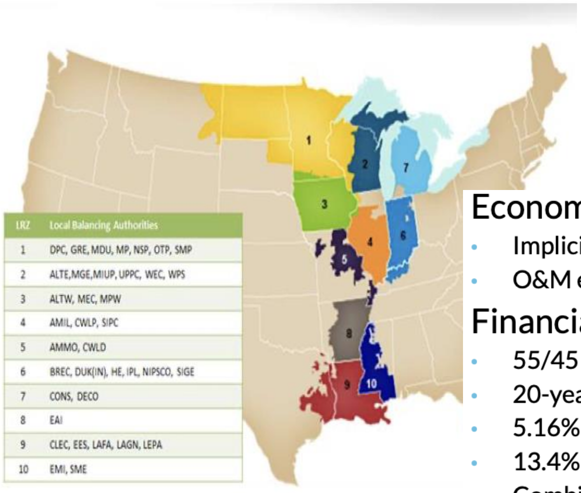
COST OF NEW ENTRY (CONE)

<u>Definition of CONE</u>

An industry term to indicate the current, annualized capital cost of constructing a power plant, typically an advanced combustion turbine (CT).

Net CONE accounts for the profits from the sale of energy and ancillary services by subtracting them from CONE.

ZONE	PY 2023/24 CONE $\$*(MW*yr)^{-1}$	PY 2022/23 CONE $\$*(MW*yr)^{-1}$	PY 2021/22 CONE $\$*(MW*yr)^{-1}$
LRZ 1	$ 104,170	$ 91.270	$ 92,810
LRZ 2	$ 102,240	$ 89,490	$ 90,940
LRZ 3	$ 98,590	$ 86,380	$ 87,310
LRZ 4	$ 102,200	$ 90,300	$ 90,720
LRZ 5	$ 109,580	$ 97,190	$ 97,340
LRZ 6	$ 98,590	$ 89,040	$ 89,120
LRZ 7	$ 105,910	$ 93,770	$ 94,800
LRZ 8	$ 94,890	$ 84,310	$ 84,290
LRZ 9	$ 94,080	$ 83,520	$ 83,600
LRZ10	$ 93,820	$ 83,380	$ 84,420



Economic
- Implicit price deflator
- O&M escalation factor (2.2%)

Financial
- 55/45 debt/equity ratio
- 20-year project/finance life
- 5.16% cost of debt
- 13.4% after tax return on equity
- Combined state and federal effective tax rate of 25-31%

Capital Costs, by Local Resource Zone (EIA)
- See filing, Attachment A

Operation & Maintenance Costs (EIA)

COST OF NEW ENTRY (CONE)

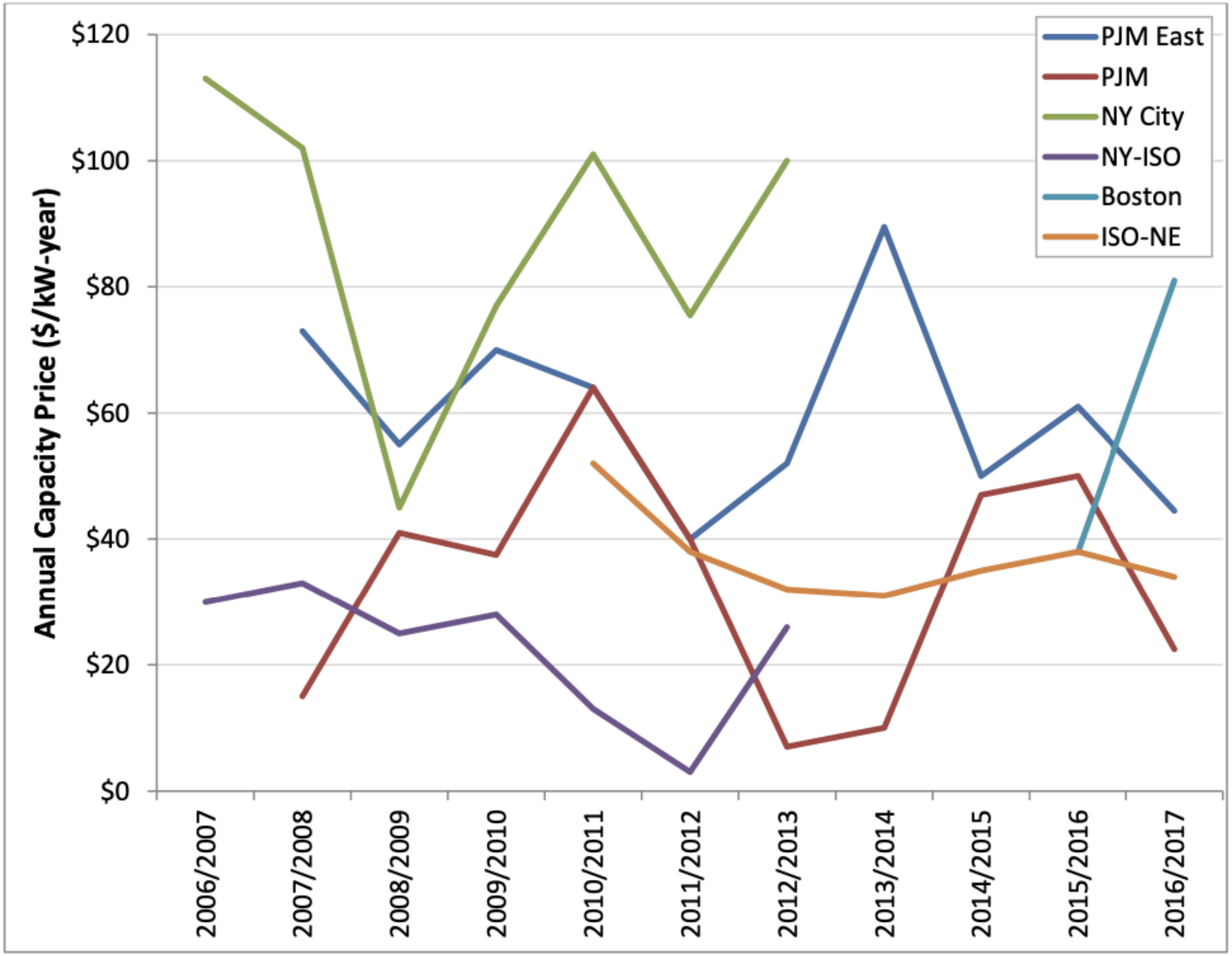


Figure 3. Capacity payments for different RTOs/ISOs and select sub-regions for commitment periods between 2006 and 2017

Source: FERC (2013)

https://www.nrel.gov/docs/fy16osti/65491.pdf

COMPARISON OF RTO/ISO CAPACITY MARKETS

Table 1. Overview of Capacity Markets across U.S. RTOs/ISOs

	PJM	MISO[a]	ISO-NE	NYISO	CAISO[b]
First auction	2007/8	2013/14	2010/11	2006/7	2016
Forward period	3 years	Short term (~ 2 months)	3 years	Short term (~2–30 days)	Short term
Commitment period	1 year	1 year	1 year	6 months or for specific month	N/A
Procurement	▪ Bilateral ▪ Mandatory auction	▪ Bilateral ▪ Voluntary auction	▪ Bilateral ▪ Mandatory auction	▪ Bilateral ▪ Voluntary & mandatory auction	▪ Bilateral ▪ "Back stop" capacity[5] at fixed price

Note: ISO-NE is discussing major reforms to its capacity markets in 2025

https://www.nrel.gov/docs/fy16osti/65491.pdf

DEMAND RESPONSE (DR)

Demand response is the ability of retail customers to respond to wholesale electricity prices

PJM provides for equivalent treatment of generation and demand resources

- Retail customers have the opportunity to participate in energy, capacity, and other markets and receive payments for the demand reductions they make (including the use of backup generation)
- Curtailment Service Providers (CSPs) aggregate the demand of retail customers, register with PJM, submit verification of demand reductions, and receive payment
- DR can participate in the day-ahead or retail energy markets, the capacity market (both DR and energy efficiency), and the synchronized reserve, regulation and day-ahead scheduling reserve markets
- DR gaming of baseline is a concern

MISO proposes demand response rule changes to stem market fraud, gaming

The proposal is in response to Federal Energy Regulatory Commission enforcement actions involving Voltus, Ketchup Caddy, Big River Steel and Linde.

Published March 24, 2025

https://www.utilitydive.com/news/miso-dr-demand-response-rule-ferc-fraud/743275/

CAP [FLOOR] & TRADE

- ICAP aka UCAP: FLOOR & TRADE
  UCAP is unforced capacity, i.e., a unit's availability times its capacity
    e.g., A 100 MW unit with 90% availability can sell 90 MW of UCAP
- PJM's capacity market is called the Reliability Pricing Model (RPM)
- New England's capacity market is a forward capacity market (FCM)
- Renewable Portfolio Standard: FLOOR & TRADE
- Emission Allowance Markets: CAP & TRADE
- These markets for capacity, renewable energy credits and emission permits interact with energy markets
- In addition, production tax credits (PTC) affect marginal costs, which therefore affect energy markets

CAPACITY MARKET DESIGN CHOICES

Design Choice	Description and Rationale	Example
Forward Capacity Market (FCM)	By selling and buying capacity approximately 3 years into the future, increases competition	ISO-New England (ISO-NE) PJM
Zonal Capacity Requirements	Accounts for transmission limits within a market to obtain capacity in needed zonal locations	ISO-NE, PJM,NYISO
Demand Curve	Amount of total capacity purchased varies with price to reflect the declining value of capacity and to reduce capacity price volatitly	ISO-NE, NYISO, PJM
Descending-clock auction	Allows for price discovery while limiting market power	ISO-NE
Reconfiguration Auctions	Multiple auctions to allow for the selling and purchasing of capacity to balance portfolios	ISO-NE, NYISO, PJM

Objectives of Capacity Design Choices:

- Aligns with desired outcomes
- Reduce the exercise of market power
- Reduce potential for mis-pricing errors
- Confidentiality of bids and offers
- Administrative simplicity

TYPES OF AUCTIONS

- Sealed Bid Auction (SBA)
  - "Final and best" bids/offers submitted in advance that are confidential
  - Lowest-bid or highest-offer wins
  - No information is publicly revealed during the process

- Descending Clock Auction (DCA)
  - Price to buy decreases until supply equals demand
  - No round structure
  - Everyone observes when a bidder withdraws

- Hybrid Descending Clock Auction
  - A sealed bid auction with rounds
  - Used by ISO-NE
  - Allows for price discovery

- Vickery Auction/Sealed-bid Second-Price Auction
  - The highest bidder wins but the price paid is the second-highest bid

https://www.iso-ne.com/static-assets/documents/2016/07/20160714-dca-forum.pdf

ISO-NE RECONFIGURATION AUCTIONS

Reconfiguration auctions provide an auction-based mechanism for resources to acquire, increase, or shed all or part of their capacity supply obligations (CSOs) for the entire capacity commitment period (CCP). CSOs may be adjusted through annual reconfiguration auctions (ARAs) or for specific months of the CCP through monthly reconfiguration auctions (MRAs). A resource can adjust its CSO by submitting the following:

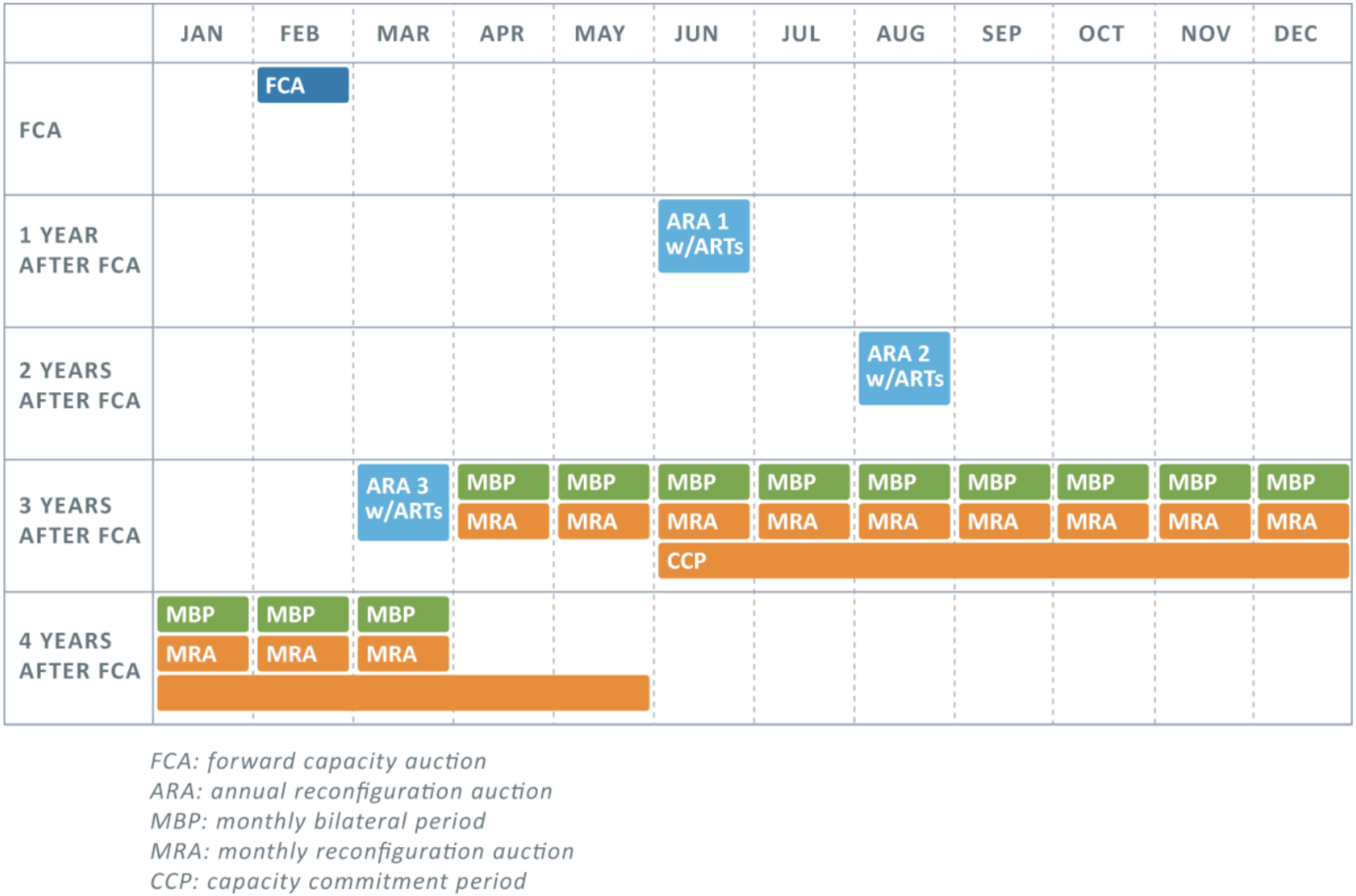
- **Demand bids** to shed all or part of its CSO
- **Supply offers** to increase or acquire a CSO, if its qualified capacity is greater than its current CSO

Unlike CSO bilaterals, no counterparty is needed to participate in a reconfiguration auction.

Additionally, ARAs allow the ISO to procure or release capacity on behalf of load by using sloped demand curves in the auction. The ISO does not participate in MRAs, which do not use sloped demand curves.

https://www.iso-ne.com/markets-operations/markets/forward-capacity-market/fcm-participation-guide/reconfigurations-auctions

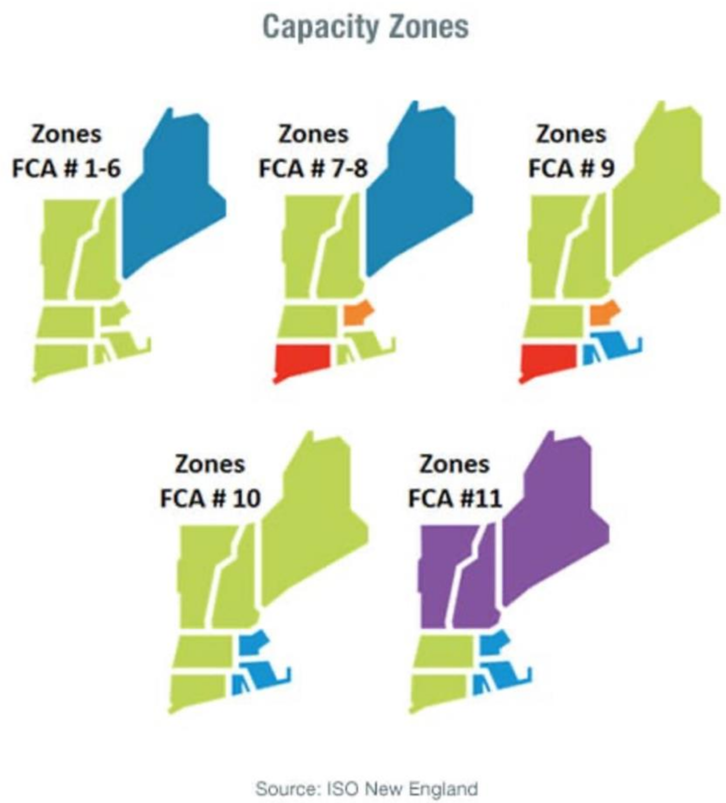
ISO-NE RECONFIGURATION AUCTIONS



https://www.iso-ne.com/markets-operations/markets/forward-capacity-market/fcm-participation-guide/reconfigurations-auctions

ZONAL CAPACITY REGIONS

ISO-NE Capacity Zones



New York Capacity Zones

- New York City
- Long Island
- Rest of State

MISO

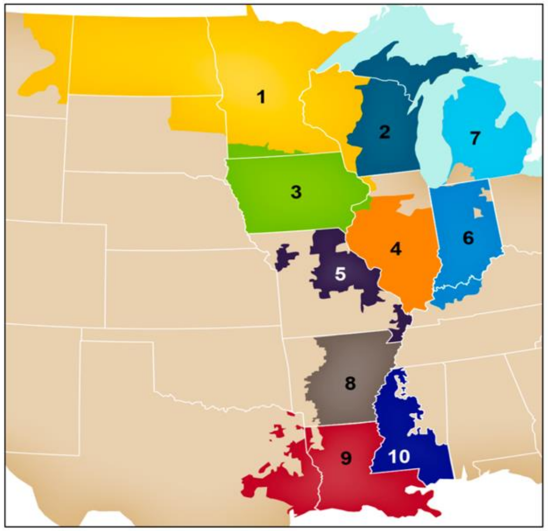


Figure 5: Local Resource Zones Map

https://isonewswire.com/2017/10/30/get-easy-access-to-helpful-iso-ne-maps-and-diagrams-on-new-webpage/

ISO-NE CAPACITY PROCUREMENT

ISO-NE procures capacity supply through a forward capacity market (FCM). The sequence of steps is as follows:

1. **Qualification/Accreditation:** ISO-NE qualifies each resource to offer into the FCM for up to an accredited number of MW, based on its characteristics.
2. **Demand Determination:** ISO-NE conducts a probabilistic study (as described above) to determine the necessary reserve margin; then updates the load forecast to produce an Installed Capacity Requirement (ICR),[6] Net ICR, Local Sourcing Requirements (LSRs), and Maximum Capacity Limits (MCLs) for export-constrained zones. ISO-NE then uses those metrics to construct demand curves known as "Marginal Reliability Impact" curves.
3. **Forward Capacity Auctions (FCAs):** ISO-NE administers its Forward Capacity Auction (FCA) approximately three years before each delivery year. The FCA optimizes the selection of offers (expressed in $/MW-month) against the Marginal Reliability Impact curves to maximize social surplus. Cleared resources take on a capacity supply obligation (CSO) for the capacity commitment period (CCP) and will be paid in that period.
4. **Annual Reconfiguration Auctions (ARAs):** Each subsequent year approaching the delivery year, ISO-NE administers reconfiguration auctions, where suppliers can buy out of their obligations and have them assumed by other suppliers; ISO-NE can also buy or sell capacity to the extent the load forecast changes.[7]
5. **Certification:** Just before each delivery year, committed resources are certified for their readiness to provide capacity.
6. **Capacity Commitment Period (CCP):** Resources with a CSO must offer into the energy and ancillary services markets and must be available during shortages, subject to performance penalties and incentives under ISO-NE's Pay-for-Performance system. Incentives and Penalties are paid at a volumetric ($/MWh) rate[8] for providing energy or ancillary services during shortage events, levied as a penalty for those performing below their obligation or a bonus for those paying above. The obligation is set at the CSO times a balancing ratio, calculated by the ratio of actual load + operating reserve divided by total CSOs outstanding. Thus, resources taking on lower CSOs will be less exposed to penalties and more exposed to upside, although they will have the same performance incentive per MWh either way as long as the performance incentives are fully funded.[9]

<u>Summary</u>

Qualification/Accreditation

Demand Determination

Forward Capacity Auctions

Annual Reconfiguration Auctions

Certification

Capacity Commitment Period

https://www.mass.gov/doc/capacity-resource-accreditation-for-new-englands-clean-energy-transition-report/download

MISO CAPACITY MARKETS

Resource Adequacy

Resource adequacy ensures there is enough available power to meet peak demand at all times. It is a key function of MISO. MISO serves as an intermediary between energy sellers and buyers in its region through the Planning Resource Auction. MISO's resource adequacy construct complements the jurisdiction that regulatory authorities have in determining the necessary level of adequacy. It also works in concert utilities that provide demand forecasts that help drive the development of local and regional requirements. MISO began determining resource adequacy on a seasonal, rather than annual, basis in Fall 2022.

Planning Resource Auction (PRA)

The annual Planning Resource Auction (PRA) demonstrates sufficient resources and allows market participants to sell capacity, via an auction, to other market participants who may expect a shortfall. MISO sets the capacity requirements in its region for each season of the June 1 to May 31 time period.

MISO bases the region's energy needs, including a planning reserve margin, on multiple studies including members' demand forecasts for peak use. It determines the reserve margin from the annual Loss of Load Expectation study. MISO accepts auction offers the last four business days of March, applies constraints calculators, then approves or rejects the transactions within the first 20 business days of April.

https://www.misoenergy.org/planning/resource-adequacy2/resource-adequacy/#t=10&p=0&s=FileName&sd=desc

CAISO CAPACITY CONSTRUCT

The purpose of the resource adequacy program is to ensure the California ISO system has enough capacity to operate the grid reliably. Along with the California ISO and the California Energy Commission (CEC), the California Public Utilities Commission (CPUC) and other local regulatory authorities (LRAs) establish procurement obligations for all load serving entities within their respective jurisdictions.

The bilateral transactions between load serving entities and electricity suppliers that result from resource adequacy requirements provide revenue to compensate the fixed costs of existing generators. The resource adequacy program includes California ISO tariff requirements that work in conjunction with requirements and processes adopted by the CPUC and other local regulatory authorities.

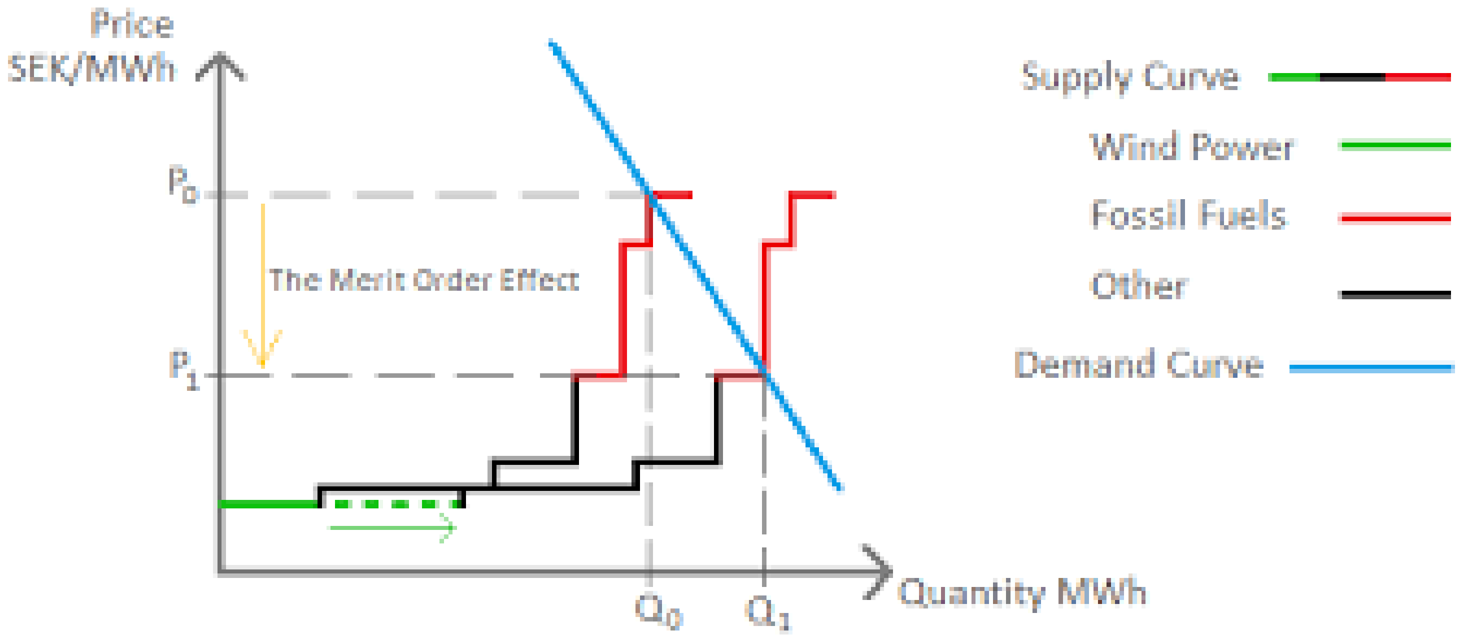
The resource adequacy program includes procurement requirements for three types of capacity:

1. System resource capacity for reliability during system-level peak demand;
2. Local resource capacity for reliability in specific areas with limited import capability; and
3. Flexible resource capacity for reliability during ramping periods.

Load serving entities make filings to the California ISO to demonstrate they have procured enough capacity to fulfill their obligations for all three types of resource adequacy. Once established in a supply plan, entities must make capacity available to the California ISO market according to rules that depend on requirement and resource type.

https://www.caiso.com/documents/2022-annual-report-on-market-issues-and-performance-jul-11-2023.pdf, p. 214

CAPACITY MARKETS AND ENERGY PRICES



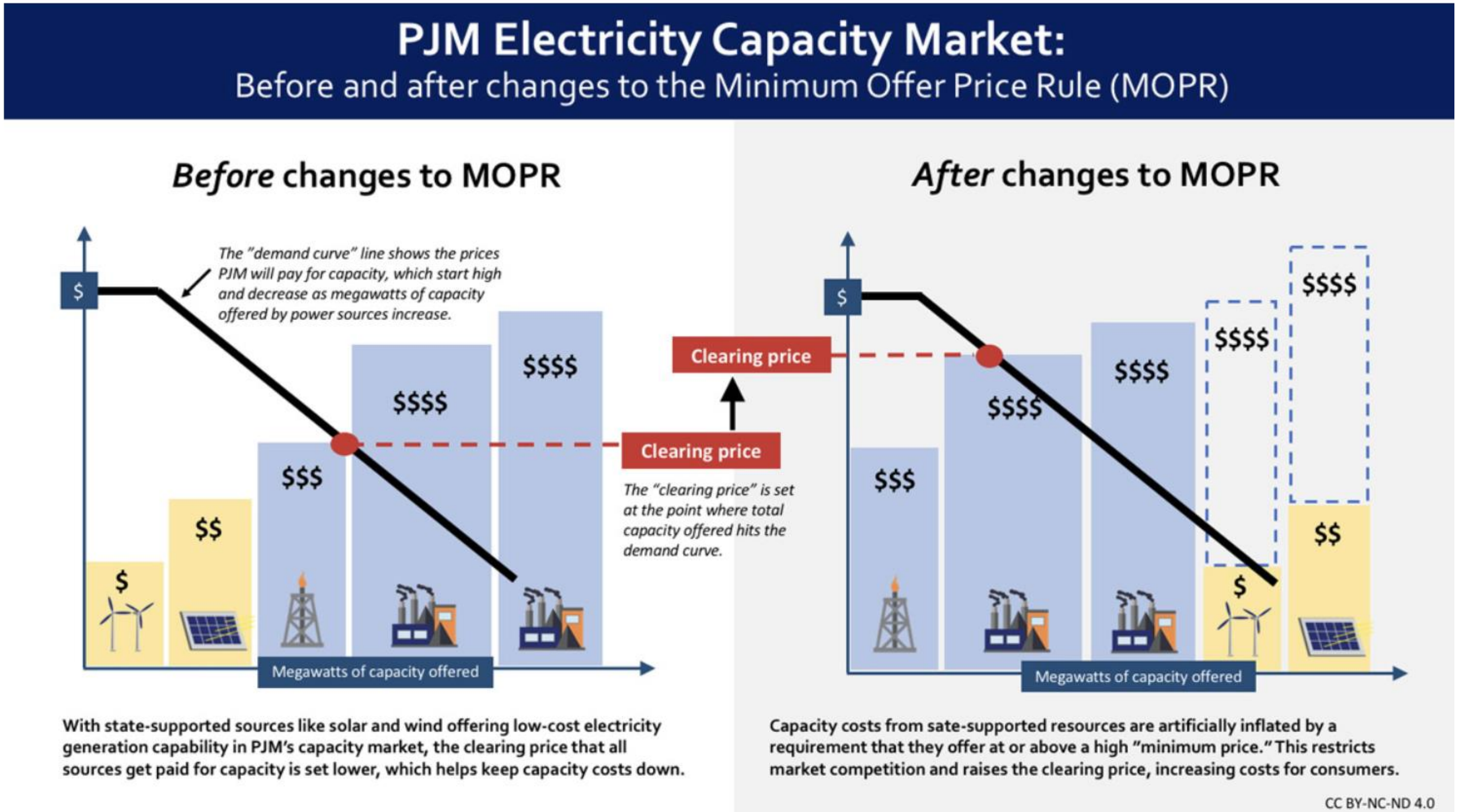
MINIMUM OFFER PRICING RULE (MOPR)

- Intended to ensure that capacity sellers who are net buyers of capacity cannot exercise buyer-side market power by offering capacity at an artificially low price
- Applied to natural gas units whose revenues were guaranteed by states, i.e., resources that receive state subsidies
- Also applied to state-subsidized renewable and nuclear resources
- FERC has adopted a "focused MOPR"

https://www.resources.org/common-resources/three-insights-from-the-debate-over-minimum-offer-price-rules-in-electricity-markets/

https://pjm.com/-/media/committees-groups/cifp-mopr/2021/20210630/20210630-cifp-mopr-pjm-proposal.ashx

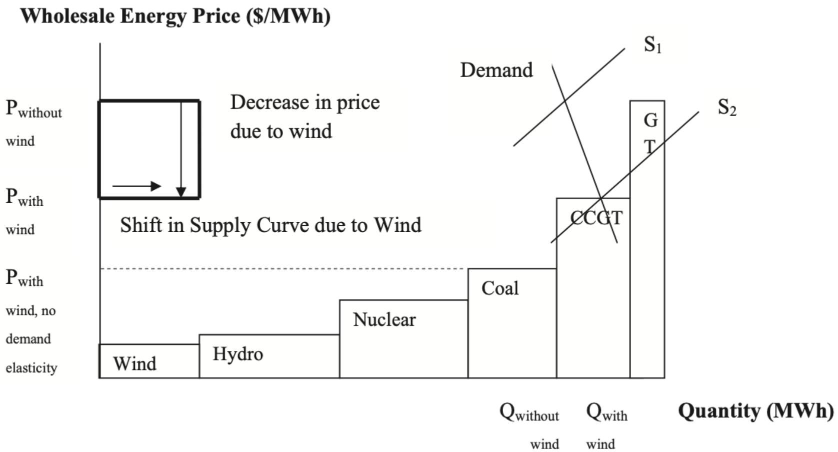
MINIMUM OFFER PRICING RULE



Note: This slide is from 2019; FERC has since revised MOPRs

https://www.sierraclub.org/articles/2019/08/ferc-order-could-cost-pjm-consumers-billions-and-set-back-state-clean-energy

PRICE SUPPRESSION EFFECT



Note: CCGT denotes natural gas firedcombined-cycle gas turbine; GT denotes gas turbine.

Figure 5: Illustration of Price Suppression Transfer Payment Adjusted for the Capacity of the Resource (Definition 3)

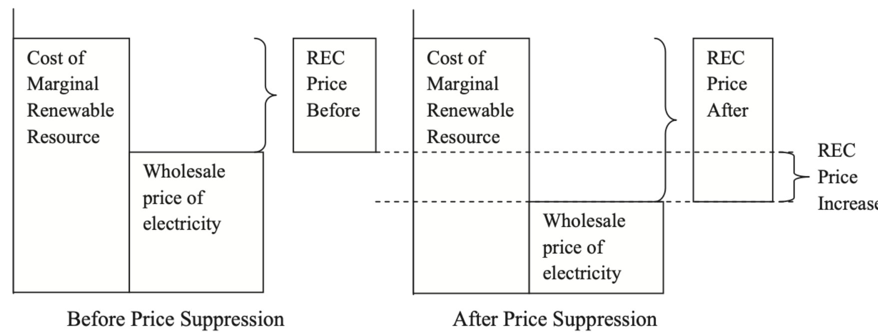
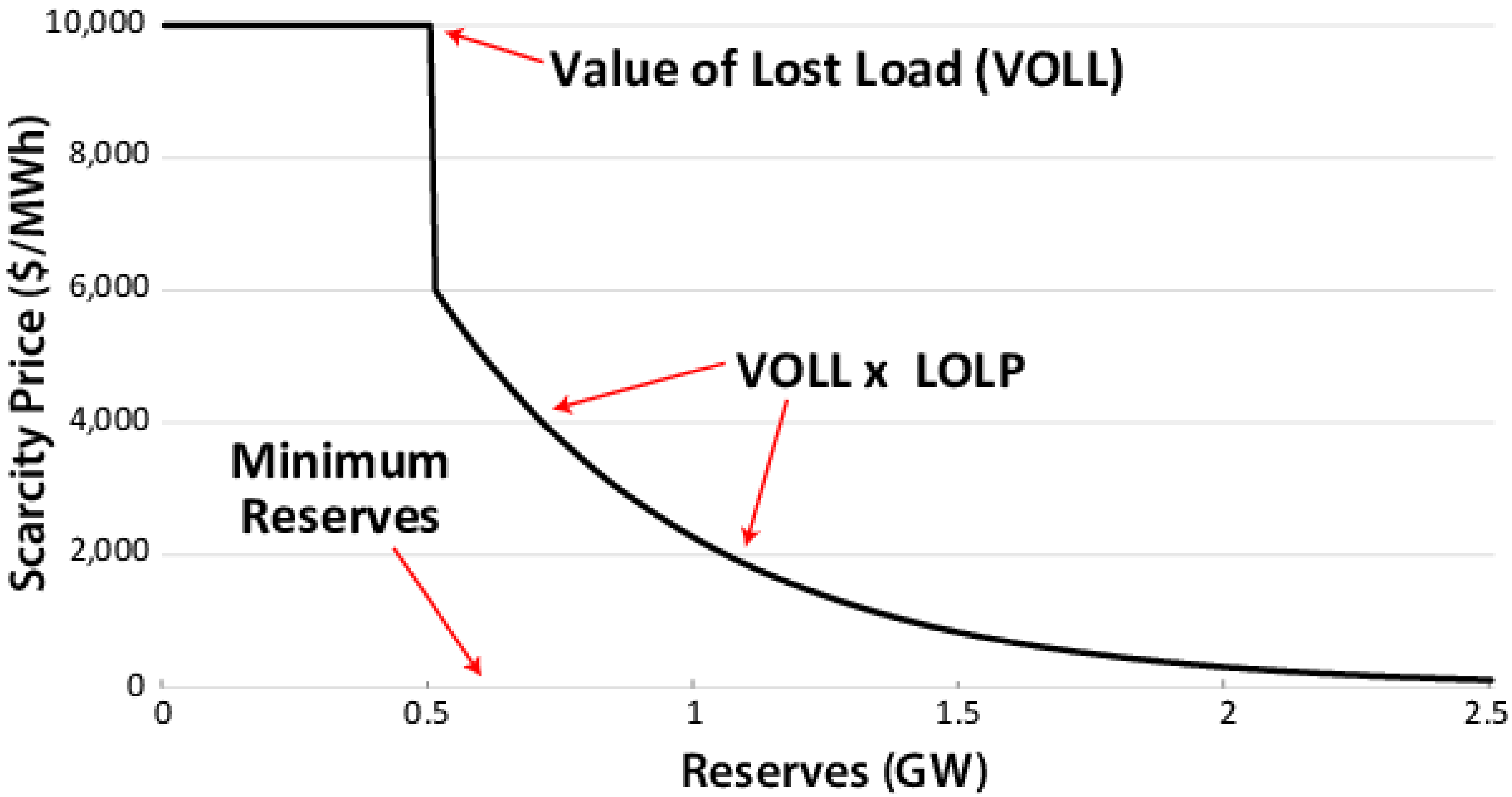


Figure 6: The REC Price-Impression Effect Due to Wholesale Energy Price Suppression

Felder, Frank A. "Examining electricity price suppression due to renewable resources and other grid investments." *The Electricity Journal* 24.4 (2011): 34-46.

OPERATING RESERVE DEMAND CURVE (ORDC)



3. Emerging Issues with Capacity Markets

RESOURCE ADEQUACY EMERGING ISSUES

- Extreme weather, both hot and cold
- Weather-dependent renewables
- Effective load carrying capability (ELCC)
- Chronological modeling of energy storage
- Resource adequacy requirement, mean and variance
- Dependent failures
- Economic incentives

EMERGING CHALLENGES WITH TRADITIONAL RESOURCE ADEQUACY ASSESSMENTS

Traditionally, RA assessments …	**Emerging challenge …**
Resources are predominantly **dispatchable**	Resources are becoming predominantly **non-dispatchable** (variable renewable resources, VRE)
The present state of most dispatchable resources **does not depend significantly on the past** and does not require chronological simulation	The present state of storage and load flexibility **resources depends on past states** and requires chronological simulation
Describe the system's high-risk conditions during the **peak demand** hour or a few top hours reasonably well	The system's high-risk conditions **may not occur during peak demand periods**, but during other hours in the year
Characterize stress conditions using **historical data**	Increases in extreme weather events, VRE adoption, and impending electrification of end uses makes **historical data less relevant** and creates challenges related to how to characterize possible reliability and resilience events
Assume that **outage events are uncorrelated** with each other and occur randomly	Evidence shows **high correlations of failures** within a class of power system assets and across infrastructure systems (e.g. natural gas and electricity)

https://live-etabiblio.pantheonsite.io/sites/default/files/ra_project_-_final.pdf

ROLE OF DEPENDENT FAILURES

- Historically, resource adequacy (RA) has been based upon independent failures of generation units
- In highly reliable systems (in general and electric power systems in particular), causes of system failures (e.g., power outages) are due to dependent failures
- Other names include common-cause failures and correlated failures
- Empirically, this is the case with electric power systems

OUTAGE RATES VARY WITH TEMPERATURE

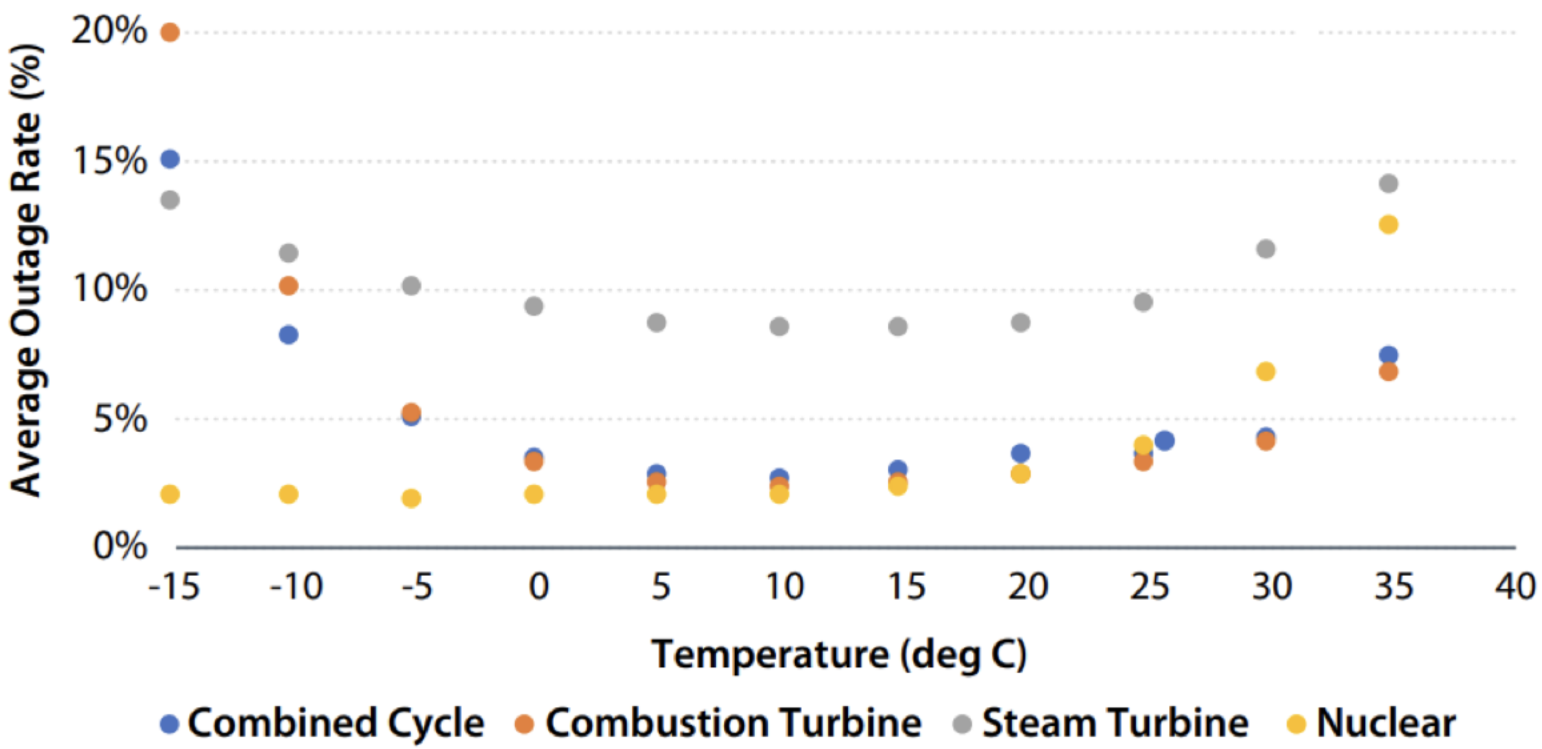
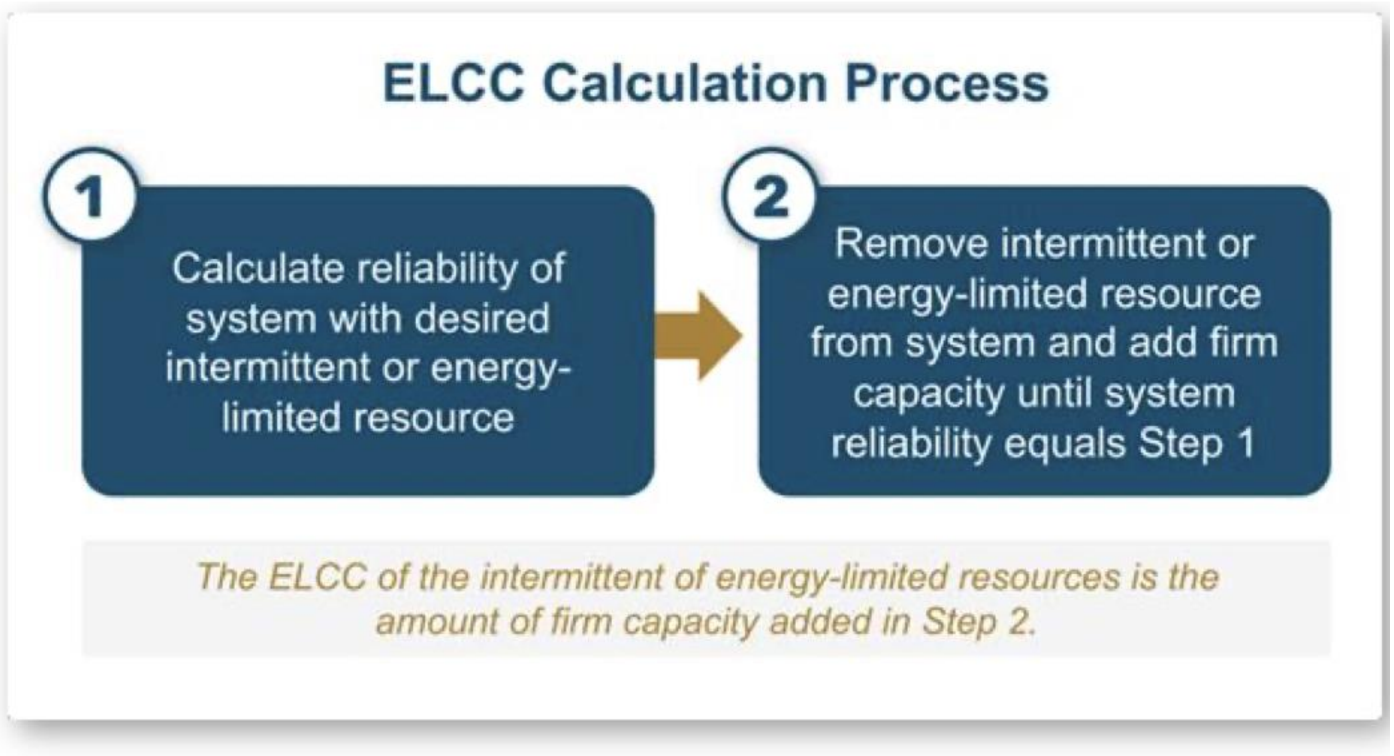


Figure 2. Historical outage rates for fossil and nuclear power plants as a function of temperature.[20]

https://www.energy.gov/sites/default/files/2024-04/2024%20The%20Future%20of%20Resource%20Adequacy%20Report.pdf

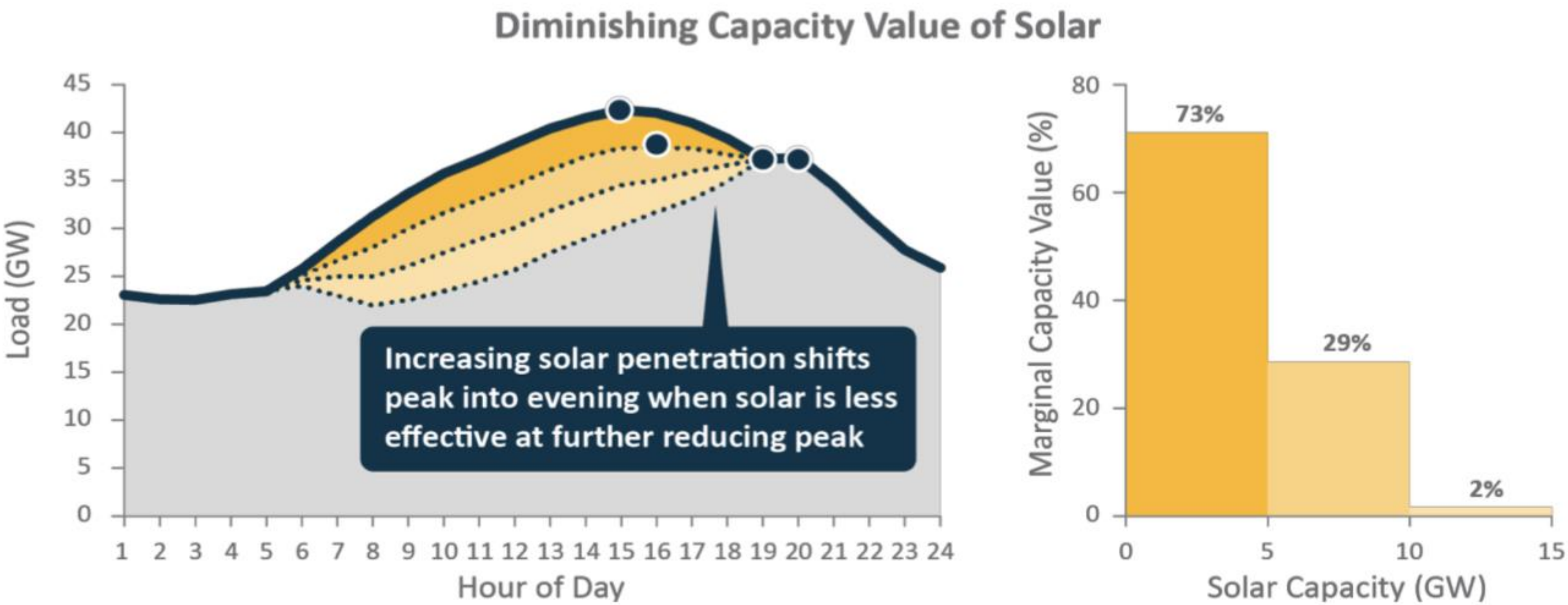
EFFECTIVE LOAD CARRYING CAPABILITY (ELCC)

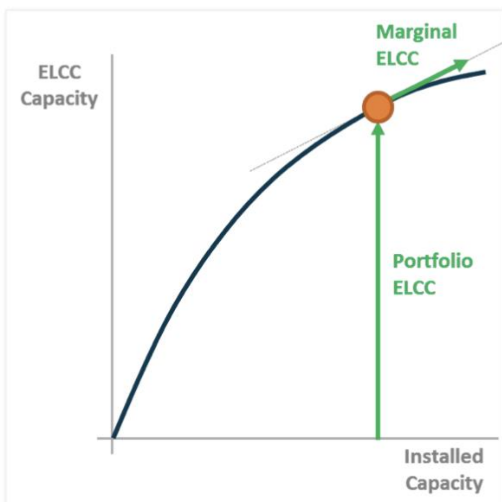
- Definition
  - A measurement of a resource's ability to produce energy when the grid is most likely to experience electricity shortfalls



https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf

ELCC: SOLAR EXAMPLE





https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf

RAPID INCREASE IN U.S. BATTERY INSTALLATIONS

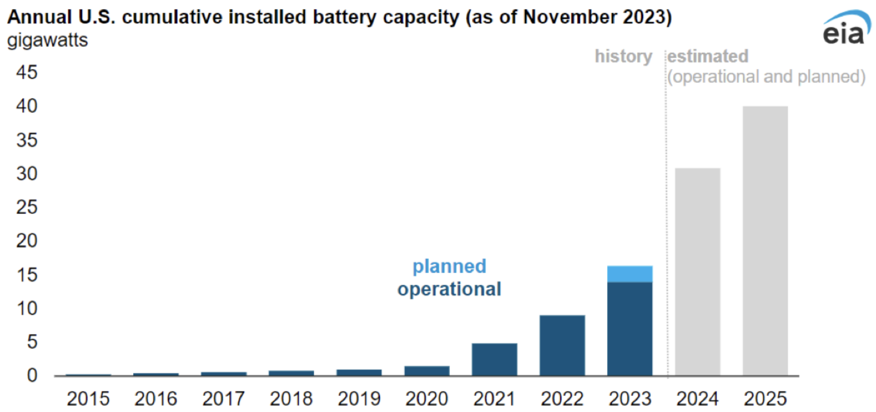
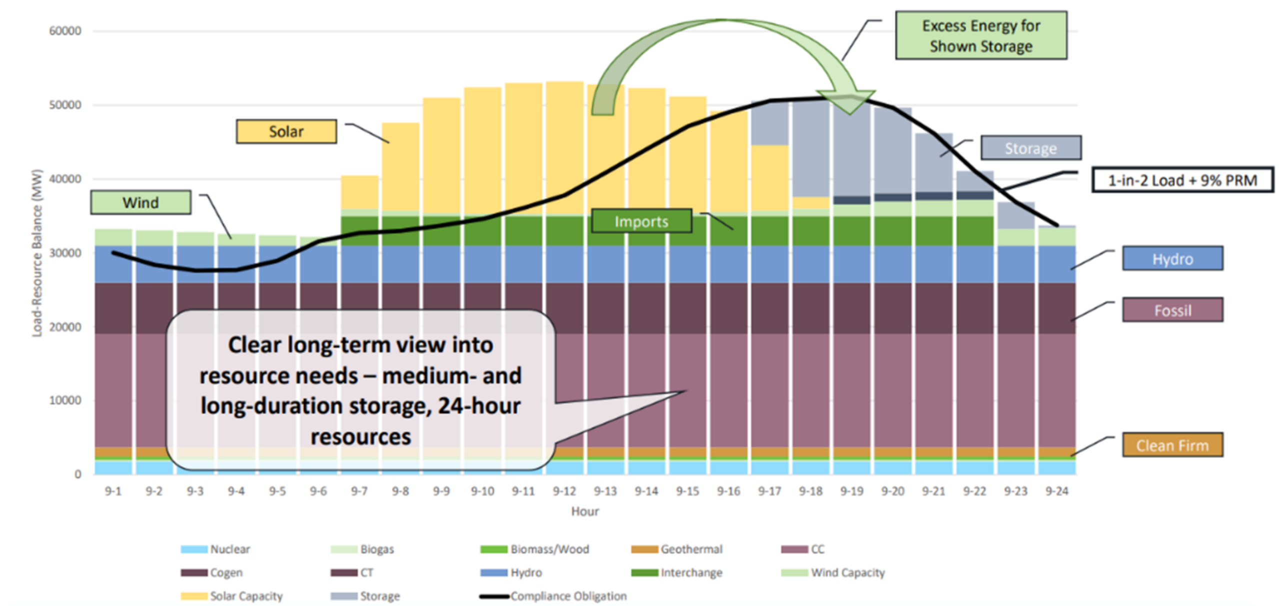


Figure 3. Total power sector battery capacity historical and projected through 2025. Battery capacity is projected to more than double by 2025 representing rapid deployment of storage and its growing potential to contribute to meeting resource adequacy needs.[46]



https://www.energy.gov/sites/default/files/2024-04/2024%20The%20Future%20of%20Resource%20Adequacy%20Report.pdf

READING THE RELIABILITY TEA LEAVES

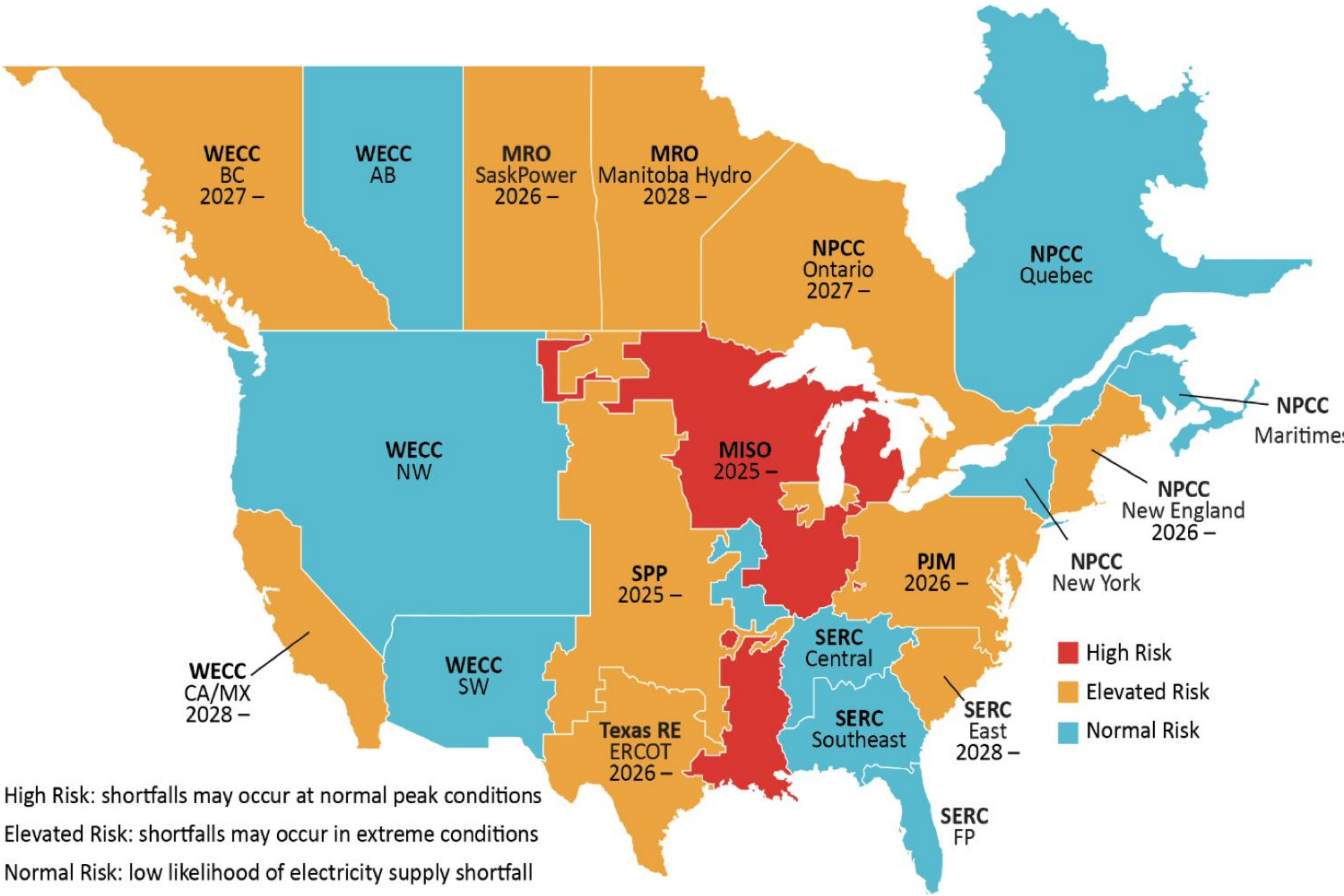


Figure 1: Risk Area Summary 2025–2029

https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_Long%20Term%20Reliability%20Assessment_2024.pdf

COURSE WRAP UP

Remaining Capacity Market Issues:

- Should there be capacity markets?
- If so, what should be their key design features?
- How to accommodate variable and intermittent resources and energy storage?
- How to improve resource adequacy models to accommodate common cause and dependent failures?

Please contact me at any time if you have questions, comments or want more information

THE END IS HERE

KNOWLEDGE SELF-CHECK

1. What are the different rationales for capacity markets?
2. What are the basic elements of capacity markets?
3. How is the capacity of a generation unit determined?
4. What is effective forced outage rate?
5. How do capacity markets handle transmission limitations?
6. How do capacity markets handle demand response?
7. What is effective load carrying capability and why is it important?
8. What are the implications of energy limited resources such as some hydro and energy storage in capacity markets?
9. What is meant by independent failures vs dependent failures/correlated failures/common-cause failures and what are some examples?

TERMINOLOGY AND ABBREVIATIONS CHECK

CONE
DR
EFOR
ELCC
EUE
FCM
Installed Capacity
LOLE and LOLP
Merit Order Effect

N-1
One ‘time’ in ten years
ORDC
Reconfiguration Auctions
Reliability
Resource Adequacy
RPM
Security
UCAP

More Information and Resources

MORE INFORMATION

Key Legal References and Documents

Key FERC documents regarding electricity markets are available at http://www.ferc.gov/docs-filing/docs-filing.asp

Other General Sources that Cover Capacity Markets

Harvard Electricity Policy Group: http://www.hks.harvard.edu/hepg/

The Electricity Journal: http://www.journals.elsevier.com/the-electricity-journal/

Steven Stoft, Power System Economics: Designing Markets for Electricity

ISO-NE: https://www.iso-ne.com/about/what-we-do/in-depth/capacity-vs-energy-primer

NYISO Capacity Manual, https://www.nyiso.com/documents/20142/2923301/icap_mnl.pdf/234db95c-9a91-66fe-7306-2900ef905338

MORE INFORMATION

Books, Reports, and Papers Related to Capacity Markets

Aagaard, T. S., & Kleit, A. N. (2022). *Electricity capacity markets*. Cambridge University Press.

Cramton, P., & Stoft, S. (2005). A capacity market that makes sense. *The Electricity Journal*, *18*(7), 43-54.

Jaffe, A. B., & Felder, F. A. (1996). Should electricity markets have a capacity requirement? If so, how should it be priced?. *The electricity journal*, *9*(10), 52-60.

National Energy Technology Laboratory (2019). Power Market Primer. Chapters 4-5. https://www.netl.doe.gov/projects/files/Power%20Market%20Primers%20Rev%2001.pdf

Forward Capacity Auction Formats, ISO-NE, July 2016, https://www.iso-ne.com/static-assets/documents/2016/07/20160711-dca-v-sealed-bid.pdf

Websites

ISO-NE: https://www.iso-ne.com/markets-operations/markets/forward-capacity-market

MISO: https://www.misoenergy.org/planning/resource-adequacy2/resource-adequacy/#t=10&p=0&s=FileName&sd=desc

PJM: https://www.pjm.com/markets-and-operations/rpm

MORE INFORMATION

General Books

Conspiracy of Fools: A True Story, Kurt Eichenwald, 2005, Broadway Books (about Enron)

Electric Universe: The Shocking True Story of Electricity, David Bodanis, 2005, Crown Publishers

Electricity Restructuring in the United States: Markets and Policy from the 1978 Energy Act to the Present, Steve Isser, 2015, Cambridge University Press

Market Power and Market Manipulation in Energy Markets: From the California Crisis to the Present, Gary Taylor, Shaun Ledgerwood, Romkaew Broehm, and Peter Fox-Penner, 2015, Public Utilities Reports