Resource Adequacy and Storage in High VRE Penetration Systems

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November 17, 2020

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Changing context in many countries

Context of the 1990s and early 2000s

- Policy : Focus on competition and market integration
- Market: Focus on day ahead wholesale market integration
- Technology: dominance of variable costs technologies ('dash for gas')
- Consumers: passive in absence of enabling decentralised technologies (decentralised generation, storage, DSR, etc.)
- Networks: focus on optimisation of the use of existing infrastructure

Current context

- Policy : focus on decarbonization and security of supply
- Market: focus turning to intra day and real time markets to integrate variable renewables
- Technology: dominance of fixed costs (CAPEX) / decentralised technologies
- Consumers: rise of prosumers require rethink of articulation of retail and wholesale markets
- Networks: Need to reinvest to adapt / upgrade grid to decentralised generation and growth of RES in some locations

- **Current EU wholesale 'Target Model' was designed in a different policy, market and technology context …**
  … and needs to evolve to provide adequate price signals for the power system decarbonization

Fabien Roques 2019

What is Resource Adequacy?

- This is a term traditionally used in the U.S. to reflect the generating resources necessary to balance supply and demand with a very low probability that a generation supply deficiency will lead to involuntary curtailments of load.
  - Reflects System reliability criterion
  - Standard of one loss of firm load every ten years is common in the U.S.
  - Translated into a planning/forecast reserve margin
  - Forecast future peak demand and associated uncertainties, calculate generating capacity and demand response required to meet peak demand consistent with reliability criteria, and evaluate future generation needed to meet capacity and demand response targets
  - Some variant of this process is used everywhere in the U.S. except (at least directly) in ERCOT (most of Texas)
- In Europe this is referred to as “Security of Supply”
- Many countries and several U.S. states have also set aggressive decarbonization goals (e.g. 100% carbon free by 2050) that are often not consistent with carbon mitigation incentives (e.g. carbon prices)
  - Supplemental mechanisms required to push system to meet decarbonization constraints
- How do we harmonize reliability and decarbonization goals?

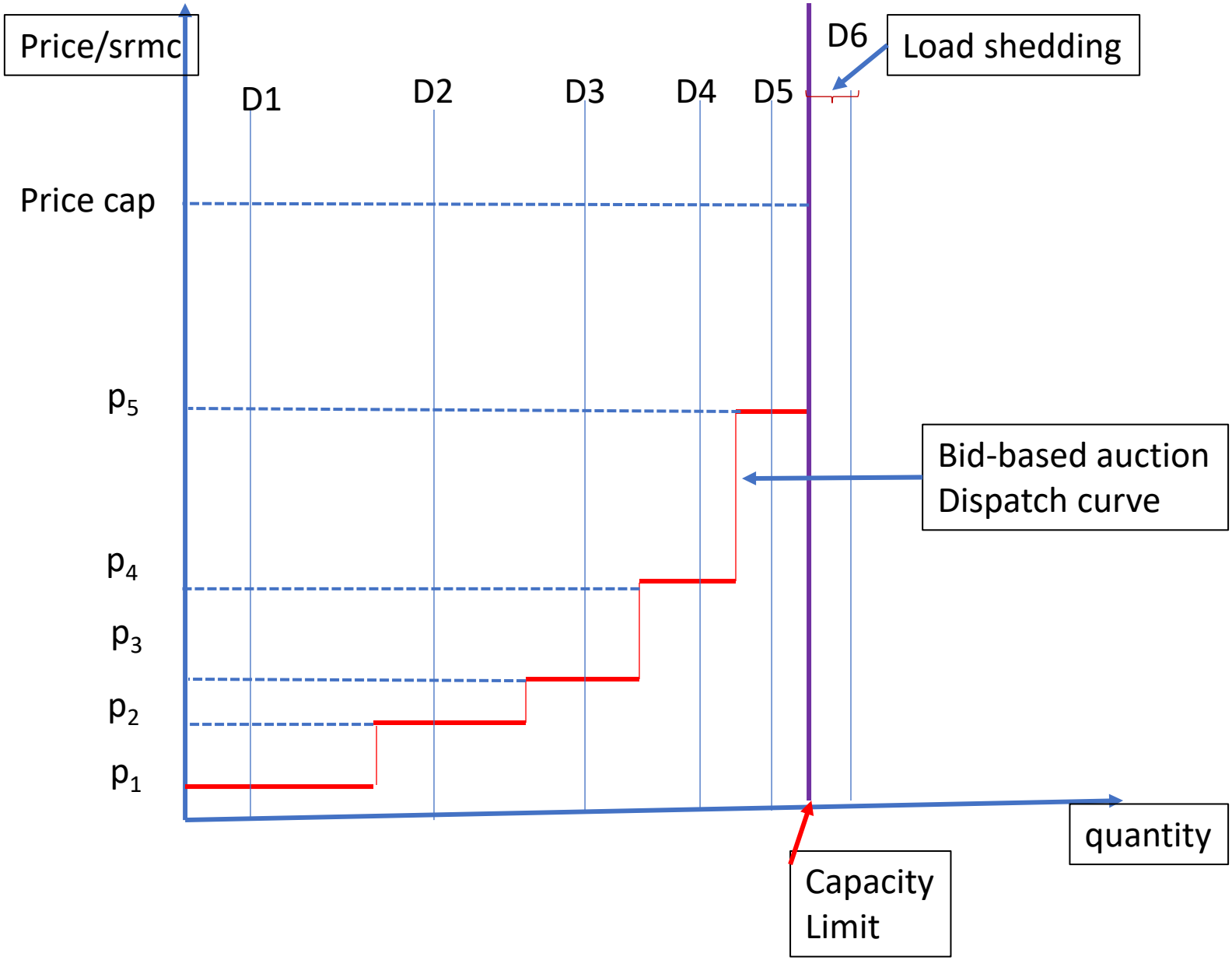
Alternative Approaches to RA Responsibility

- Place RA Responsibility on Load Serving Entities (bundled or unbundled/retail choice)
  - Ownership of generating capacity and/or LT PPAs
  - California and most areas without retail choice
    - Distribution utilities + CCAs
  - Variations in mix of contracts and ownership
- Forecast Capacity Needs for ISO area to meet RA requirement given peak demand and supply forecasts and associated uncertainties to specify forward demand for capacity to meet reliability criteria and a forward capacity market to award and price capacity
  - ISO New England
  - New York ISO
  - PJM
  - MISO
  - E&W
- "Energy-only market" that relies on "scarcity pricing" during certain "stressed" operating reserve contingencies using an administrative ORDC with price cap reflecting VOLL (ERCOT now USD9,000/MWh), LOLP, Duration
  - ERCOT (Texas)
- Energy-only market without ORDC
  - Australia (AUD 15,000)
  - Alberta (CAD 1,000 price cap)

Regardless of Approach the Analytical Issues Have Traditionally Been Fairly Similar

- Procedures developed initially for systems with primarily dispatchable fossil and nuclear generating capacity
  - "static" generation dispatch curve given generating capacity mix
  - Variable demand (hourly, daily, seasonal)
  - Inelastic demand not responsive to short run price variations
- Forecast peak demand for up to ten years and uncertainties around these forecasts
- Choose reliability criteria and target reserve margin(s) --- annual, seasonal, monthly
  - LOLP
  - ERCOT uses estimate of VOLL ($9,000/MWh) to position ORDC
  - Reserve margins typically selected imply that the implicit value of VOLL elsewhere is very high
- Forecast generation supplies, demand response, and associated uncertainties needed to meet target reliability criteria (reserve margins)
- Use the forecasts of generation supplies and demand response needed to define generation/demand response need to meet reliability criterion with high probability at times of highest load
- In states/countries where RA is placed on the LSEs this defines their generation and demand response obligations, often reflected in an IRP, and requiring some combination of ownership and PPAs
- In ISOs with centralized capacity markets this process defines the target demand for capacity and demand response reflect as a "demand for capacity" curve in the capacity market
- ERCOT ORDC is derived from first principles (LOLP, VOLL, unnerved energy, duration, etc.) rather than a crude reserve margin or LOLP target

Traditional dispatchable generation



Reserve Margins and Loss of Load

Detailed Reliability Metrics across Planning Reserve Margins in Base Case

Reserve Margin (%)	Total Annual Loss of Load			Average Outage Event		
	LOLE (events/yr)	LOLH (hours/yr)	EUE (MWh)	Duration (hours)	Energy Lost (MWh)	Depth (MW)
6.0%	2.51	7.99	16,402	3.18	6,531	2,053
7.9%	1.36	4.02	7,555	2.95	5,555	1,882
8.9%	0.91	2.62	4,750	2.88	5,214	1,811
9.8%	0.64	1.77	3,020	2.76	4,719	1,709
10.8%	0.44	1.19	1,921	2.68	4,323	1,614
11.8%	0.29	0.74	1,145	2.56	3,938	1,541
12.7%	0.18	0.46	664	2.49	3,592	1,445
13.7%	0.12	0.28	370	2.38	3,186	1,339
14.6%	0.08	0.18	229	2.26	2,939	1,300
15.6%	0.04	0.08	97	2.14	2,517	1,174
17.5%	0.01	0.03	29	2.00	2,142	1,069

Notes:
Table reflects reliability outcomes under our Base Case assumptions (3-Year Forward LFE, 2011 Weather at 1% Probability).

Source: Estimating the Economically Optimal Reserve Margin in ERCOT, ERCOT (2014)

ISO-New England System-wide Demand Curve For Capacity

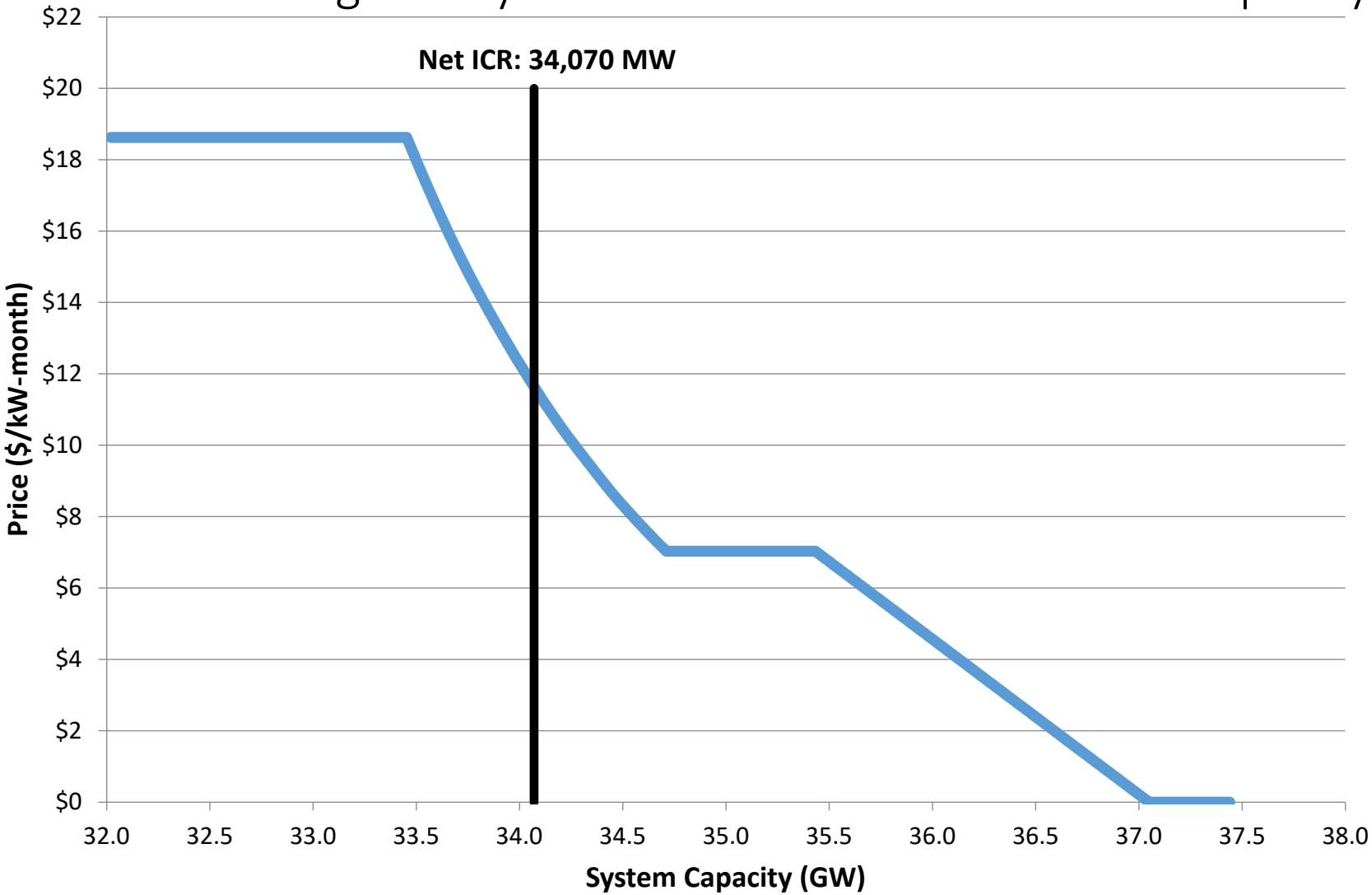
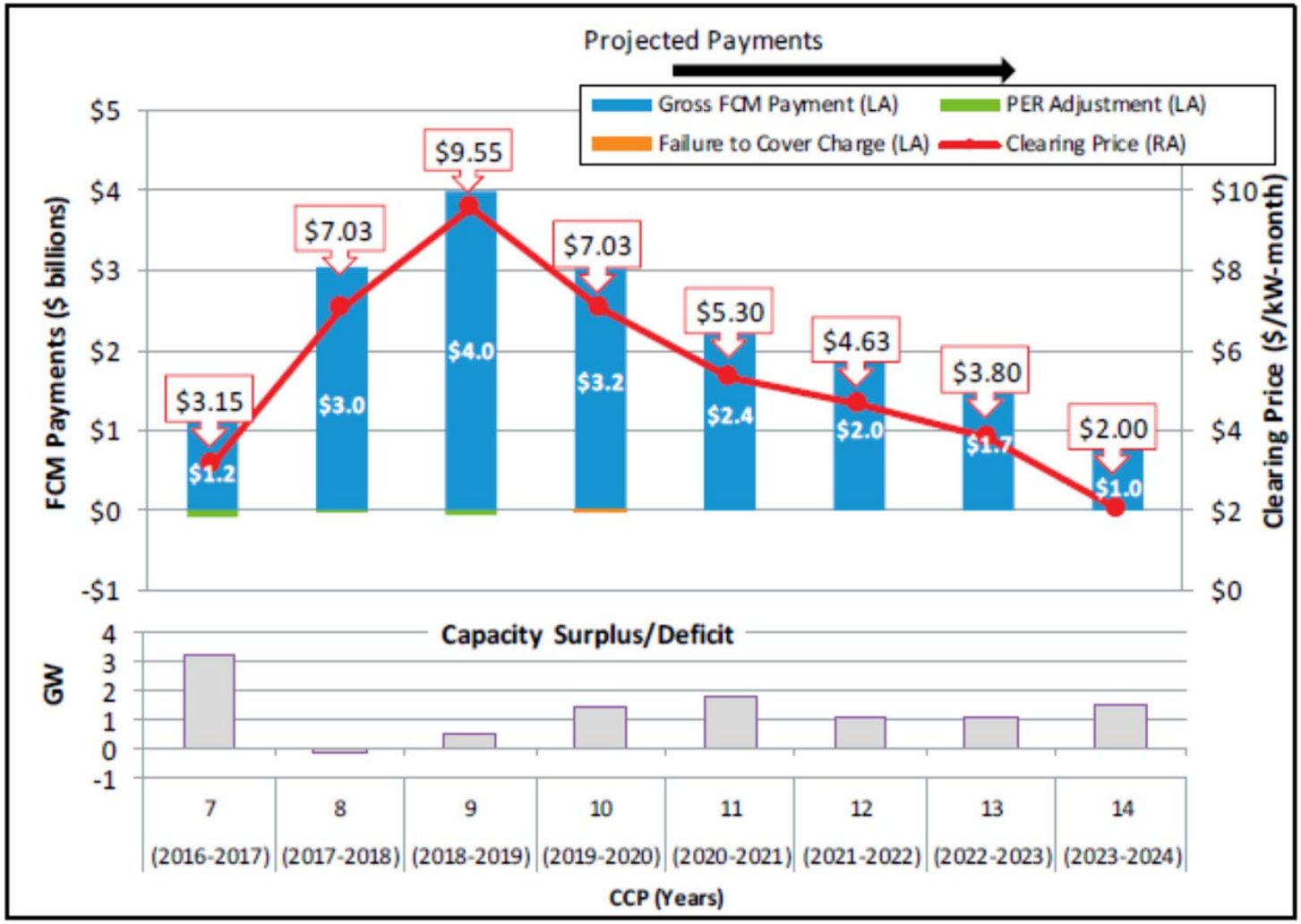
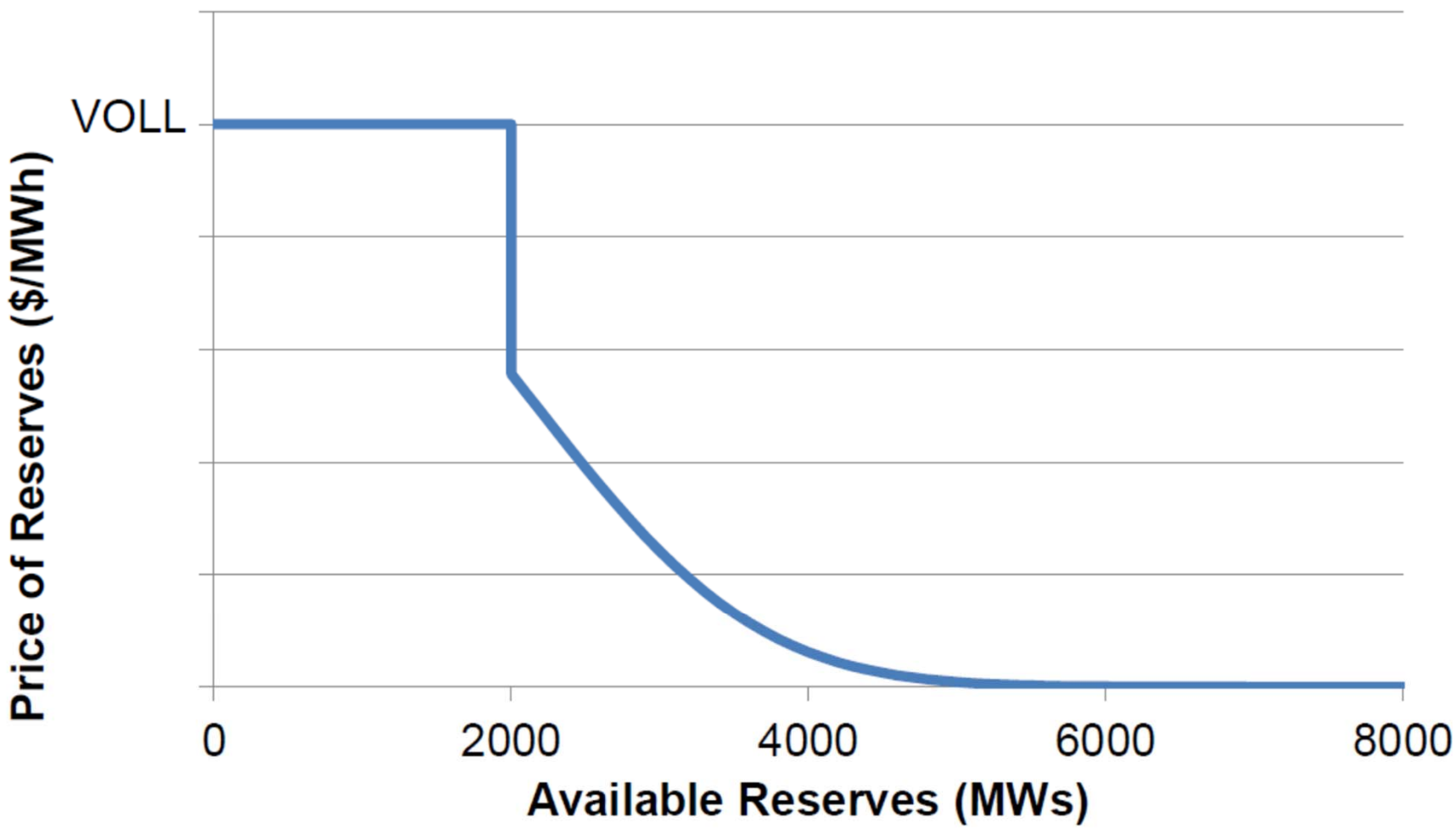


Figure 1-9: FCM Payments and Capacity Surplus by Commitment Period

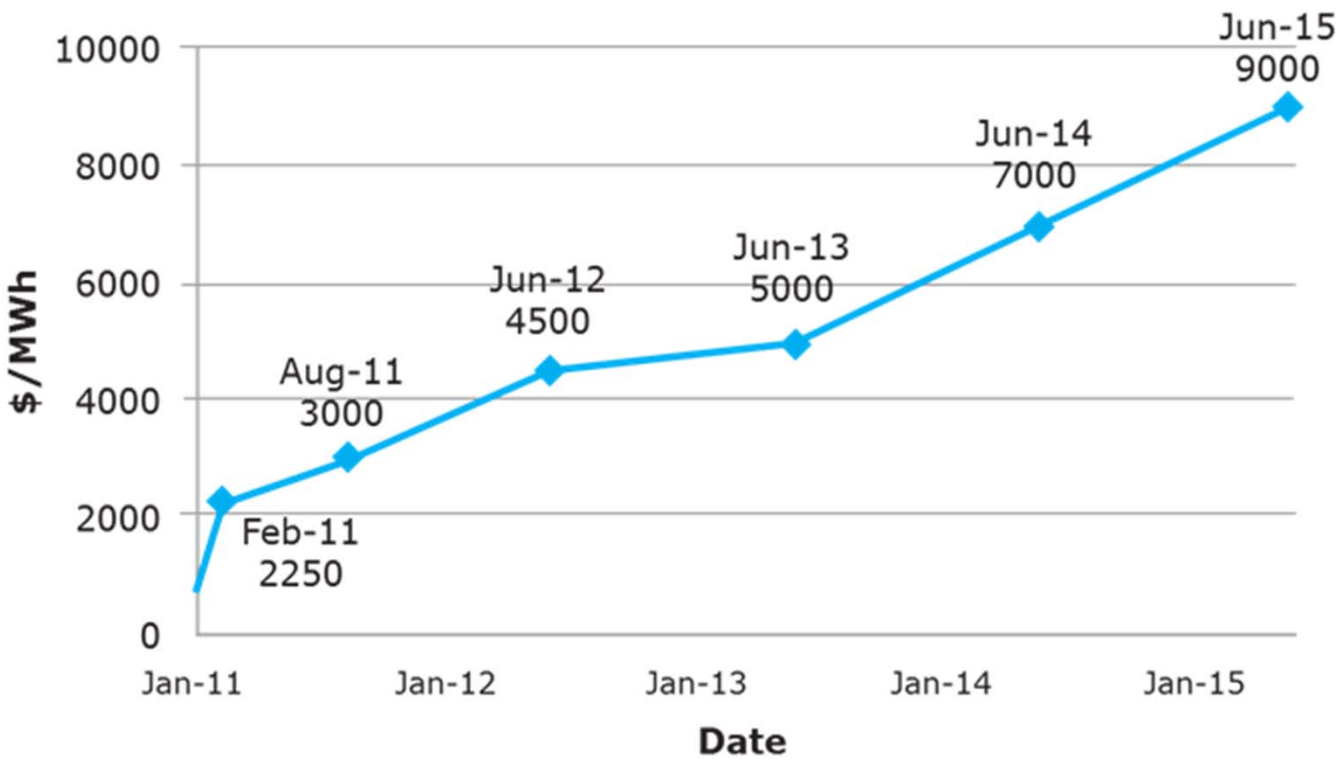


ISO-NE May 2020

The Operating Reserve Demand Curve (ORDC)



ERCOT PRICE CAP

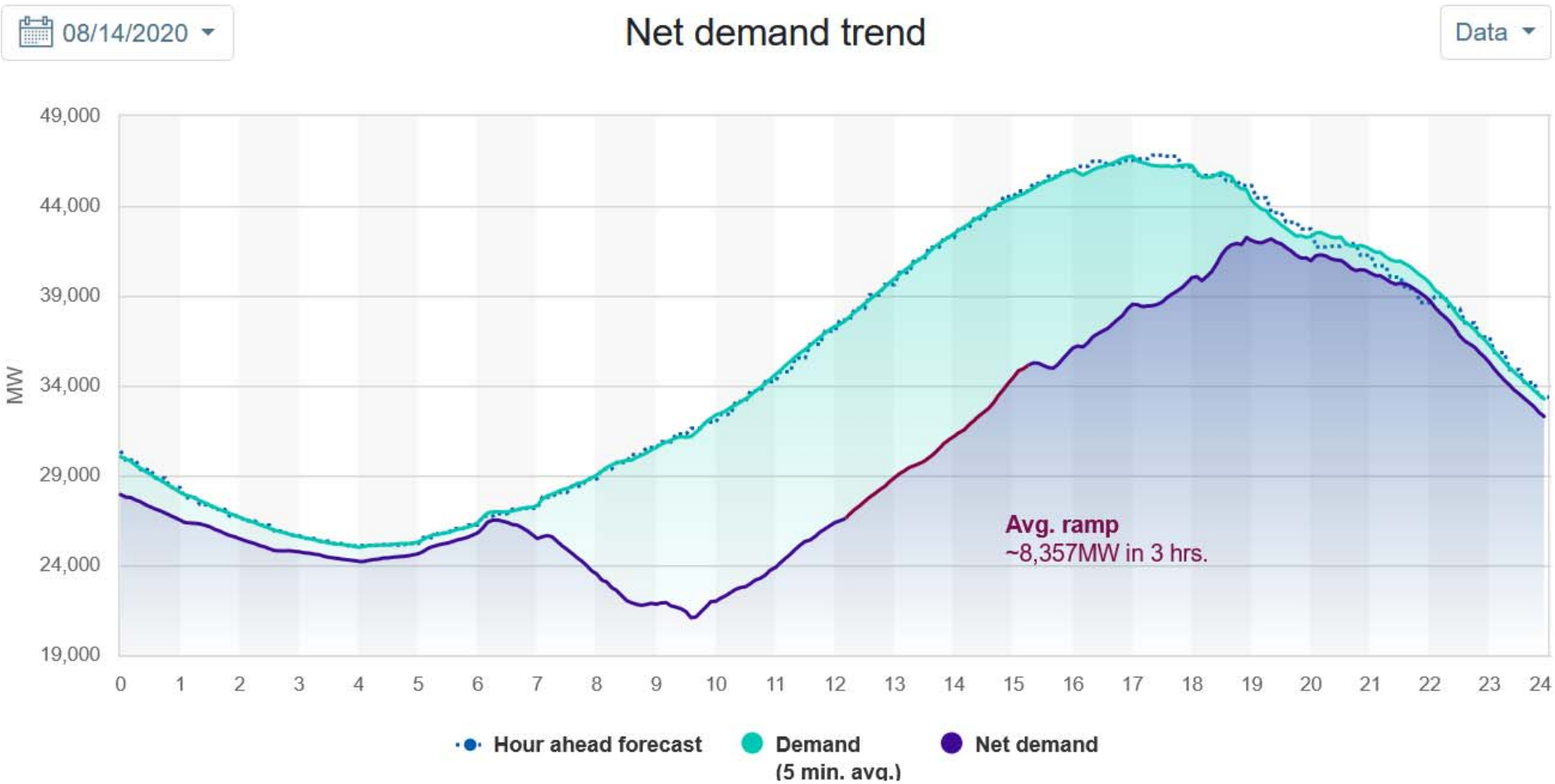


ERCOT

Deep penetration of VRE to meet binding carbon constraints requires harmonizing RA and decarbonization constraints

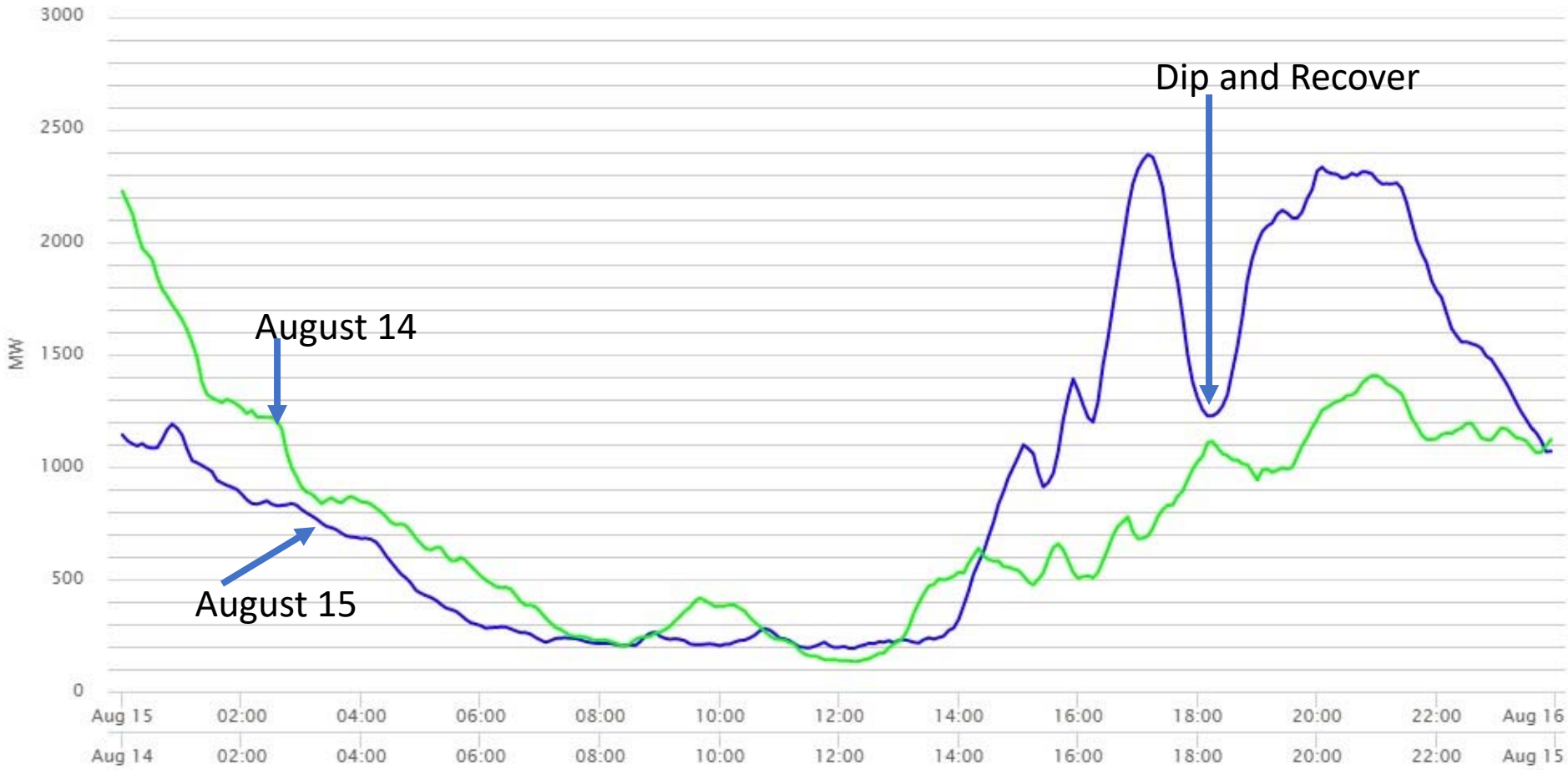
- The traditional RA approaches are based on static economic dispatch curves for systems composed primarily of dispatchable generation
  - Demand moves up and down a static supply curve
  - Perhaps varying by season or by month
- With high penetration of VRE generation the short-run supply curve isn't static but moves back and forth considerably with exogenous and uncertain variations in wind and solar output
  - Stochastic variations in wind and solar generation must be accounted for carefully in the analysis
  - This affects the RA value of different types of resources
    - e.g. in solar dominated systems the RA value of additional solar is often very small
    - Focusing primarily on meeting peak demand is no longer valid
    - RA value (and energy prices) depends on production under stressed system conditions which may not be the same as the time of peak demand
  - RA goals and decarbonization goals must be harmonized
- Attributes of VRE supply (and storage) and demand response must be taken into account both for RA assessment and for defining new market products
  - Flexibility
  - Ramp Rates
  - Real time operational needs (inertia, reactive power, voltage support, stability) as deep penetration of wind and solar with inverters replace dispatchable generation with spinning turbines
  - Capacity values

Net Demand August 14, 2020



CAISO

CAISO WIND GENERATION ON AUGUST 14 and 15, 2020



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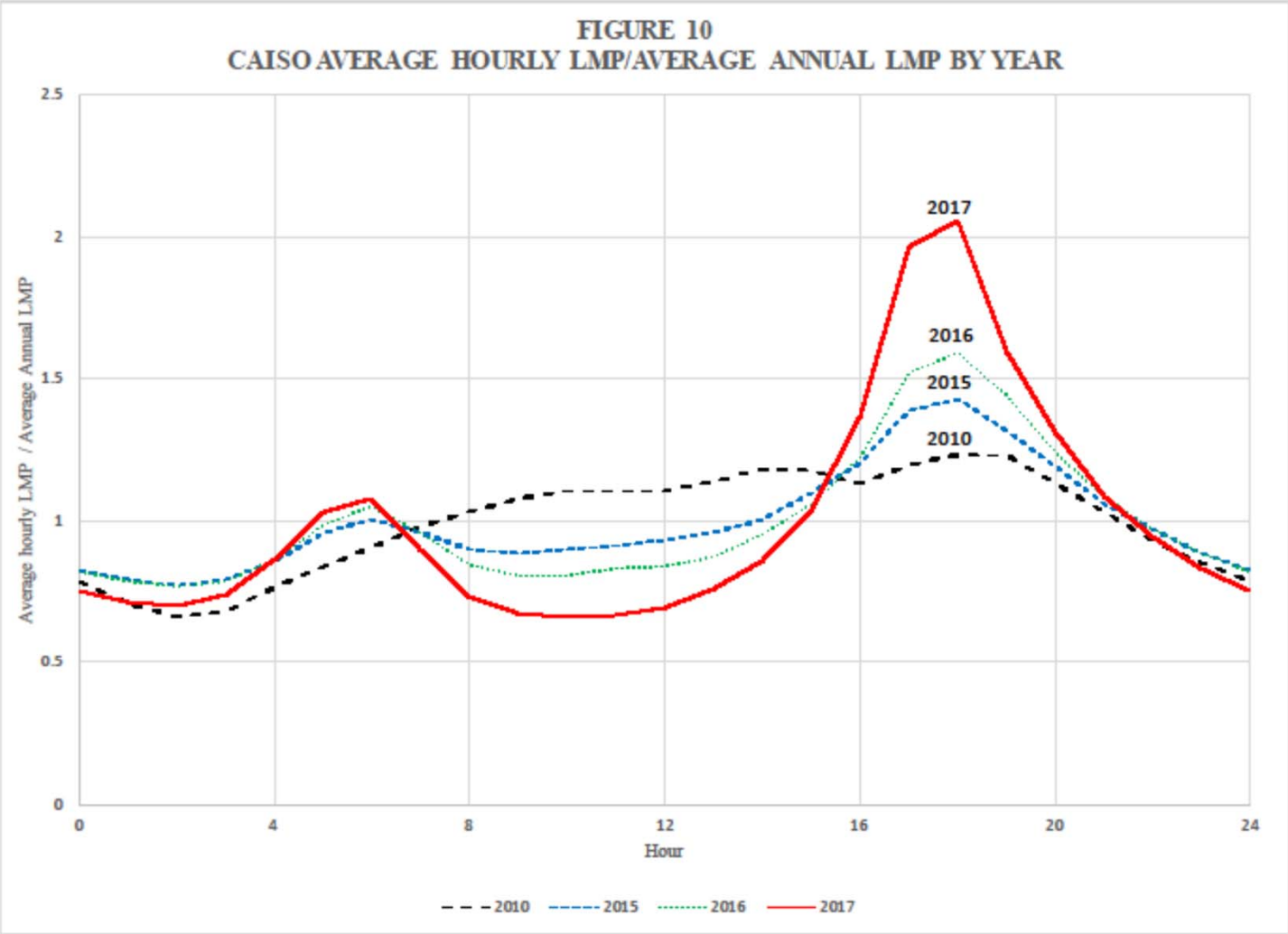
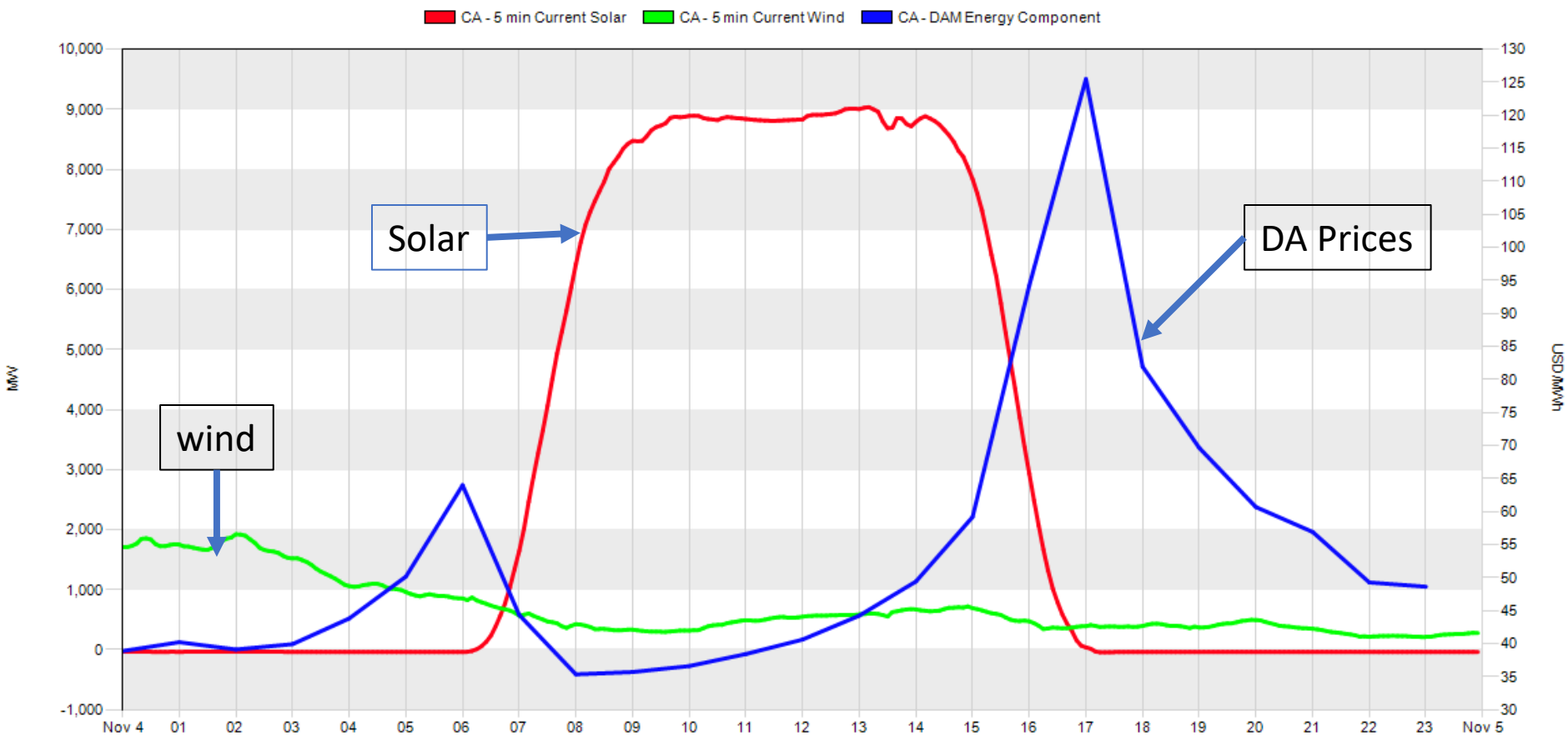


FIGURE 10
CAISO AVERAGE HOURLY LMP/AVERAGE ANNUAL LMP BY YEAR
Average hourly LMP / Average Annual LMP
2.5
2
1.5
1
0.5
0
0
4
8
12
16
20
24
Hour
2017
2016
2015
2010
2010
2015
2016
2017

Joskow 2019

CAISO Day-Ahead Prices
Wind and Solar Generation
November 4, 2020



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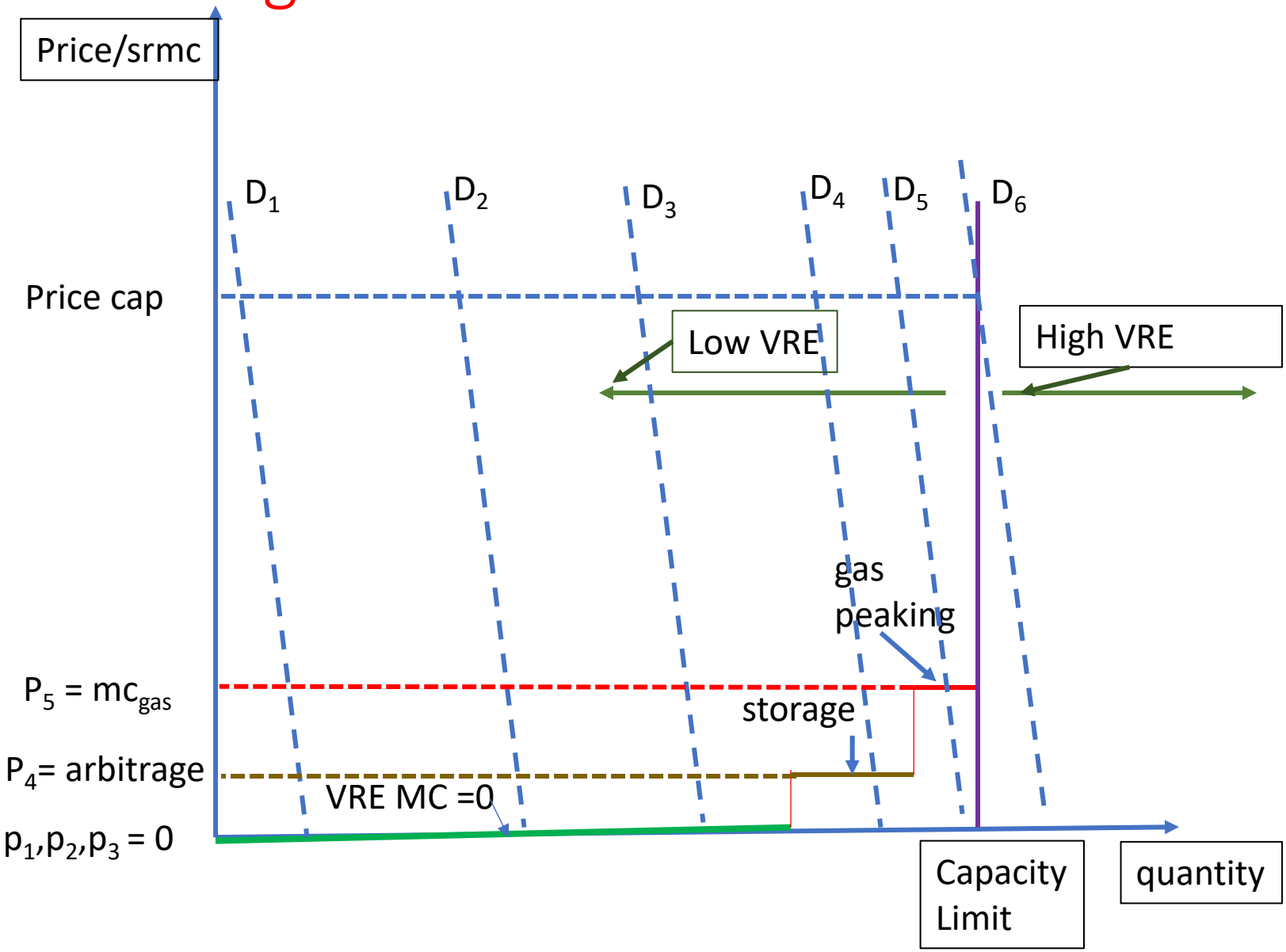
High VRE Penetration Market



Responding to the attributes of VRE generation: Effective Load Carrying Capability (ELCC)

- More sophisticated modelling of the supply side, LOLP, duration of loss of load, expected stressed conditions, etc. to account for stochastic properties of wind and solar generation as well as storage to complement demand modeling
  - Now calculate LOLP distribution for 8760 hours (or smaller group of very similar hours)
  - Resources that can supply reliably during high LOLP hours get high ELCC value and resources supplying in low LOLP hours get low values (credits, discounts)
  - Value in meeting RA constraint can be different from value in meeting carbon constraint
- California (CPUC) is farthest along in ELCC analysis and application

Region	BTM PV	Fixed PV	Tracking PV	Tracking PV Hybrid	Wind	Wind Hybrid
PGE	4.3%	5.4%	6.9%	99.6%	21.8%	54.0%
SCE/SDGE	3.6%	4.6%	5.4%	99.9%	18.0%	47.0%
AZ APS		4.6%	5.4%	99.0%	38.8%	78.3%
NM EPE		4.6%	5.4%	99.0%	38.8%	78.3%
BPA					32.7%	57.2%
CAISO	**4.0%**	**5.0%**	**6.2%**	**99.8%**	**19.9%**	**50.5%**
Average	**4.0%**	**4.8%**	**5.8%**	**99.4%**	**30.0%**	**62.0%**

Table ES2. Recommended ELCC Values for 2026

Region	BTM PV	Fixed PV	Tracking PV	Tracking PV Hybrid	Wind	Wind Hybrid
PGE	1.3%	2.1%	3.4%	98.8%	17.9%	43.5%
SCE/SDGE	0.6%	1.2%	1.9%	96.4%	17.8%	35.3%
AZ APS		~0.0%	1.9%	96.0%	30.8%	79.2%
NM EPE		~0.0%	1.9%	96.0%	30.8%	79.2%
BPA					32.8%	52.8%
CAISO	**1.0%**	**1.7%**	**2.7%**	**97.6%**	**17.9%**	**39.4%**
Average	**1.0%**	**0.8%**	**2.3%**	**96.8%**	**26.0%**	**58.0%**

CPUC Advice Letters 4243-E, 3560-E, 5868-E, July 21, 2020; See also CPUC Decision 19-09-043, September 26, 2019

Table ES3. Recommended ELCC Values for 2030

Region	BTM PV	Fixed PV	Tracking PV	Tracking PV Hybrid	Wind	Wind Hybrid
PGE	0.4%	1.3%	3.4%	93.4%	20.5%	39.2%
SCE/SDGE	~0.0%	~0.0%	~0.0%	93.0%	17.4%	31.7%
AZ APS		~0.0%	~0.0%	90.5%	30.2%	63.4%
NM EPE		~0.0%	~0.0%	90.5%	30.2%	63.4%
BPA					28.2%	51.6%
CAISO	**0.2%**	**0.7%**	**1.7%**	**93.2%**	**19.0%**	**35.5%**
Average	**0.2%**	**0.3%**	**0.9%**	**91.9%**	**25.3%**	**49.9%**

CPUC Advice Letters 4243-E, 3560-E, 5868-E, July 21, 2020; See also CPUC Decision 19-09-043, September 26, 2019

Application of ELCC Values is Evolving

- Where individual LSEs have RA responsibility these values can be used to "credit" resources' contributions to RA obligation
- In ISOs with centralized capacity markets it might be used to "discount" capacity of various kinds both for capacity price purposes and meeting system RA "demand" purposes
  - This is more complicated than first meets the eye
- In ERCOT the stochastic properties of wind and solar are already factored into the LOLP analysis underlying the ORDC, though solar penetration is expected to grow considerably
  - Could affect the position of the ORDC curve if more operating reserves are required to achieve LOLP metrics
  - But DA and real time prices for energy and ancillary services will reflect how tight the system is at different times throughout the year
  - The price cap likely will have to be higher and/or the ORDC curve shifted right if Texas were to adapt aggressive decarbonization targets
- More broadly, a deep penetration VRE system is better matched to an ORDC approach like in ERCOT
  - Distribution of wholesale prices will change dramatically
  - Much more net revenue in a small number of very high price hours
  - Linking wholesale market prices with retail market prices becomes more important
  - Stimulating demand flexibility when prices are high will reduce costs and increase efficiency

Grid-based Energy Storage

- Energy storage is an important resource in high VRE systems --- especially as the system gets to very low levels of traditional dispatchable generating capacity
- There are many potential storage technologies at various stages of technical readiness
  - Stored hydro
  - Pumped hydro
  - Li-ion
  - Redox Flow
  - Metal-air (zinc, sodium, potassium, iron, silicon, magnesium, aluminum)
  - Thermal (multiple designs)
  - Compressed air
  - Green Hydrogen
- Capital costs, conversion losses, energy density, power density, discharge duration vary quite widely
  - Stored hydro and pumped hydro face environmental and public acceptance challenges
  - Among batteries we have the best sense for costs and operating performance of Li-ion
  - Some other technologies are better suited to long duration storage which is likely to be needed to meet traditional reliability standards in high VRE system

Estimated Conversion Efficiencies for Different Storage Technologies

Technology	~RTE (%)
Li-ion	85%
RFB	80%
Metal-air	46%
Hydrogen (electrolysis)	48%
Thermal	50%
Pumped Storage	80%

Storage has multiple potential applications

- “Shifting” energy supply from one period, when prices are low, to another when prices are high (intertemporal price arbitrage)
- Supply capacity to contribute to reliability (RA)
- Frequency regulation and other ancillary services
  - Demand is limited
- Defer transmission and distribution needs
- At least in the U.S. a battery can rarely be supported by price arbitrage in the energy market alone today
  - State mandated procurement with PPA

CAISO Day-Ahead Prices
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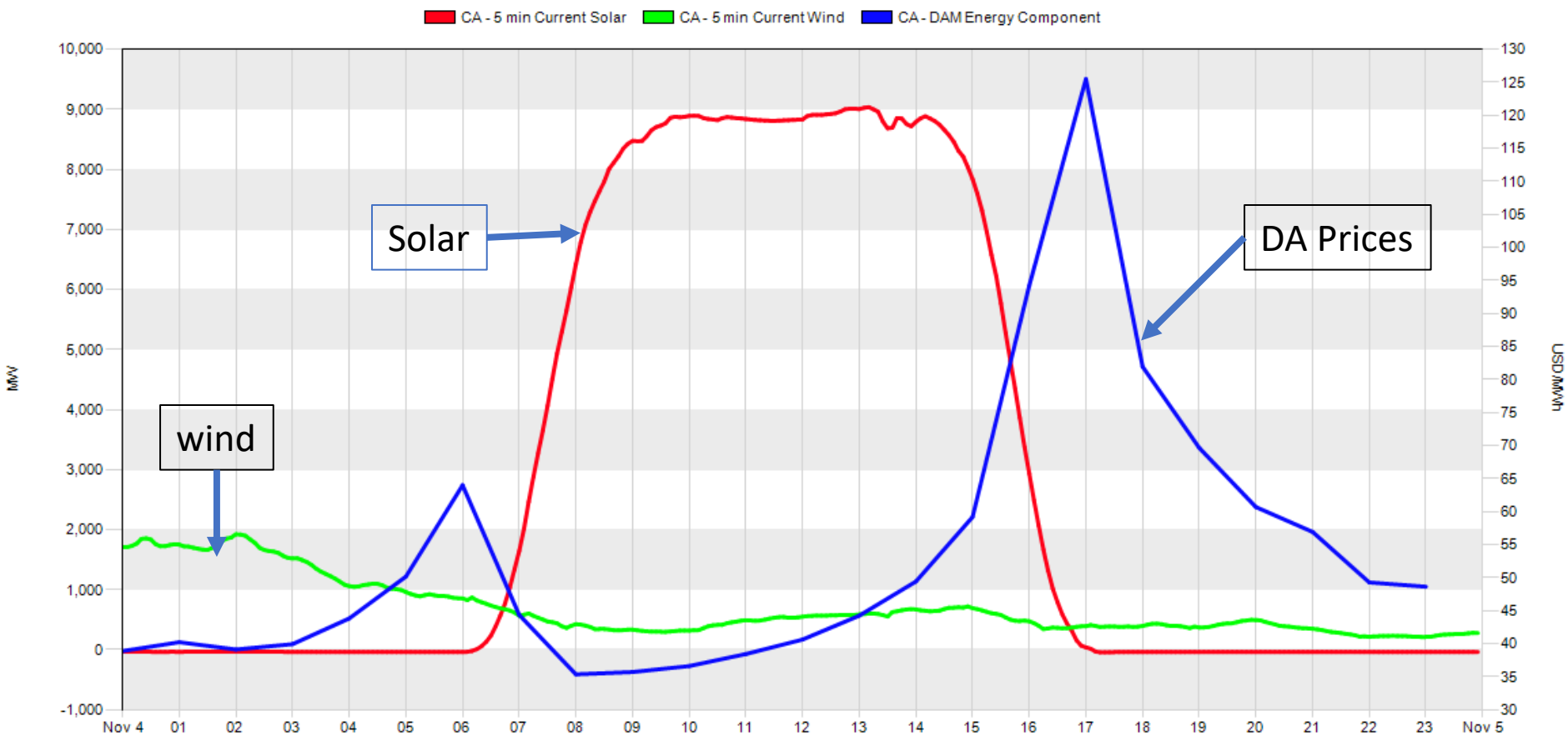

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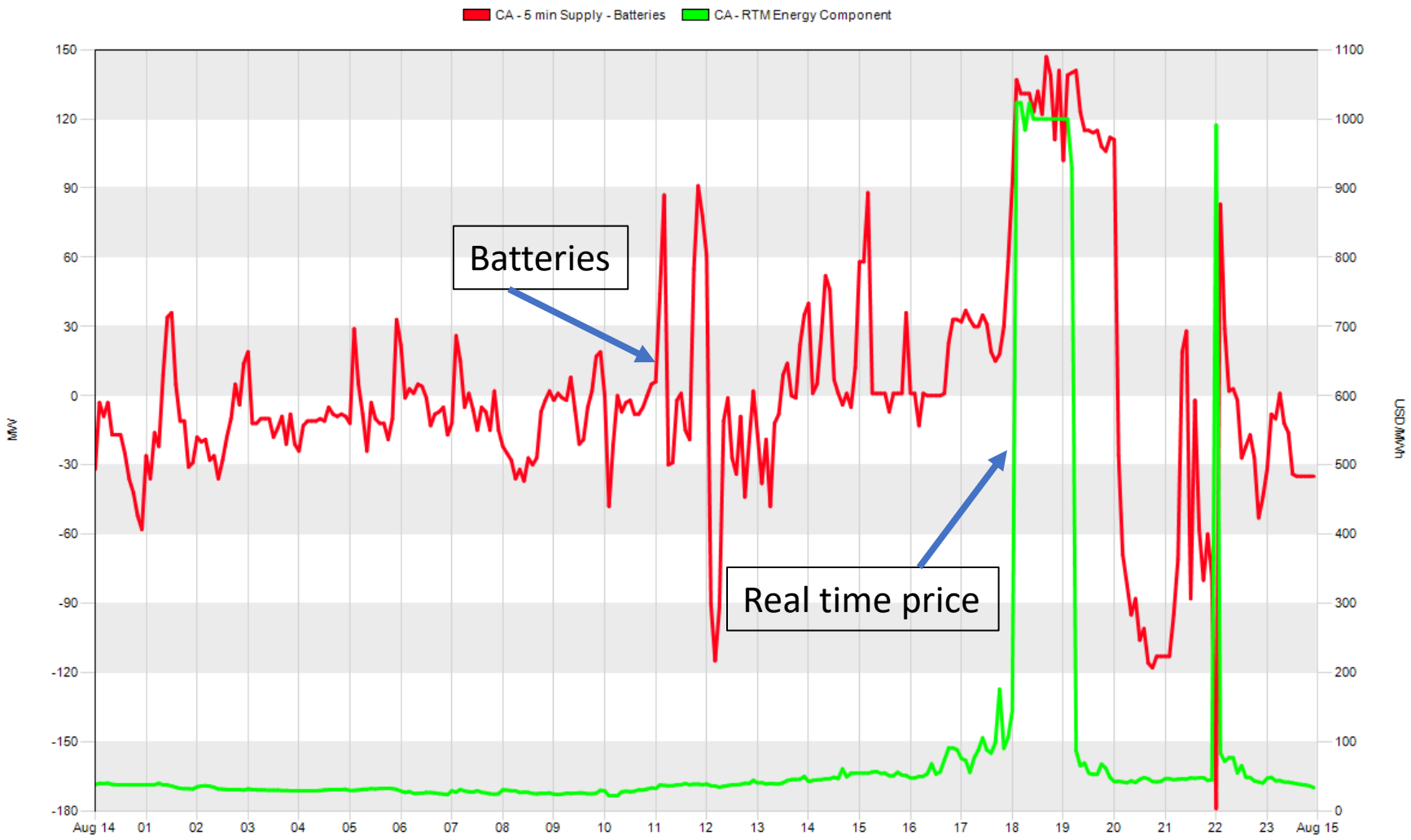
Integration of storage into wholesale markets

- Eligibility to participate in all wholesale markets for which the storage technology meets performance criteria
  - Storage facilities are negative (net) generators with energy generation limits (not loads and positive generators
  - Buy low and sell high
  - Well suited for ramping and reliability early in the evening in solar dominated systems
  - Well suited for supplying ancillary services though demand for these services is limited
- Can be included in RA calculation and capacity markets but energy supply constraints must be taken into account
- In “energy-only markets” getting the prices in a small number of high price hours right is necessary to provide appropriate incentives
- Integration into transmission planning and compensation mechanisms may be more challenging
  - Storage treated as (net) generators not load to avoid inefficient transmission cost allocations
  - But generation is separated from transmission planning and operations
  - Well suited to competitive procurement regime for transmission

CAISO August 14, 2020



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