Scalable Markets for the Energy Transition: A Blueprint for Wholesale Electricity Market Reform

Energy Systems Integration Group Forecasting and Markets Workshop

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Energy+Environmental Economics

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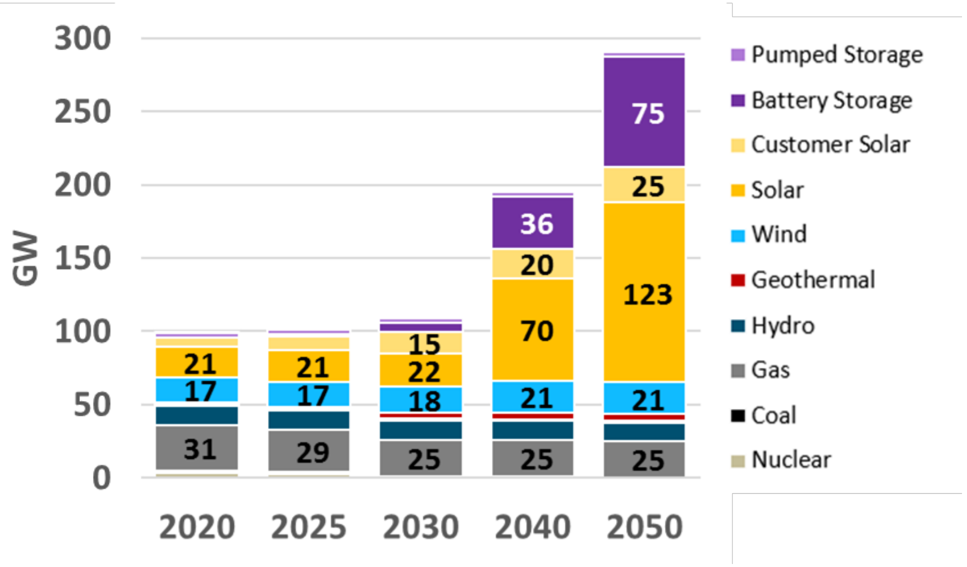
Advancing technology and policies are creating challenges for wholesale electricity markets

+ Resource mix is changing rapidly in many markets

- Fuel costs → Fixed costs
- Firm & dispatchable → Variable & dispatch-limited
- Capacity constrained → Capacity & energy constrained
- Grid scale → Mix of grid scale & customer sited
- Increased need for operating flexibility



+ Potential "Externalities" in our current electricity markets

1. Operational flexibility to address wind and solar variability and uncertainty
2. Investment signal for resources needed to maintain resource adequacy
3. Price signal to reflect societal value of reduced greenhouse gas pollution

Link to full report: https://www.ethree.com/scalable-markets-for-the-energy-transition-a-new-e3-report/

Partial funding provided by Electric Power Supply Association

A variety of proposals have been offered to rethink our energy and capacity markets

Design	Description
Centralized forward clean energy procurement	Market operator procures clean energy through centralized auction
Centralized multi-attribute procurement	Market operator uses centralized auction to simultaneously procure multiple products (e.g. capacity + clean attribute + flexibility)
Energy-only market with mandatory long-term procurement	Load-serving entities are responsible for procurement of hourly energy requirements through long-term bilateral contracts
ISO-run carbon pricing	Generators pay administratively determined carbon price and incorporate into market bids
Temporal- and spatially-matched clean energy production	Clean energy procurement should match load on an hourly basis and meet requirements for “deliverability”

Challenges

+ Multi-attribute auctions are highly complex, perhaps unworkably so
+ Mandatory centralized procurement shifts risk to captive ratepayers
+ Market designs that are tied to a single-market cannot easily scale to entire country
+ Forward energy contracting may not be sufficient to ensure resource adequacy
+ Effectiveness of partial carbon pricing may be hindered due to leakage

https://www.wri.org/events/2020/12/market-design-clean-energy-transition-advancing-long-term

Observations and Conclusions

+ Observations

- The physical needs of the grid will remain largely the same as today.
- The physical capabilities of the resources that serve those needs will change – dramatically.
- The "clean" attribute of clean energy serves a societal need, not a grid need.
- Wholesale electricity markets have played an important role in facilitating carbon reductions to date.
- Existing institutions have been successful in financing capital-intensive clean energy projects.

+ Conclusions

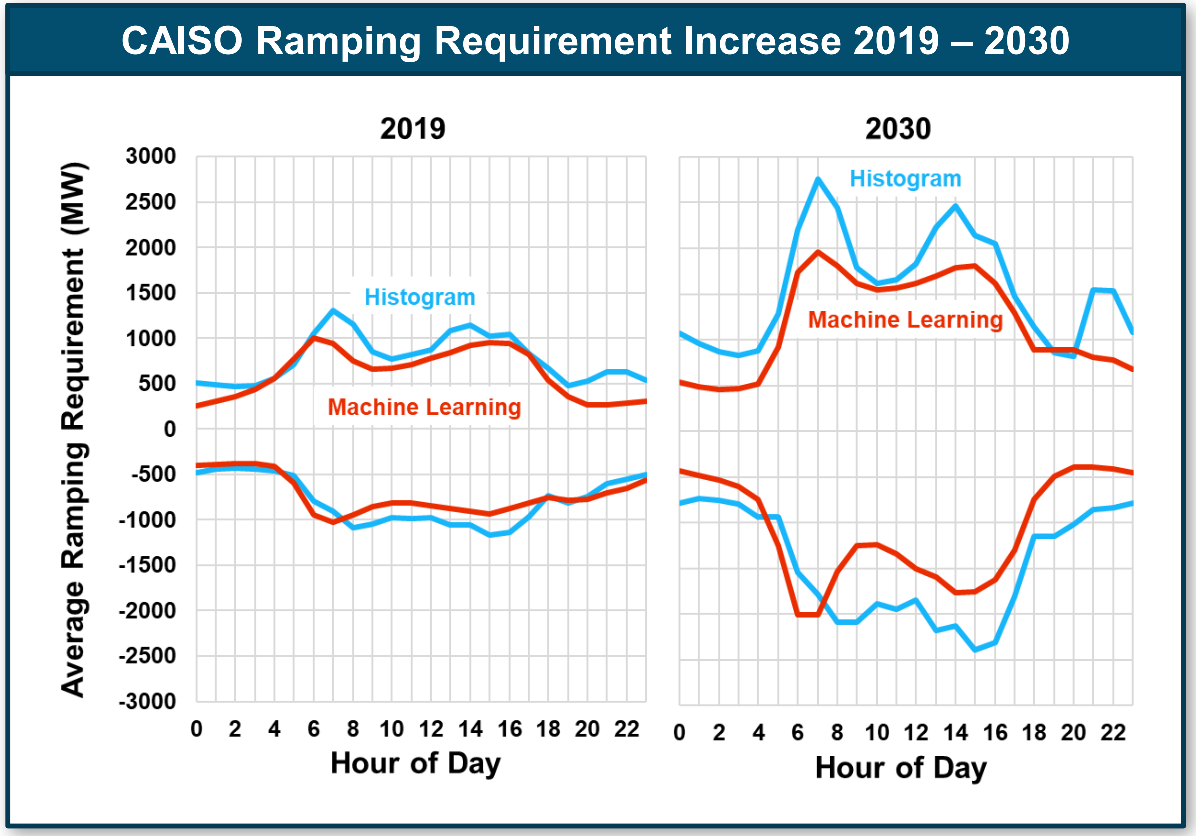
1. The general structure of existing capacity, energy, and ancillary services markets should be preserved.
2. The types of reforms needed in existing markets are generally enhancements to promote efficiency rather than fundamental structural overhauls.
3. Capacity markets should continue to focus on capacity, which is unrelated to clean energy.
4. Compensation of the clean attribute should occur in a context that is removed from grid operations.

Reforms should be focused on refining and reinvigorating, rather than reinventing, our market institutions

Energy and Grid Services Market Reforms

Dynamic operating reserves calculations

- **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 maintain reliability while minimizing system costs**

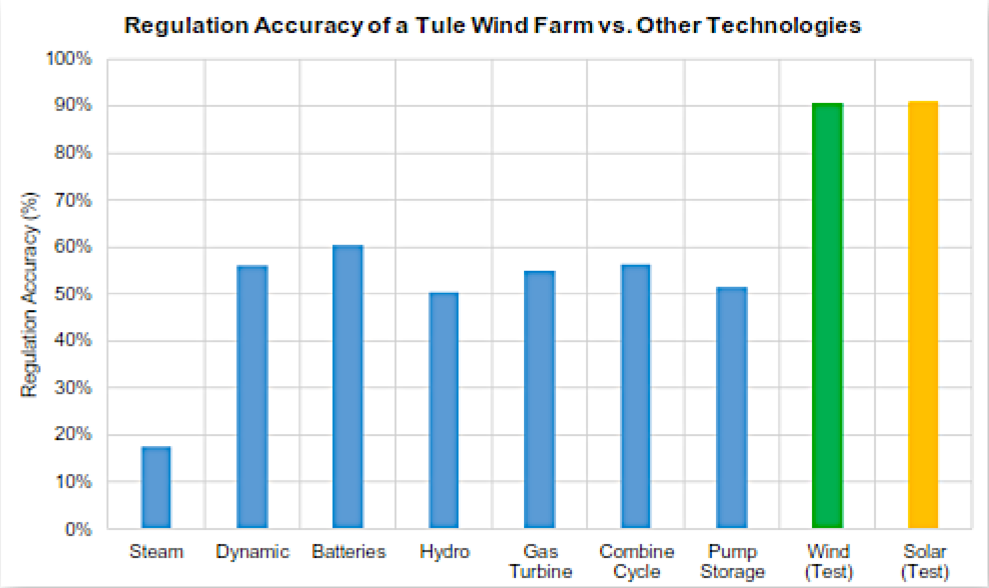


Source: E3, Predicting Reserve Needs Using Machine Learning, project partially funded with grant from ARPA-E

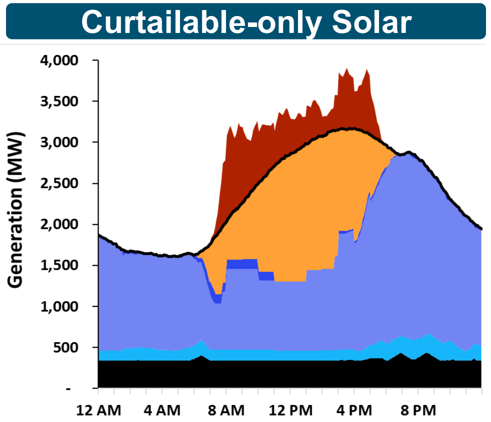
arpa-e CHANGING WHAT'S POSSIBLE

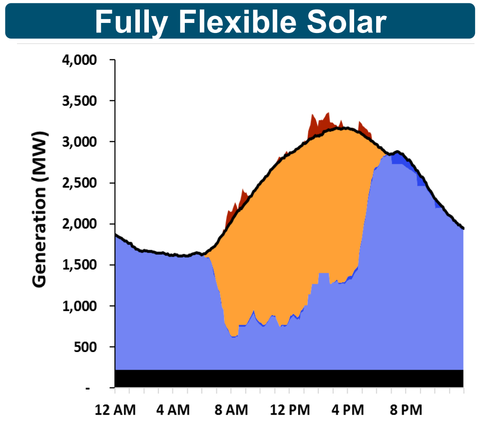
Fully flexible wind and solar resources

+ **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: CAISO

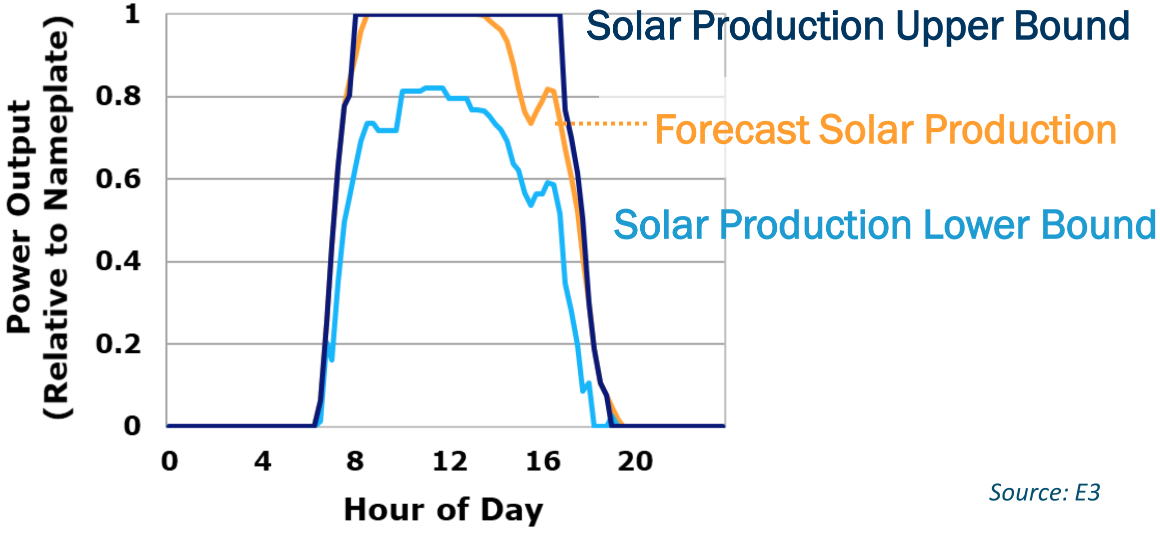




Source: E3, https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf

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 future arbitrage opportunities**
  - Includes hydropower with reservoir storage



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

Fully optimize energy storage over its dispatch duration

- **Energy storage can provide multiple services: energy shifting, operating reserves, contingency reserves**

- **Market should have the capability 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

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

- **Alternatively, the market must recognize opportunity costs and future arbitrage values**
  - E.g., storage owner may bid into hourly market with a buy-sell spread reflecting opportunity cost of anticipated arbitrage
  - Automated bid mitigation must recognize storage opportunity costs

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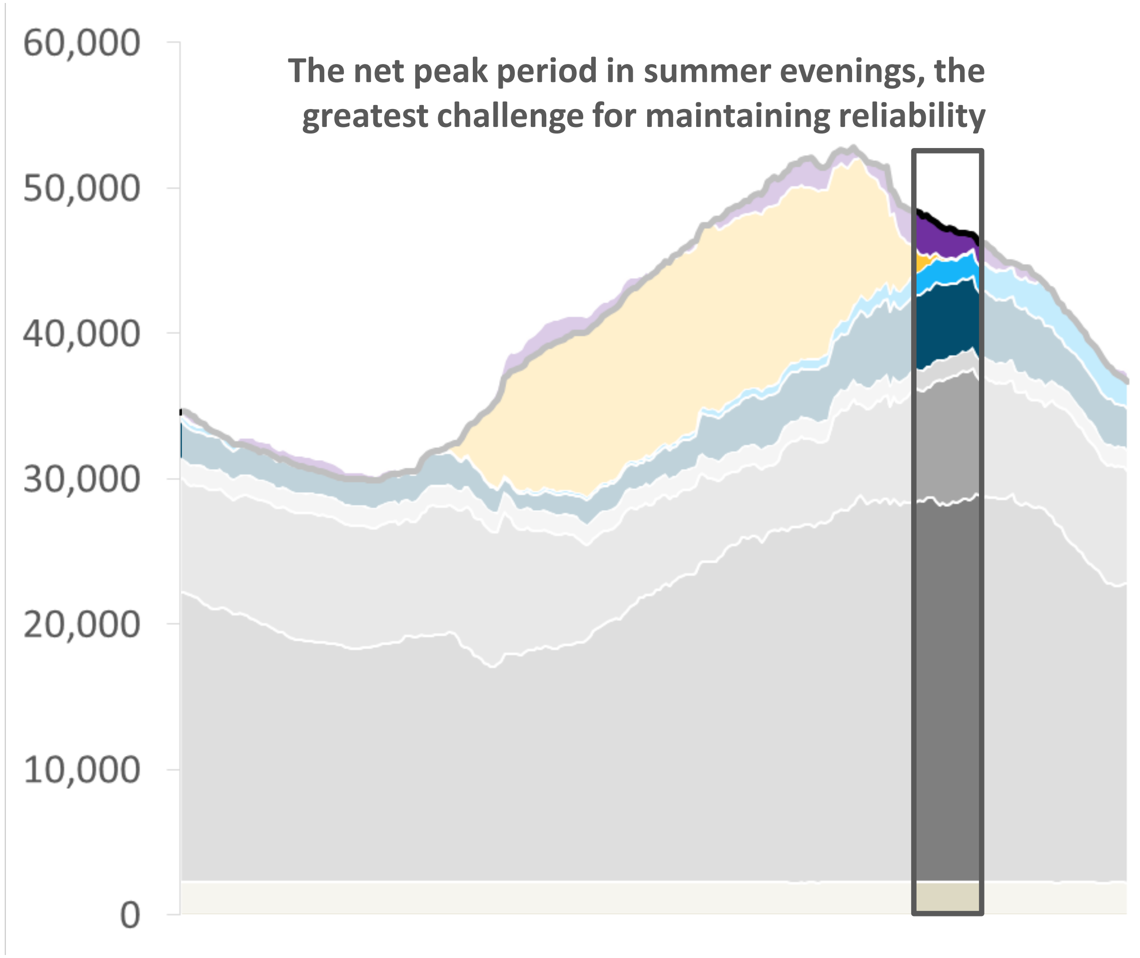
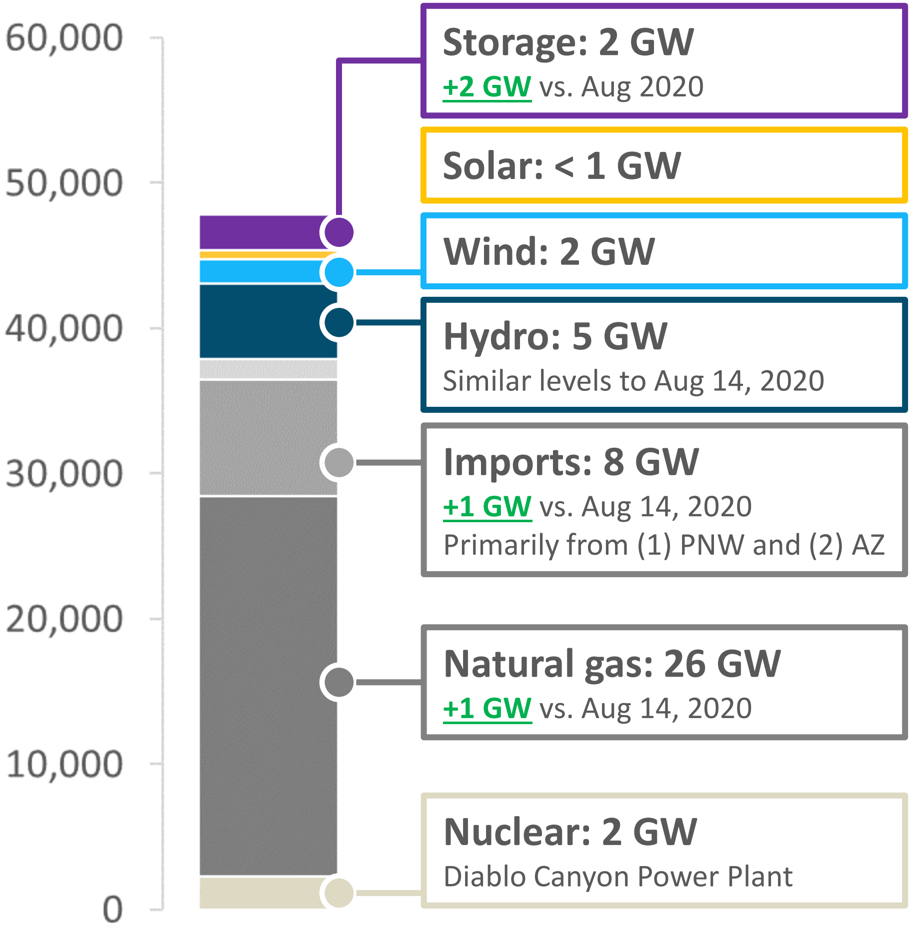
Forward Capacity Market Reforms

Determine need, allocate need and accredit resources based on their impact during critical reliability periods

CAISO System Operations on September 6, 2022
(MW)

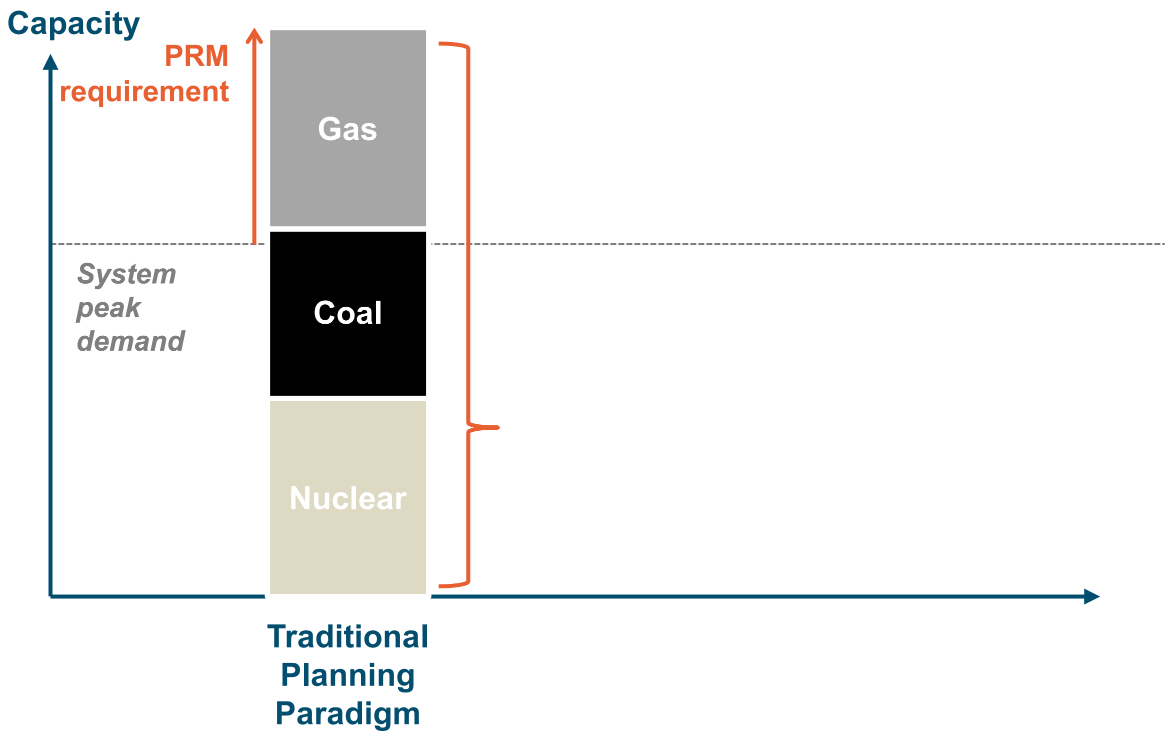


Generation During Hour of Highest Net Load
(MW)



Resource accreditation is simple in the traditional planning paradigm

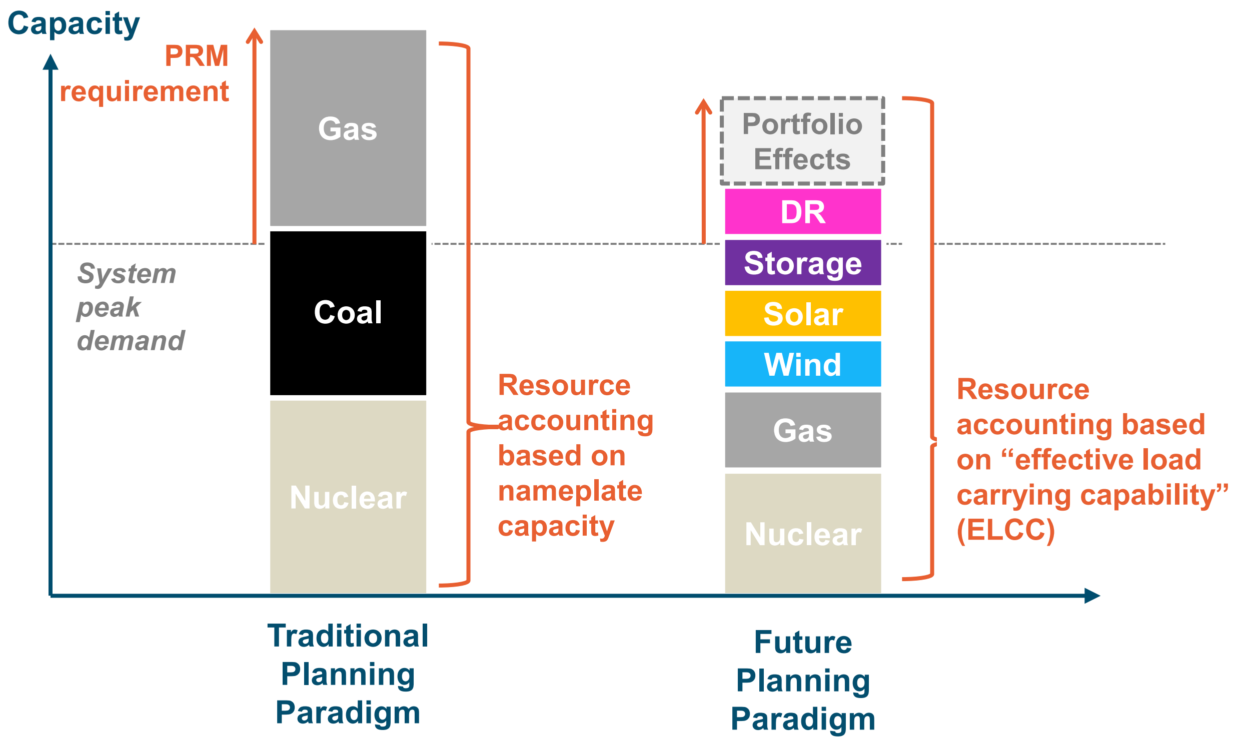
- **PRM defined based on Installed Capacity method (ICAP)**
  - Covers annual peak load variation, operating reserve requirements, and thermal resource forced outages
- **Individual resources accredited based on nameplate capacity**
  - Small differences in forced outage rates
  - No interactions among resources
  - Forced outages also incorporated through performance penalties



$$Installed\ Capacity = \sum_{i=1}^{n} G_i$$

Adapting the PRM framework for a high renewable future

- **PRM defined based on need for Perfect Capacity (PCAP)**
  - Covers annual peak load variation and operating reserves only; forced outages addressed in resource accreditation
- **Individual resources accredited based on ELCC**
  - Large differences in availability during peak
  - Significant interactions among resources
  - ELCC values are dynamic based on resource mix



$$Portfolio\ ELCC = f(G_1, G_2, \ldots, G_n)$$

Measuring ELCC of a portfolio and individual resources

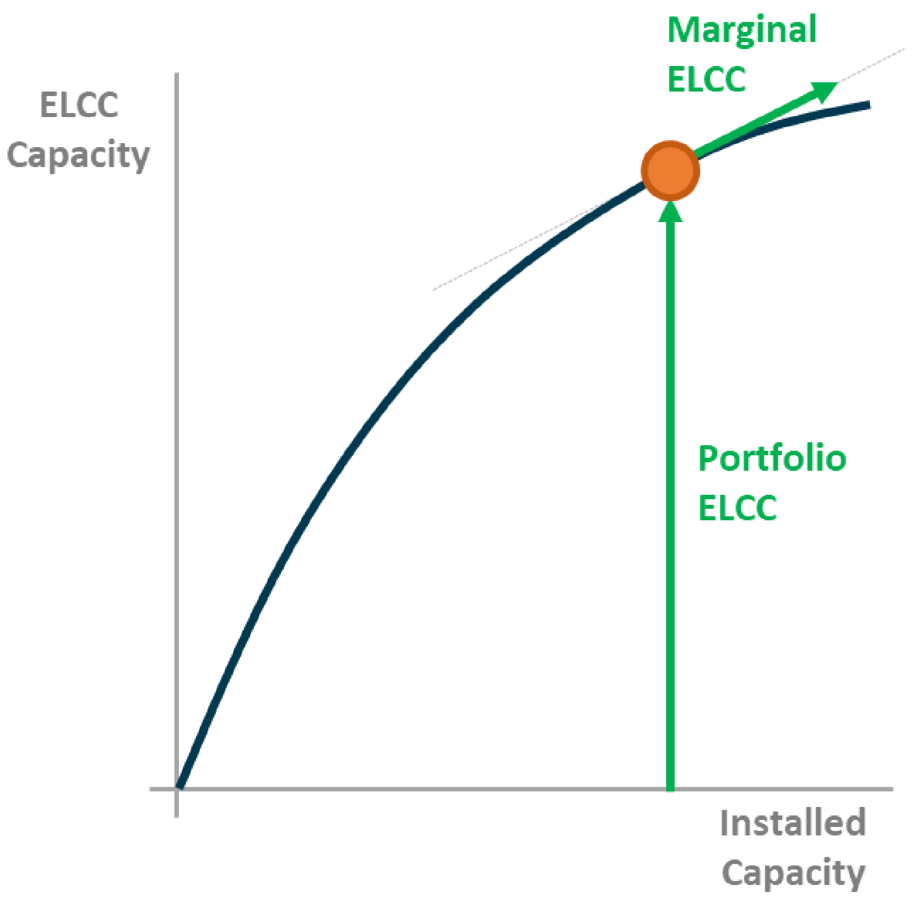
- **ELCC is a function of the portfolio of resources**
  - The function is a surface in multiple dimensions
  - The Portfolio ELCC is the height of the surface at the point representing the total portfolio

$$Portfolio\ ELCC = f(G_1, G_2, \ldots, G_n)\ (MW)$$

  - The Marginal ELCC of any individual resource is the gradient (or slope) of the surface along a single dimension – mathematically, the partial derivative of the surface with respect to that resource

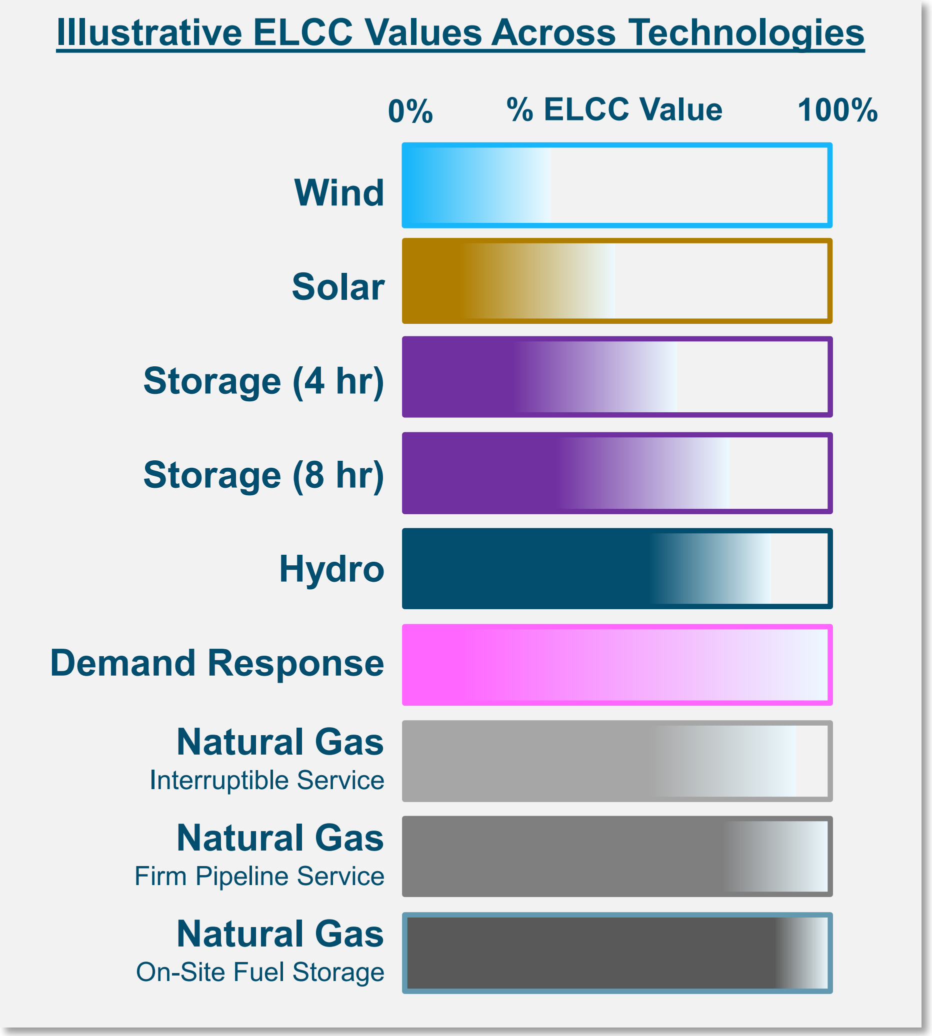
$$Marginal\ ELCC_{G_1} = \frac{\partial f}{\partial G_1}(G_1, G_2, \ldots G_n)\ (\%)$$

- **The functional form of the surface is unknowable**
  - Marginal ELCC calculations give us measurements of the contours of the surface at specific points
  - It is impractical to map out the entire surface



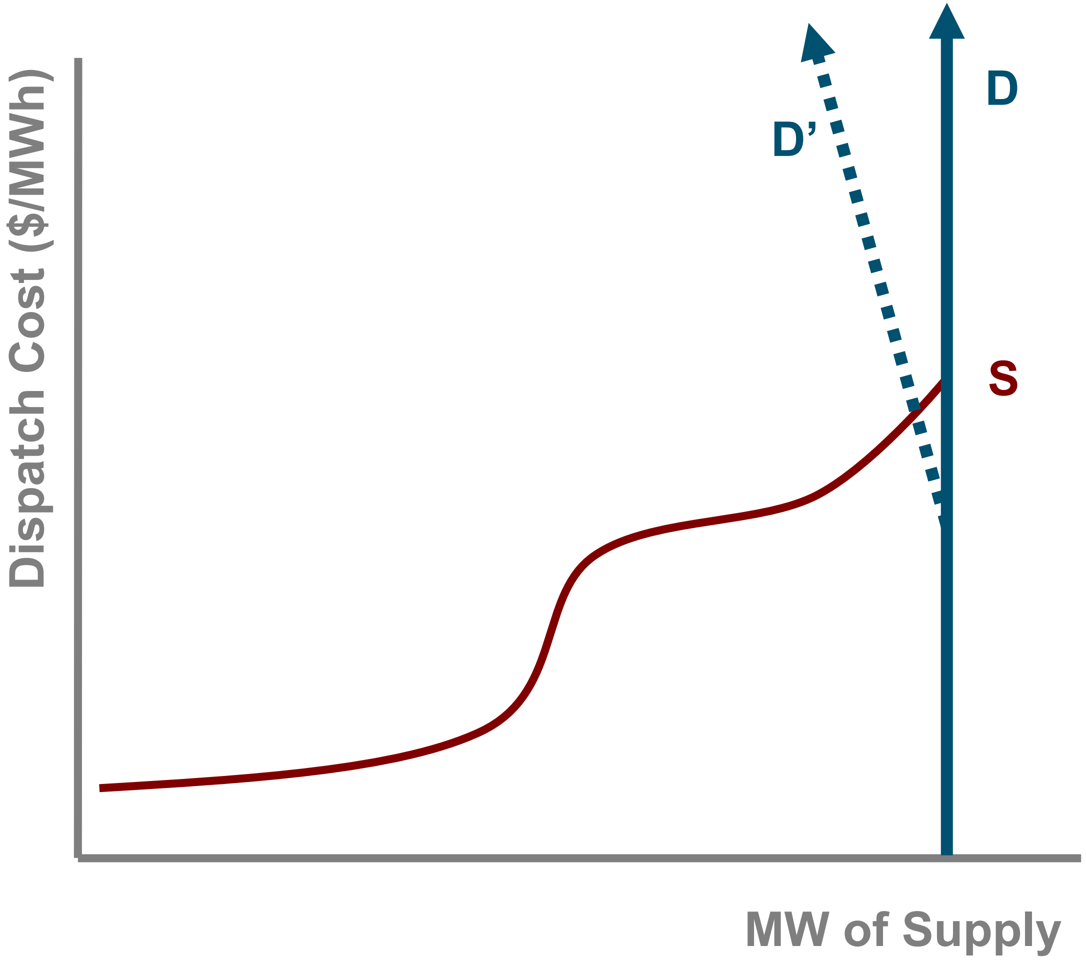
No resource is perfect: Accreditation based on marginal ELCC sends efficient price signals for market entry and exit

- **Capacity accreditation needs to recognize that no resource is "perfect": all resources are subject to factors that limit their availability**
  - Forced outages
  - Energy availability
  - Duration and/or use limitations
  - Hourly variability in output
  - Temperature-related and correlated outage rates
- **Marginal ELCC captures the effect of changes to the portfolio and is the appropriate metric to use for accreditation**
  - Focuses on critical hours for reliability
  - Creates a level playing field and sends good price signals for market entry and exit
  - Most organized markets in US are moving toward Marginal ELCC accreditation (NYISO, ISO-NE, PJM, MISO)



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**



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Clean Energy Attribute Markets

What characteristics should clean energy attribute markets have?

Key Characteristic	Description
Scalability	Should be robust enough to drive high penetrations of clean energy, e.g., 85% of generation
Economic efficiency	Can achieve high clean energy penetration and deep carbon reductions at lowest nationwide cost
Stability	Provides a stable and predictable investment signal for the value of new clean energy resources
Liquidity	Creates a liquid market for clean energy attributes, resulting in low transaction costs and low compliance costs and risks
Urgency	Does not require creation of extensive and complicated new compliance infrastructure
Accuracy	Accurately measures and assigns responsibility for carbon emissions

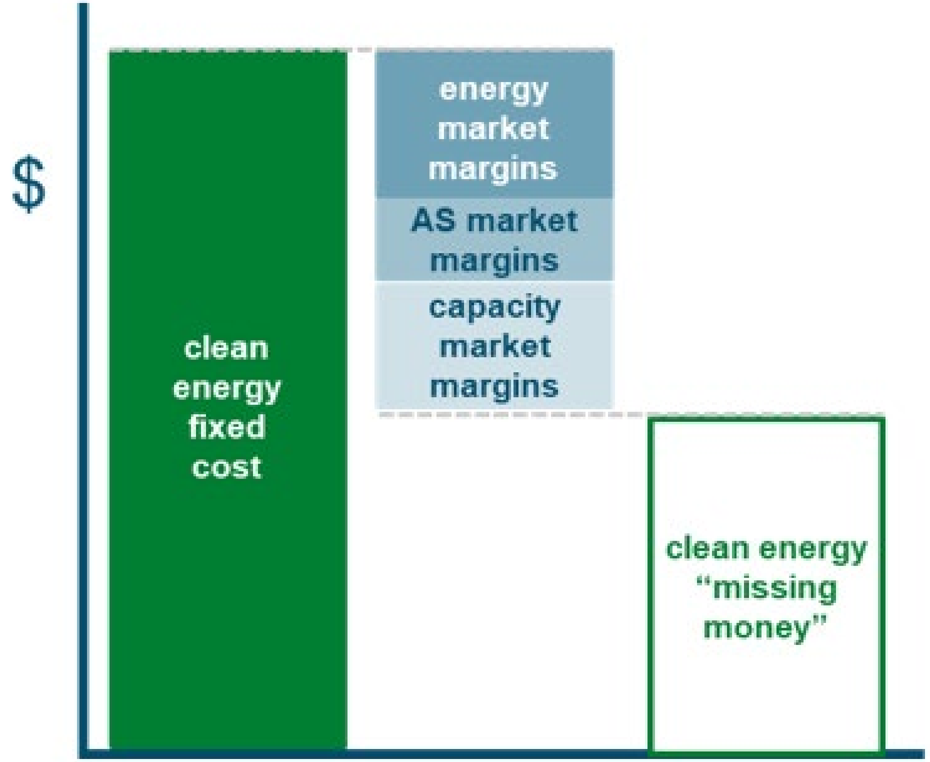
Carbon pricing has all these characteristics but is difficult to achieve politically

In lieu of carbon pricing, many jurisdictions have adopted policies focused on creating a market for clean energy

- **"Demand-pull" policies have been needed to drive clean energy adoption because clean energy has been more expensive than conventional energy**
  - Demand-pull policies solve the clean energy "missing money" problem by creating additional compliance value
  - RECs represent the missing money or "green premium" that clean energy projects need to compete with conventional energy
  - REC prices provide a visible value signal for clean energy developers

Procuring clean energy is the inverse of pricing emitting energy

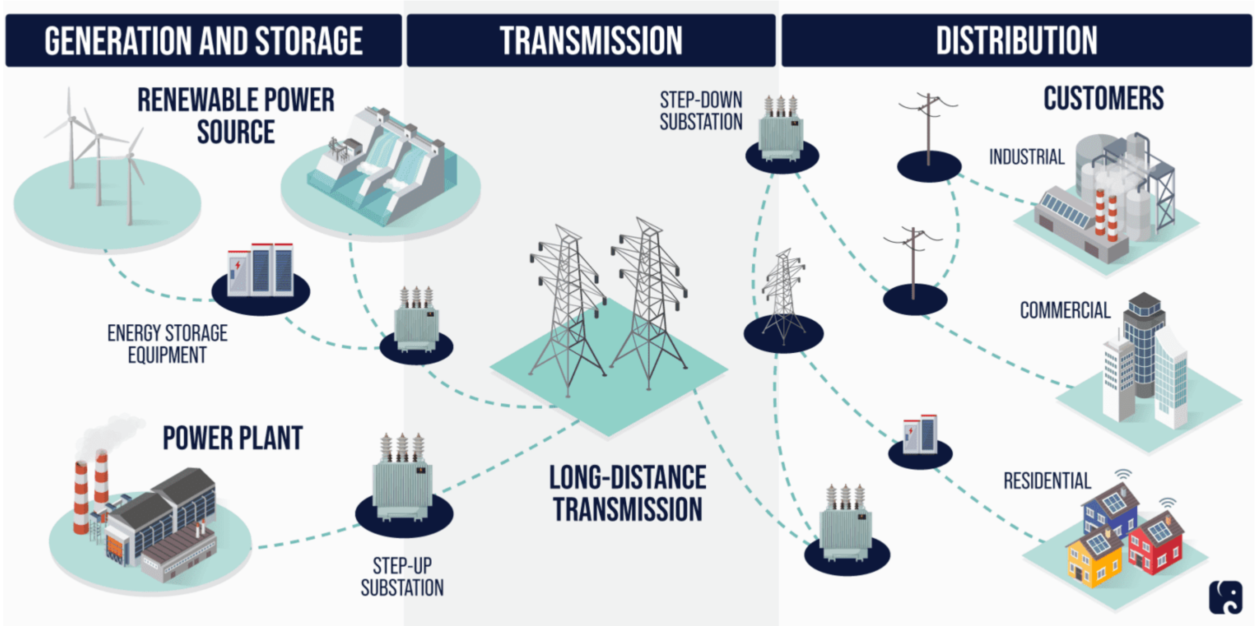
Clean Energy "Missing Money" Problem



Specified energy purchases are a convenient fiction

- **Specified energy does not physically serve load on a networked power system**
  - Generators inject into the grid in one location, displacing other generators with higher operating costs
  - Loads withdraw from the grid in another location, served by a mix of generators on the system

- **This fiction is important!**
  - Billions of dollars have been invested based on the notion that electric load can be served with specified clean energy supplies
  - Since 1995, 243 GW of wind and solar capacity has been added to the U.S. grid(s), representing approximately $500 billion dollars of capital deployed



https://www.rpc.senate.gov/policy-papers/infrastructure-cybersecurity-the-us-electric-grid

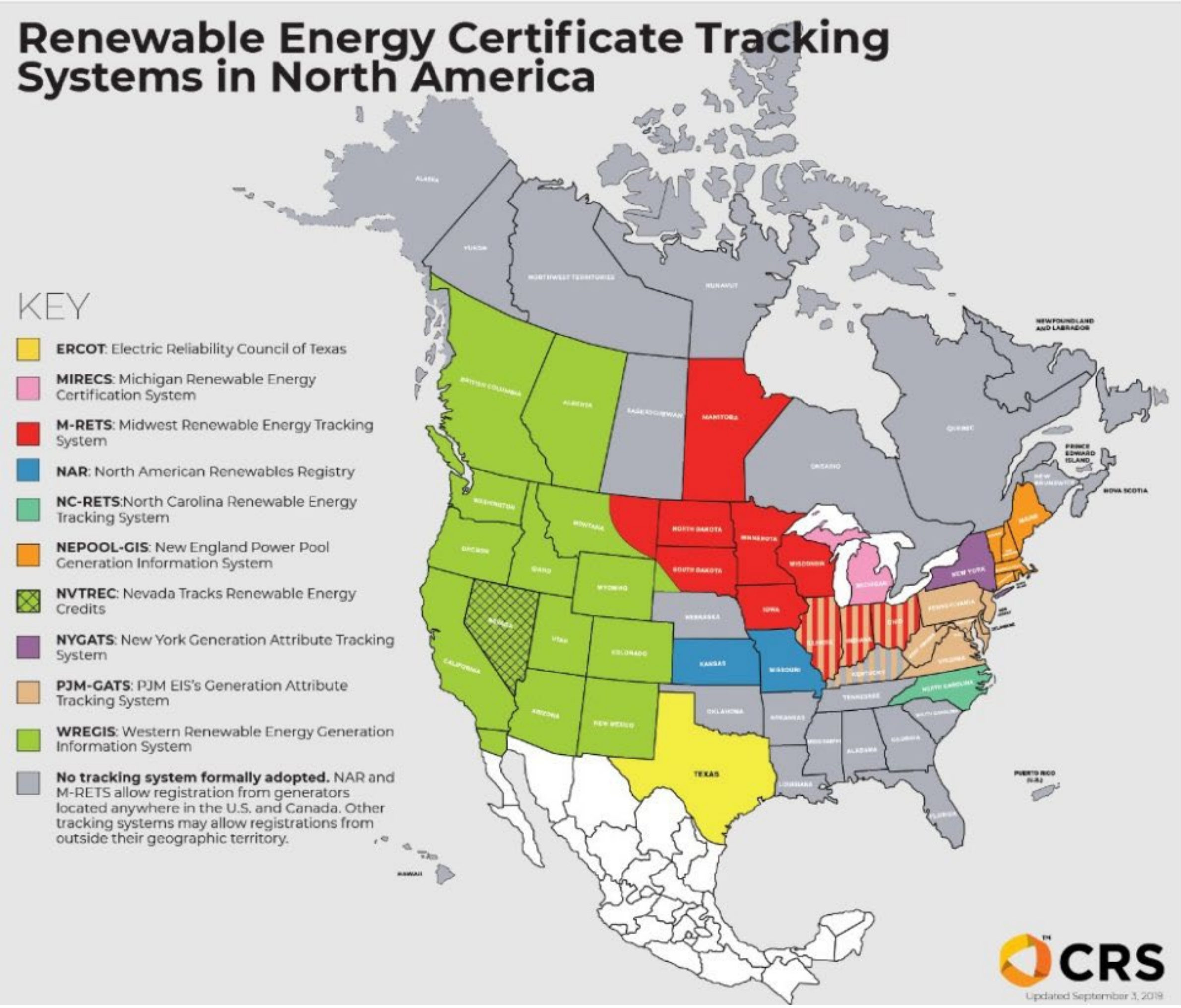
RECs are needed to implement demand-pull clean energy policies

Clean Energy Content Verification

- A mechanism is needed to verify the clean energy content of energy purchases
- The creation, trade, and retirement of RECs are verified and tracked by independent organizations to ensure no double-counting of renewable attributes across jurisdictions

Portfolio Balancing

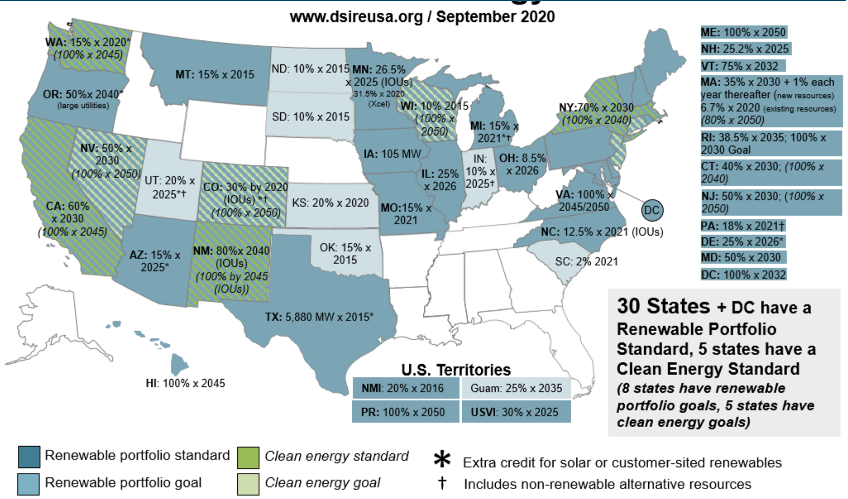
- REC trading enhances efficiency by providing a tool for portfolio balancing and a visible price signal
- REC trading is an important tool for voluntary clean energy purchasers, who may not have the means to balance their load with their own supply



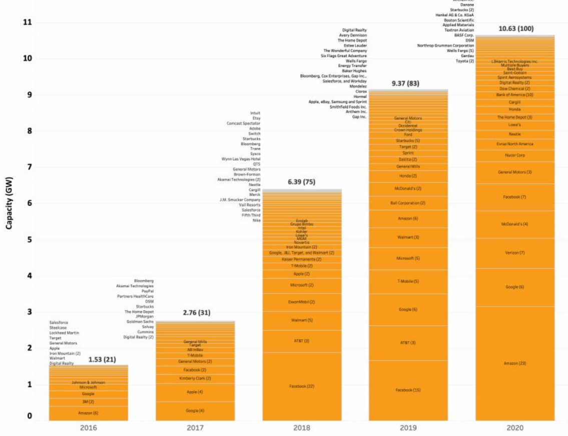
Today's clean energy incentives are highly fragmented and inconsistent across the US

- **Universal carbon pricing is most efficient but is hard to pass (carrot is more politically appetizing than stick), and patchwork carbon pricing creates leakage issues**
- **In the absence of federal action, others rush to fill the void:**
  - States
  - Utilities
  - Large energy buyers (corporates)
- **Wild variety in metrics (renewable? clean? carbon?), definitions, and level and timing of targets**

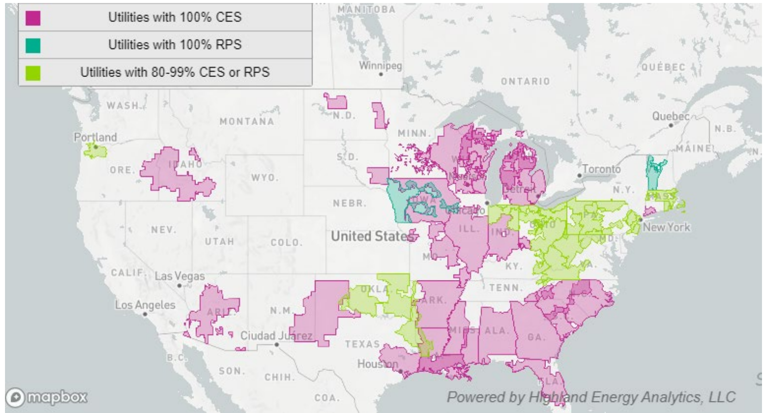
State RPS/CES Policies



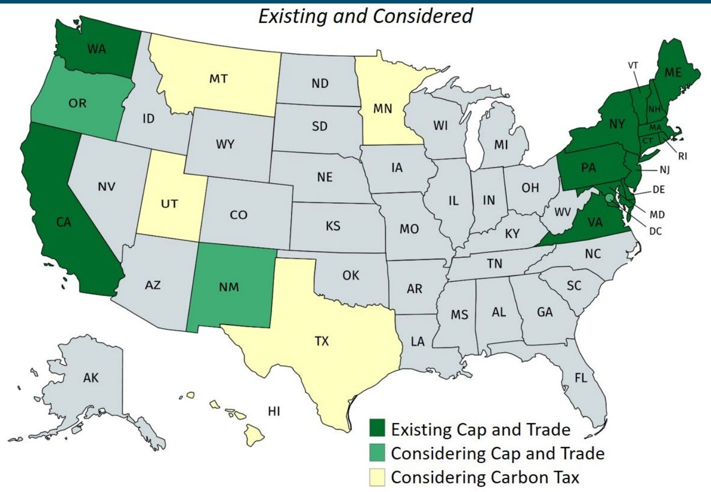
Voluntary Corporate Procurement (>10 GW renewable PPAs in 2020)



Utility Goals



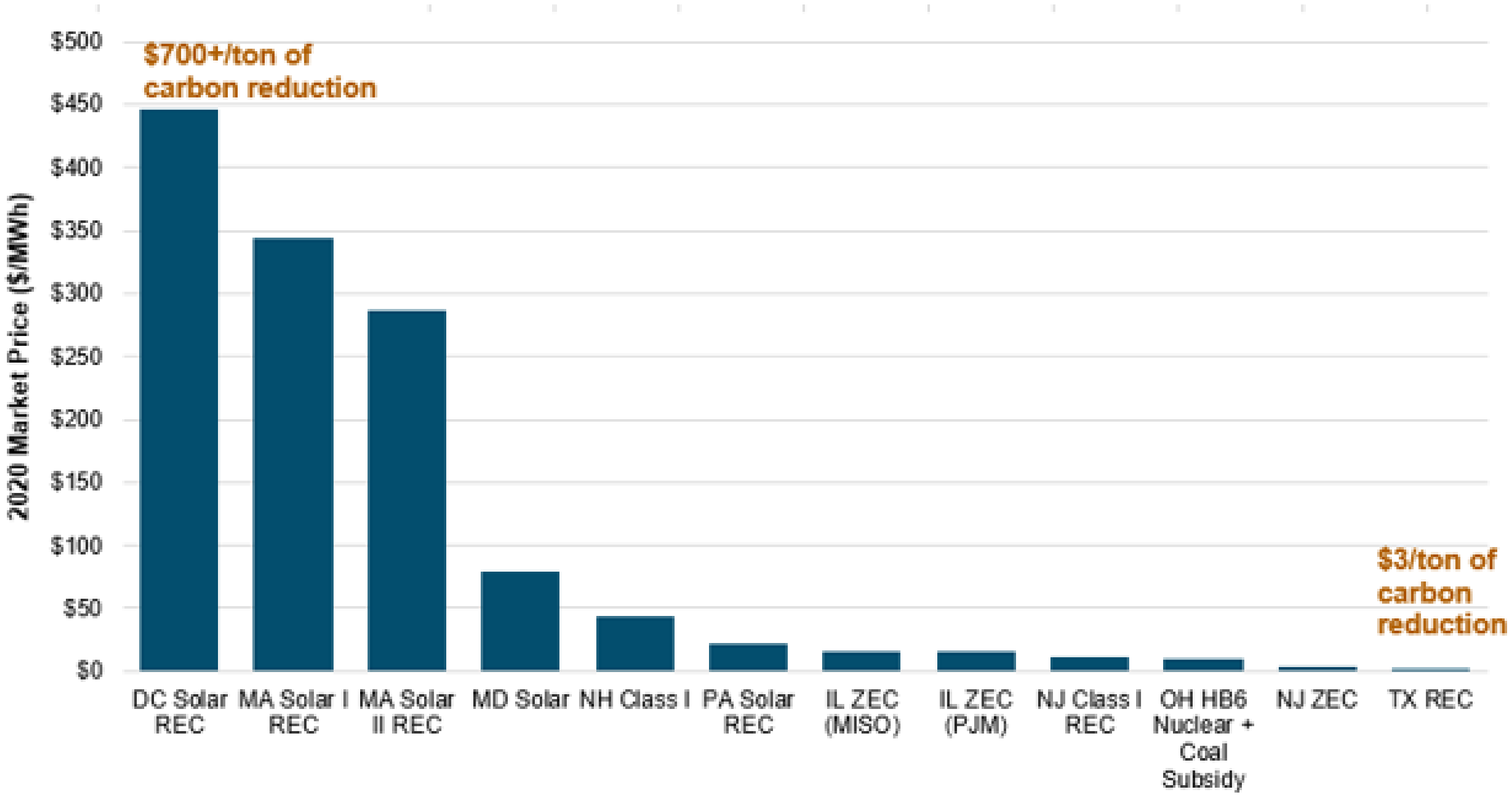
State Carbon Pricing Policies



Result is inconsistent and highly inefficient approach at reducing carbon emissions

- **Why pay $400+/MWh for a clean MWh when there are other sources for $1/MWh?**
  - These programs provide other benefits, but are inefficient at reducing carbon
- **Piecemeal, fractured approach can't scale to meet long-term goals such as 85% carbon reductions or 100% clean energy**
  - Need a lot more clean MWhs
  - Need them to be affordable to enable electrification

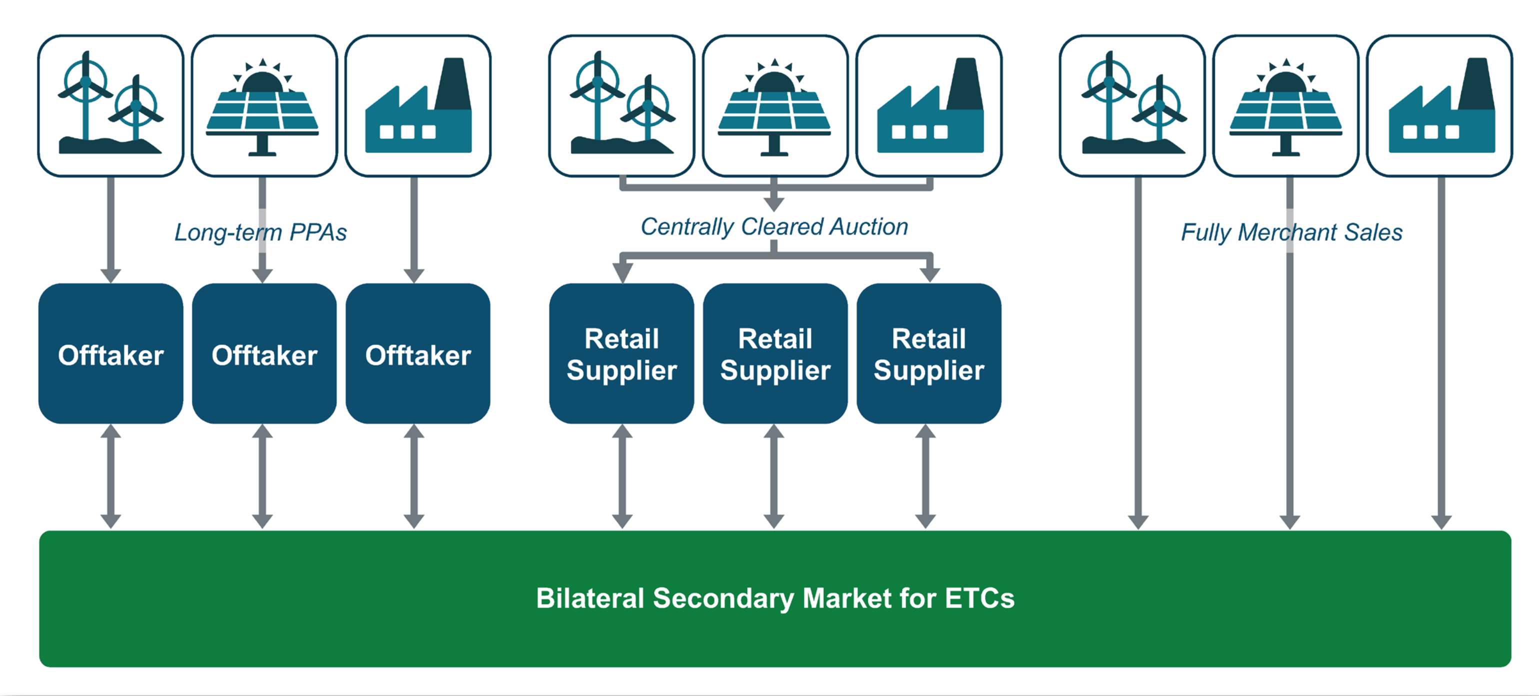
Various REC Prices and Implied Cost of Carbon Reductions



E3 Proposal: Voluntary, Bilateral Market for National Energy Transition Credits (ETCs)

+ **Standardized instrument reflecting clean energy attribute**
  - Clean MWh from renewables, nuclear, hydro, etc. compete on level playing field
  - Clean MWh gets equivalent credit no matter where it is generated
    - Regional differences in avoided CO_2 will diminish as coal is retired
  - Aligns with state/local jurisdiction
+ **Accreditation can continue as it does today**
+ **National ETCs traded on a visible platform e.g., CBOT**
  - More specific REC/ZEC products can be traded as a basis spread relative to a national ETC

Flexible Options for Trading Energy Transition Credits (ETCs)



National ETCs become the "Henry Hub of RECs"!

"Emissions First" proposal: create ETCs based on marginal grid carbon emissions

- **Emissions First coalition has advocated for an approach based on time-and-location-specific short-run marginal emissions rates (SRMER)**
  - Supported by Amazon, Meta, Intel, Salesforce, and others
- **Load and gen assessed separately based on the marginal emissions rate during their hours of operation**
  - Carbon neutrality is achieved if carbon *reductions* from clean generation are equal to carbon *emissions* attributable to load on an annual basis
- **Tradable market instrument for clean energy supply denominated in tons**

Clean energy accounting ≠ carbon accounting

Short-run marginal emissions rates for one 5-minute interval across PJM

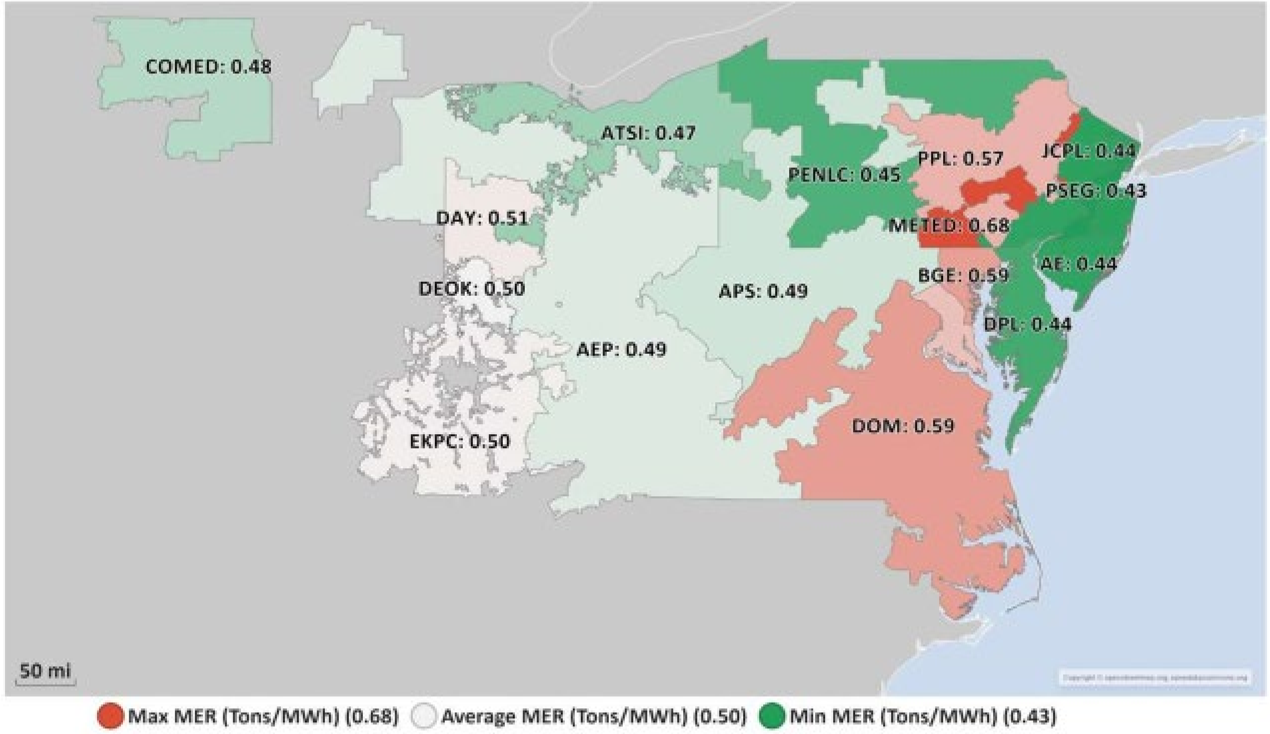


Figure 2: PJM zonal marginal CO_2 emission rate for a single 5-minute interval

https://www.emissionsfirst.com/post/putting-carbon-matching-into-practicewe

Thank you!

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