Energy+Environmental Economics

Wholesale Electricity Market Reforms for the Clean Energy Transition: an E3 Perspective

PJM Interconnection Capacity Market Workshop

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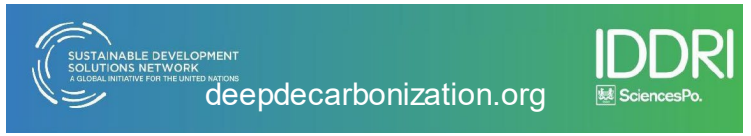
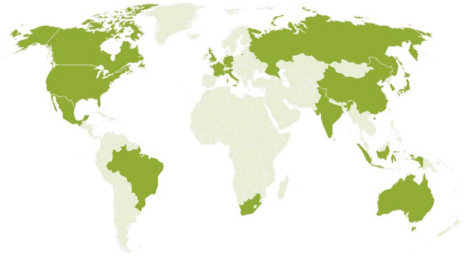
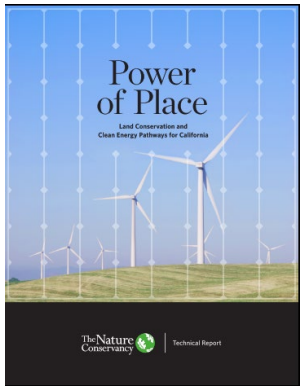
About E3: E3 has worked with a wide range of clients to understand the challenges of deep decarbonization and high renewable penetration

+ **United Nations Deep Decarbonization Pathways Project:**
  - **US-wide** Decarbonization Pathways (2016)
+ **California:**
  - **CPUC:** IRP, NEM 3.0, DER avoided costs
  - **CEC:** Title 24 building standards, Decarbonization Pathways, SB100
  - **CARB:** AB32 implementation
  - 100% RPS studies for **LADWP**, **SMUD** and **Calpine**
  - Deep decarbonization studies for **The Nature Conservancy** and **Environmental Defense Fund**
+ **100% Clean Energy Studies in Other Regions:**
  - **Hawaii:** HECO
  - **Pacific Northwest:** numerous utilities
  - **Upper Midwest:** Xcel Energy
  - **New York:** NYSERDA
  - **New England:** Calpine
  - **PJM:** Electric Power Supply Association
+ **E3 provides strategic advisory services to asset owners**





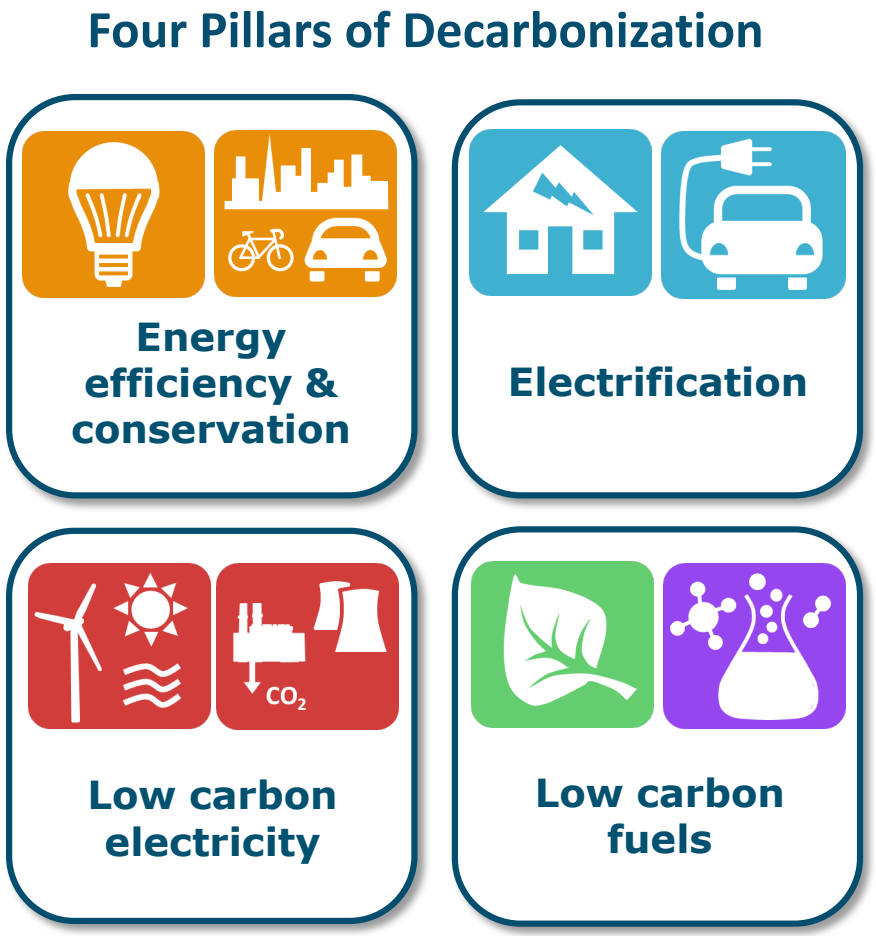


About this project

- E3 is preparing a white paper to describe potential reforms to wholesale electricity markets to facilitate rapid decarbonization of electricity supply and integration of large amounts of low-carbon electricity resources
- Ideas are based on E3's perspectives gained through fundamentals-based electricity system modeling, electricity market simulations, and experience with wholesale electricity market design
- E3 thanks the Electric Power Supply Association for its generous financial support of this project; however, all viewpoints and recommendations presented herein are solely the responsibility of E3
- Anticipated publication date in early April 2021

Setting the stage: the electricity sector must play a key role in economy-wide decarbonization

+ **Mitigating global climate change will require transitioning to cleaner energy sources across all sectors of the economy. Four pillars of decarbonization:**
  1. Energy Efficiency
  2. Electrification of fossil fuel end uses
  3. Zero-carbon electricity generation
  4. Carbon-neutral fuels
+ **Zero-carbon electricity is the lynchpin for the economy-wide transition**
  - 90+% reduction in direct electricity sector carbon emissions
  - 50+% increase in loads due to vehicle and building electrification
  - Green fuels made with electricity
+ **Many sources of clean electricity**
  - Solar, wind, hydro, geothermal, nuclear, fossil gen with CCS



Integrating clean electricity resources in large quantities requires reforms to wholesale electricity markets

- **Clean electricity resources are different from conventional resources in important ways**
  - Capital intensive
  - Low to zero variable costs
  - Wind and solar generation are variable and uncertain
- **Wholesale electricity markets must evolve in three ways to facilitate procurement and integration of clean resources**
  1. **Real-time energy and grid services markets** must facilitate deployment of grid flexibility
  2. A multi-state **clean energy attribute market** must be developed to facilitate cost-effective carbon reductions
  3. **Capacity markets** must accurately accredit all resources to ensure resource adequacy

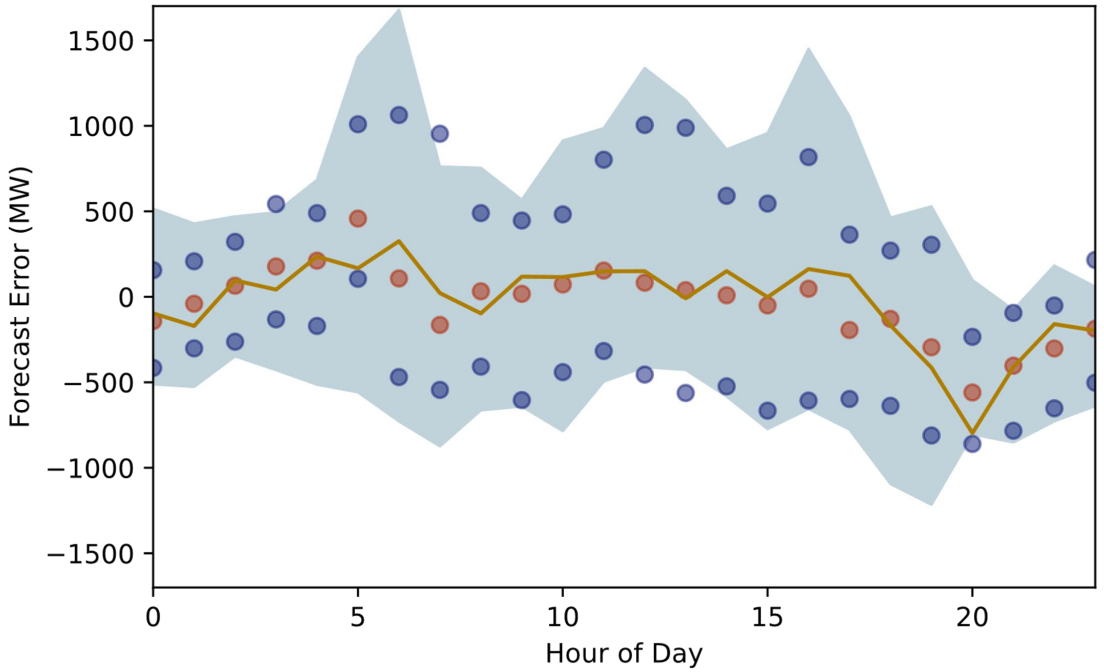
Key principles for wholesale market reforms:

(1) Identify the attributes the market needs;
(2) Identify the appropriate venue in which they should be procured;
(3) Establish mechanisms for efficient procurement.

1A. Energy and Grid Services Market Reforms: Dynamic Reserve Requirements

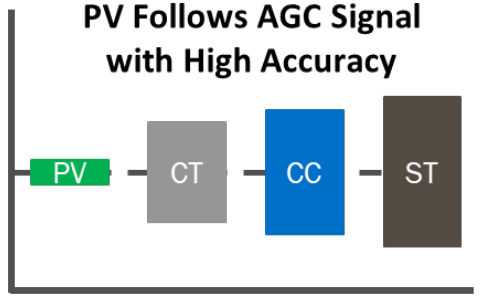
- **Wind and solar generation add to the system's need for Regulation and Flexibility Reserves**
- **As wind and solar become a large share of generation sources, variability will increase significantly**
- **Operating reserve needs will vary significantly based on system conditions:**
  - If wind and solar are low, less need for upward reserves
  - If wind and solar are high, less need for downward reserves
- **Dynamic calculation based on real-time conditions will ensure system operator commits enough resources to ensure reliability while minimizing system costs**

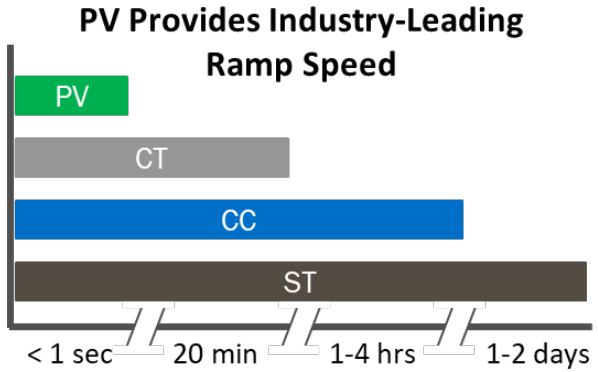
Net load forecast errors vary substantially based on grid conditions: CAISO, July 2019



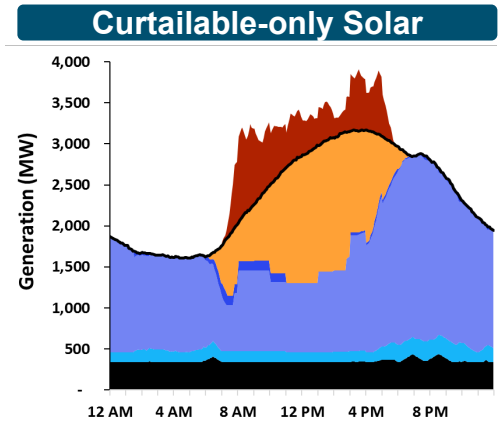
1B. Energy and Grid Services Market Reforms: Fully flexible wind and solar resources

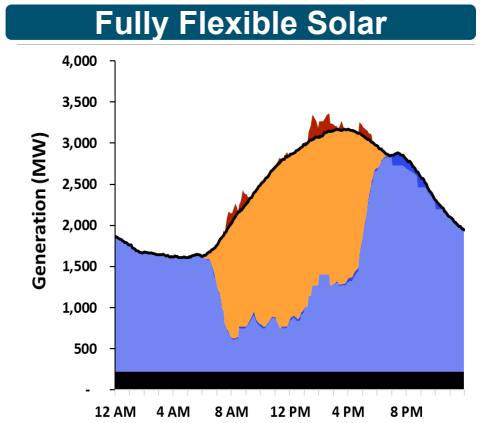
- **Wind and solar generation can be operated flexibly with much faster response than conventional generation**
- **Flexible dispatch of solar and wind has many benefits:**
  - Reduces the need for operating reserves by reducing output uncertainty
  - Flexible solar and wind can provide operating reserves; downward reserves can be provided at low cost
  - Reduces curtailment by minimizing commitment of thermal generators
  - Facilitates more efficient operation of thermal generators
- **Flexible operations of solar and wind will become imperative at higher penetrations**





Source: First Solar

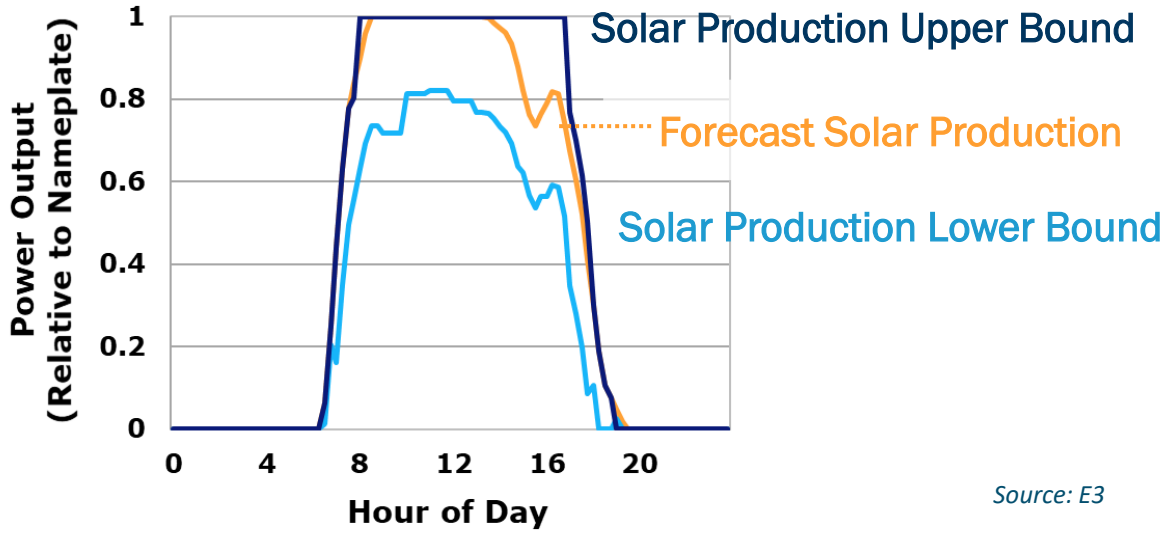




Source: E3, https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf

1C. Energy and Grid Services Market Reforms: Separate upward and downward reserve products

- **Wind and solar generation can provide both upward and downward reserves, but cost structure is asymmetric**
  - Upward reserve provision requires operating below maximum output to maintain "headroom" for upward dispatch
    - Significant cost due to lost production
  - Wind and solar can be dispatched down to zero within a few seconds
    - Relatively minimal amount of lost production
- **Energy storage devices may have different willingness to be dispatched upward or downward depending on anticipated arbitrage opportunities**



Source: E3

Illustrative Ancillary Service Bids for Wind/Solar

	Upward	Downward
REC Price ($/MWh)	$20	$20
Mileage during reserve provision	20%	20%
Lost RECs per 100 MW (MWh)	80	20
Wind/Solar Reserve Bid ($/MWh)	$16	$4

1D. Energy and Grid Services Market Reforms: Fully optimize energy storage over its dispatch duration

+ **Energy storage can provide multiple services: energy shifting, operating reserves, contingency reserves**
+ **Market should be designed to fully optimize the use of energy storage when the market optimization spans the entire storage charge/discharge cycle**
  - Market should determine when energy storage charges and discharges and which products it provides to maximize value to the system
  - E.g., day-ahead market should schedule storage charging and discharging based on system needs

Battery Storage Price Spreads at SP15 Market in 2020

Top 4 / Discharge Hours - 2020 SP15

M/H	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg
Jan							40											48	44	42					44
Feb							39											39	44	39					40
Mar																		34	43	38	34				37
Apr																		28	38	35	29				33
May																		29	42	39	31				35
Jun																		37	52	42	34				41
Jul																	36	55	81	47					55
Aug																	160	306	293	131					222
Sep																	82	159	95	55					98
Oct																48	107	118	65						84
Nov																	57	74	55	49					59
Dec							51											66	57	53					57
																						Discharge Avg			67

Bottom 4 / Charge Hours - 2020 SP15

M/H	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg
Jan												21	20	19	22										21
Feb												12	12	11	13										12
Mar											14	13	12	13											13
Apr										6	6	6	6												6
May									4	4	4	5													4
Jun								10	9	9	11														10
Jul							18	13	14	16															15
Aug			31					26	27	30															28
Sep								24	21	22	26														23
Oct									24	23	24	27													25
Nov										22	21	20	20												21
Dec											26	24	23	24											24
																						Charge Avg			17

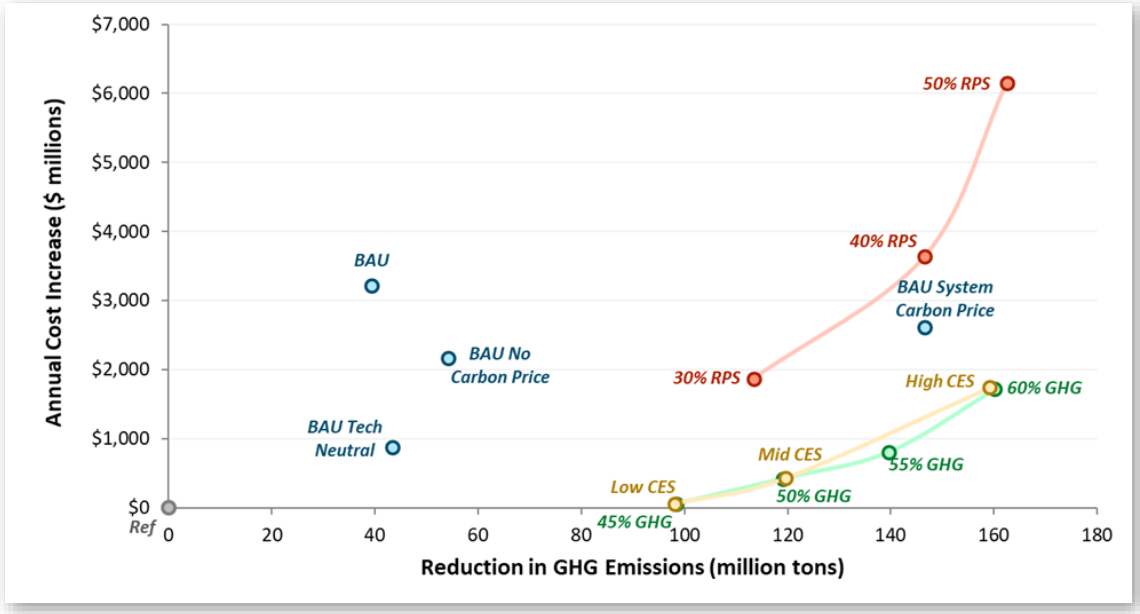
Source: E3

+ **When the market optimization period is shorter than storage duration, the market must recognize potential future arbitrage values**
  - E.g., storage owner may bid into hourly market with a buy-sell spread reflecting opportunity cost of anticipated arbitrage

2A. Clean Energy Attribute Market Reforms: Create multi-state, bilateral carbon attribute market

+ **Many studies indicate that carbon pricing results in the most efficient carbon reductions**
  - Provides appropriate financial incentives for all means of avoiding carbon emissions
  - Broad-based carbon pricing maximizes opportunities to seek out least-cost abatement
  - A national carbon price will be the most important federal carbon policy, but may take years to enact
  - State-by-state carbon pricing can lead to higher costs and higher emissions
+ **A well-designed, multi-state clean electricity standard can approach the efficiency of a systemwide carbon price without some of the negative impacts**

PJM System Costs and Emissions Savings in 2030 from Current and Alternative Policy Mechanisms



Source: E3 https://www.ethree.com/least-cost-carbon-reduction-in-pjm/

2B. Clean Energy Attribute Market Reforms: Voluntary harmonization of electricity carbon attribute

+ Common definition of carbon reduction attribute of clean energy

- Energy Transition Credit (ETC) created by delivering 1 MWh of carbon-free energy to the grid **at any time in any participating jurisdiction**
- Standardized definition is for **carbon reductions only**; does not preclude participating jurisdictions from separately valuing additional attributes of clean energy (local air quality, economic development, market transformation)

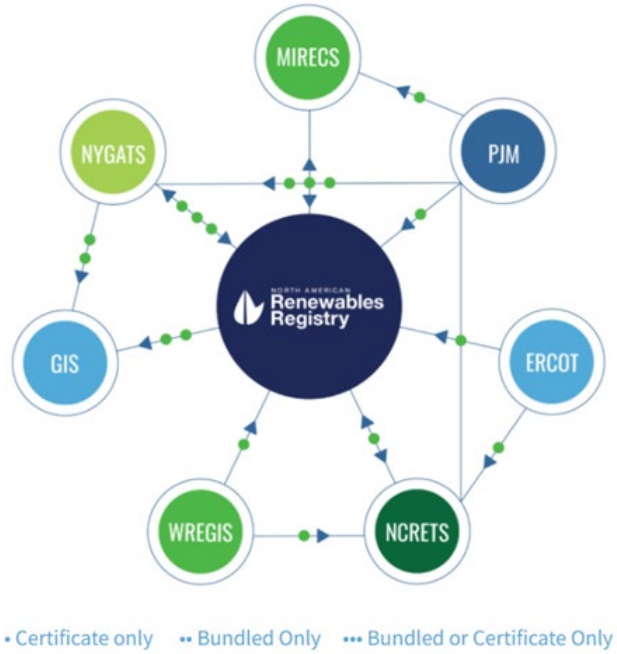
+ Created through multilateral agreement among states, local governments, corporations, etc.

- Only governance needed is a registry that tracks creation, trading and retirement of ETCs – registries already exist

+ Centralized auction is not needed

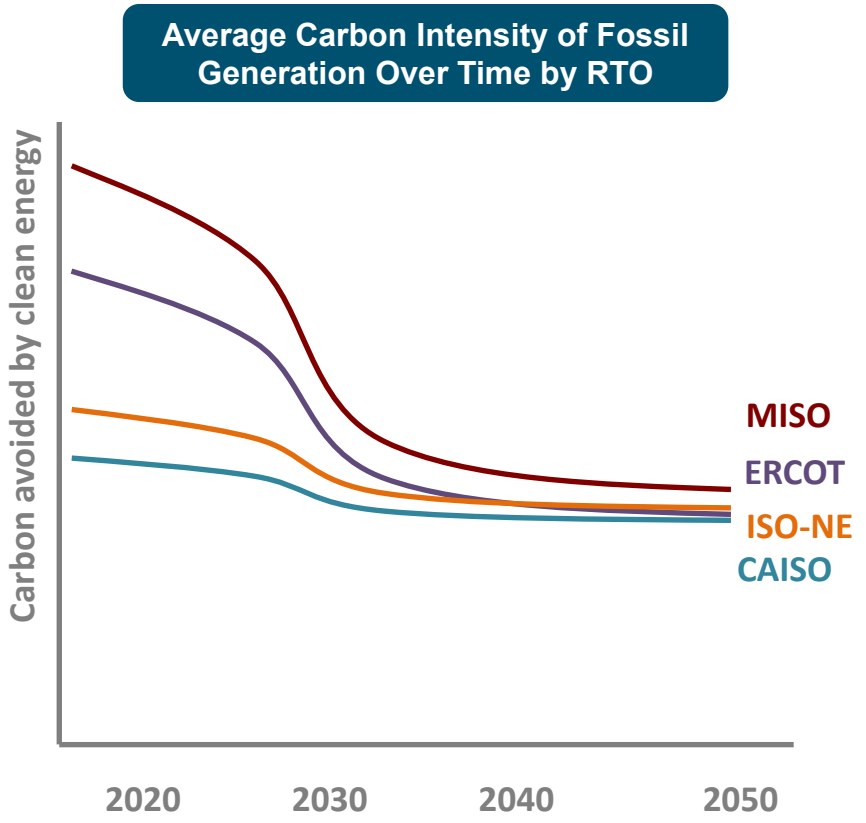
- Valuing carbon abatement is a governmental role – not a function of power systems
- Broad participation by multiple jurisdictions with aggressive goals creates stable, long-term signal for carbon reductions
- Liquidity is facilitated by a relatively simple design: 1 MWh is the same everywhere
- Does not preclude state-led auctions, e.g., in states with full retail choice

Current Renewable Energy Credit Tracking Systems



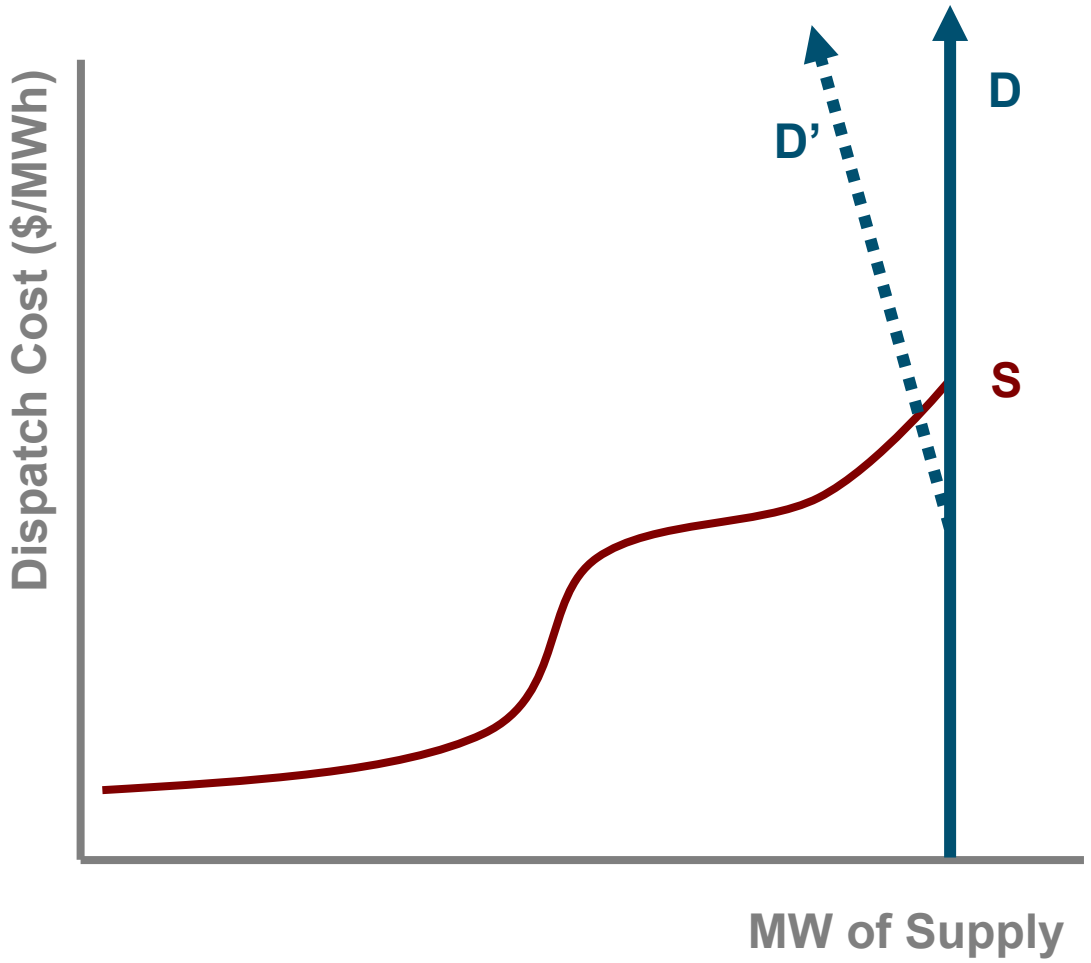
2C. Clean Energy Attribute Market Reforms: Partial credit for gas creates efficiencies

+ **Temporary, partial credit for gas generation will add efficiency benefits through economic displacement of coal generation**
  - Based on carbon intensity relative to a defined standard (e.g., 0.825 tons/MWh)
  - Declines to zero over transition period (e.g., 10 years)
+ **Addresses concerns about "leakage" created by state-led carbon pricing policies with partial coverage**
  - Partial carbon pricing policies can result in higher emissions by reducing gas generation in states with carbon pricing and increasing coal generation in states without carbon pricing
  - CES does the opposite, potentially leading to more carbon reductions due to "positive leakage"
+ **Transition to carbon pricing can be gradual**
  - Economy-wide carbon price creates additional efficiencies
  - Carbon pricing can be phased in gradually, co-existing and eventually supplanting the CES



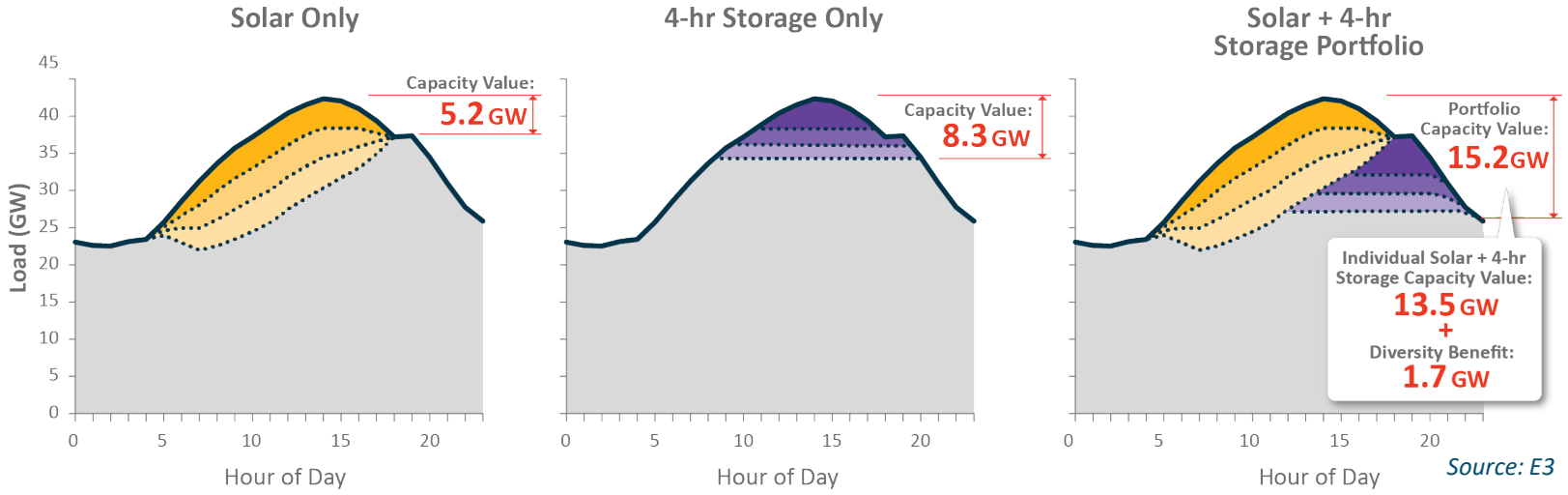
3A. Forward Capacity Market Reforms: Incorporate more price-responsive demand

- **Role of forward capacity market is to ensure sufficient capacity for resource adequacy**
  - Procure sufficient effective capacity to serve all non-price-responsive load, subject to acceptable standard for frequency of loss-of-load events
  - Capacity need not be forward procured for price-responsive or interruptible load – more demand flexibility can significantly reduce quantity of capacity needed
- **Demand forecasting methodologies should be reexamined in light of recent extreme weather events**
- **Value of lost load estimates and market behavior during emergency events must be reexamined**



3B. Forward Capacity Market Reforms: Credit all resources accurately toward capacity need

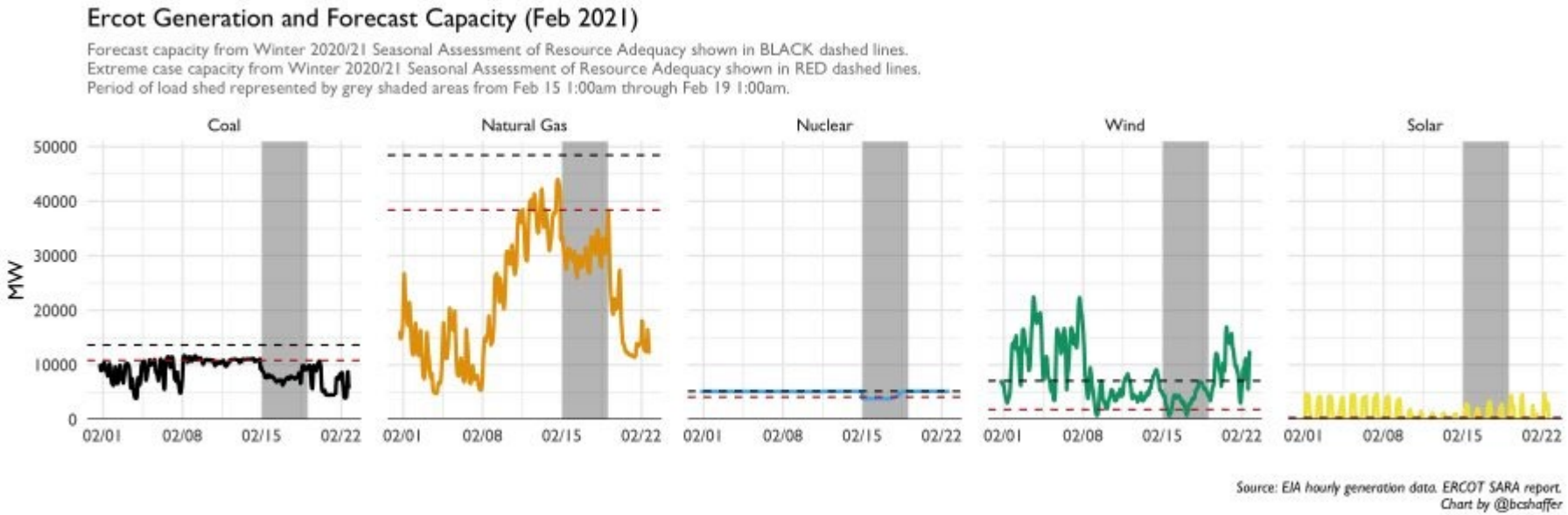
- **No resource provides "perfect capacity" – all resources are limited in some way**
  - Firm resources limited by forced outages
  - Wind, solar and hydro resources limited by energy availability and timing
  - Storage and demand response limited by dispatch duration and frequency
- **All resources should be credited based on Effective Load-Carrying Capability (ELCC), which measures their ability to avoid loss-of-load**
  - ELCC measures performance when it matters most – when loss-of-load probability is highest
  - ELCC accreditation must account for portfolio affects among dispatch-limited resources
  - Synergistic pairings:
    - Wind & solar, solar & storage
  - Antagonistic pairings:
    - Storage & demand response



Source: E3

3C. Forward Capacity Market Reforms: Firm resources must be firm

- **For "firm" resources, ELCC may be approximated by (1-FOR%)**
  - Forced outage rates must be reassessed in light of recent extreme weather performance issues
  - "Lumpy" resource outages can create conditions for loss of load
  - PJM's "Unforced Capacity" (UCAP) approach addresses this appropriately
- **Firm resources must have firm fuel supply**
  - E.g., firm transportation contract, onsite backup fuel storage



Summary of recommended wholesale market reforms

1. **Energy and grid services markets**
   - A. Dynamic calculation of operating reserves
   - B. Wind and solar universally bidding into energy and grid services markets
   - C. Separate upward and downward operating reserve products
   - D. Full optimization of energy storage
2. **Bilateral Carbon Attribute Market**
   - A. Bilateral market can serve as a temporary substitute for an economy-wide carbon price
   - B. Created through voluntary harmonization of electricity carbon attribute among multiple jurisdictions/voluntary participants; no need for centralized auction
   - C. Partial credit for gas generation can create dispatch efficiencies and positive leakage
3. **Capacity Market**
   - A. Procure sufficient capacity to serve vertical part of demand curve with acceptable reliability
   - B. Accurately credit each resource toward meeting capacity need using ELCC
   - C. Firm resources must have firm fuel

Response to questions about capacity markets reform based on key principles

Q. Should the capacity market procure flexibility?

A. No, flexibility can be optimized during **daily market operations**. Flexibility does not need to be forward procured.

Q. Should the capacity market procure clean energy?

A. No, the capacity market should procure **capacity**. Clean energy attributes should be procured in the bilateral clean attribute market.

Q. Are capacity markets biased against high capital cost resources?

A. No, capacity markets should procure capacity at **lowest net cost**.

Q. Are capacity markets biased against clean energy?

A. No, resources with higher clean energy value will be able to bid a **lower net cost** into the capacity market.

Q. Do forward purchases of energy, capacity or clean energy attributes necessarily constitute subsidies?

A. No, bilateral forward purchases are **hedges**, not subsidies.

Key principles for wholesale market reforms:

(1) Identify the attributes the market needs;
(2) Identify the appropriate venue in which they should be procured;
(3) Establish mechanisms for efficient procurement.

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Thank You!

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