

Price Formation in Wholesale Electricity Markets

Outcomes under Systems with 100% Zero-Fuel-Cost with Opportunity-Cost Resources

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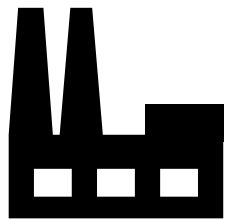
Energy Systems Integration Group

June 14, 2023



Quick explanatory example

Gen A and B have characteristics below, and demand is **50 MW**



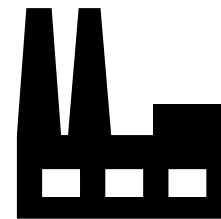
Generator A

Generating range: 0 – 40 MW

Variable cost: \$30/MWh

No load cost: \$500/h

Online, dispatched to 40 MW



Generator B

Generating range: 20 – 100 MW

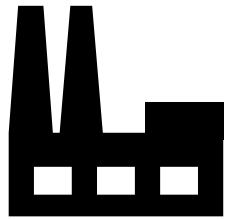
Variable cost: \$60/MWh

No load cost: \$500/h

Online, dispatched to 10 MW **X**

Quick explanatory example

Gen A and B have characteristics below, and demand is **50 MW**



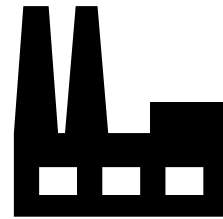
Generator A

Generating range: 0 – 40 MW

Variable cost: \$30/MWh

No load cost: \$500/h

Online, dispatched to 30 MW



Generator B

Generating range: 20 – 100 MW

Variable cost: \$60/MWh

No load cost: \$500/h

Online, dispatched to 20 MW

What is the LMP?

\$30? \$60? \$65?

Answer: It depends. Or, All of the above (depending on the ISO market)



What affects Electricity Prices?

Fuel Costs

Cross-Product
Opportunity
Costs

Cross-Temporal
Opportunity
Costs

Electrical
Losses and
Congestion

Non-convex
costs

Degradation
and Wear/Tear

Emission
pricing and
constraints

Shortage
Pricing

Constraint
Relaxation

Pricing “Circuit
Breakers”

Market
Mitigation

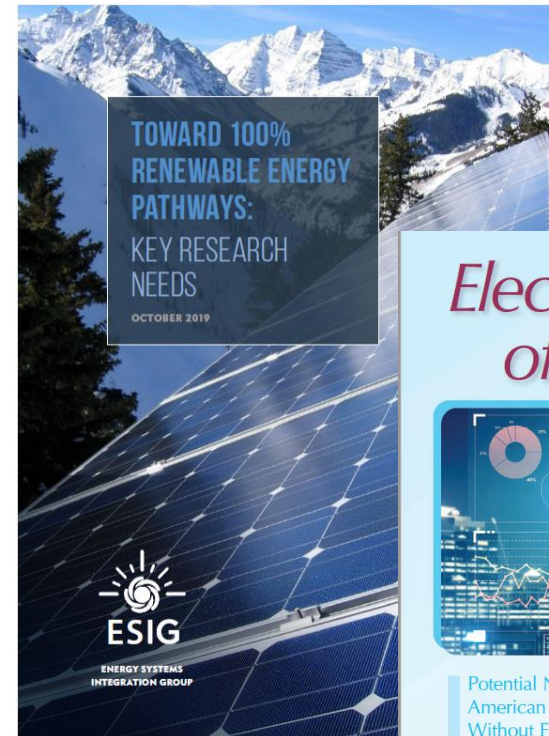
Forward
Markets &
Contracts



How will prices change in a zero-fuel-cost future?

Price formation within deep decarbonized electricity markets

- How will markets **enable** the **transition**?
- Will **average** prices **decline** or be more **volatile**?
- The **demand** side will be a crucial piece – how does it **fit**?
- Will **substantial** changes to the **design and structure** of electricity markets be necessary?
- Are the **existing** market designs **functional** for this scenario?
- Are **other mechanisms** needed to support investment

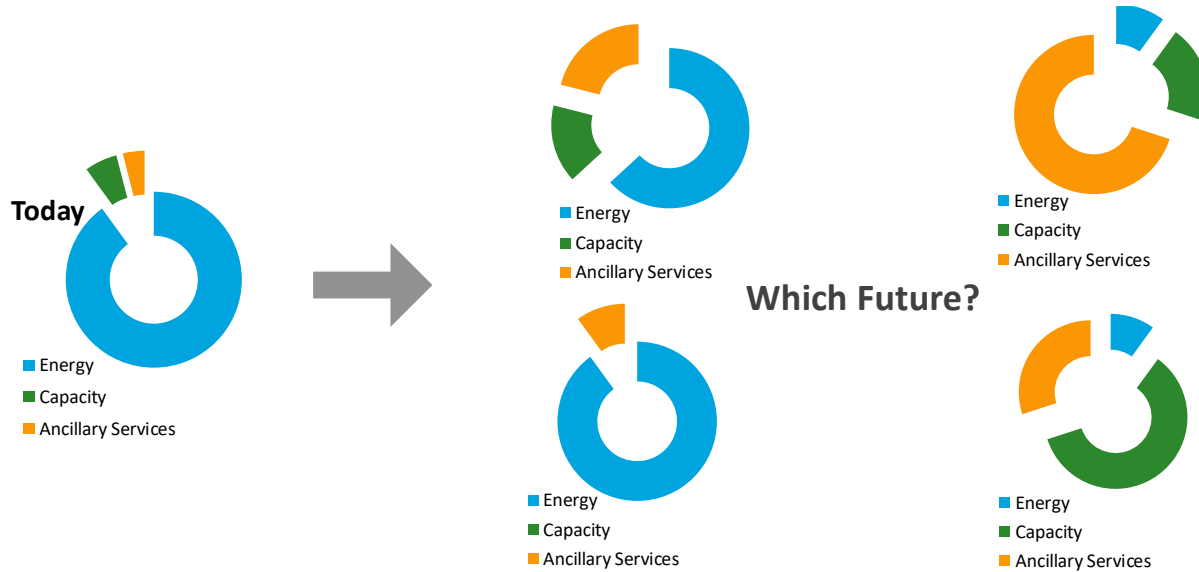


ESIG 100% Workshop

Ela, Mills, Gimon, Hogan, Bouchez, Giacomoni, Ng, Gonzalez, DeSocio, "Electricity Market of the Future: Potential North American Designs Without Fuel Costs," IEEE Power and Energy Magazine, Vol. 19, no. 1, Jan/Feb. 2021. Available: https://nxt-staging-books.s3.amazonaws.com/nxtbooks/pes/powerenergy_010221/src/pes_powerenergy_010221.pdf.

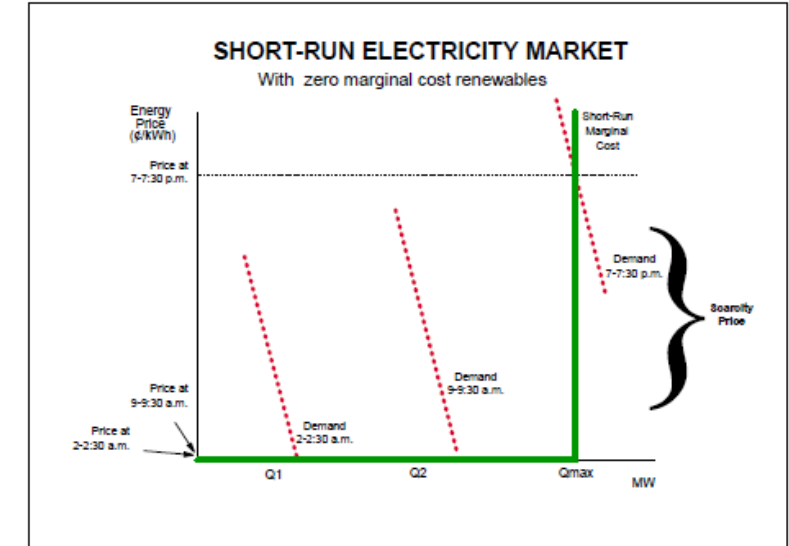
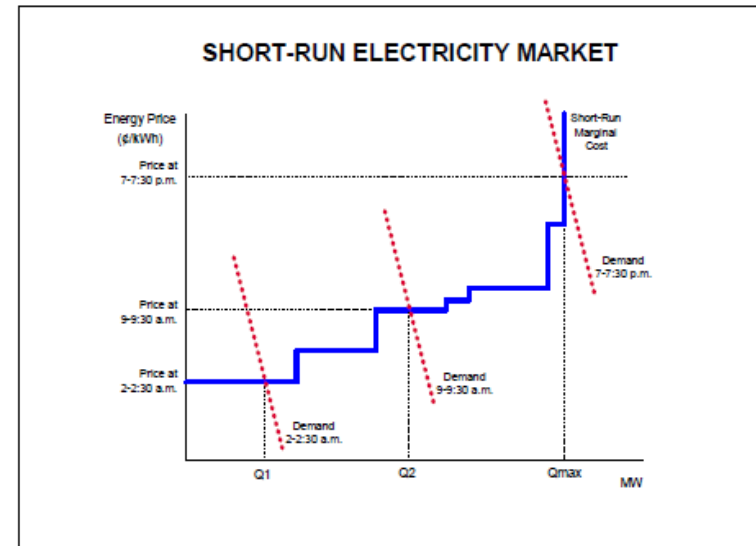
Wholesale Electricity Market Design for Rapid Decarbonization - Energy Innovation: Policy and Technology

What will Energy Prices look like? It depends!



- Investment signals, environmental policies
- Resource adequacy structures
- Responsiveness of demand
- Price formation with storage

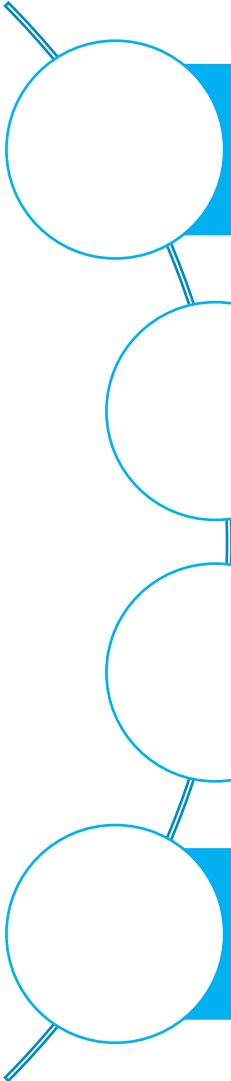
- Shortage pricing design and shortage allowance
- Renewable locations and correlation
- Cost-effectiveness of enabling technologies



W. Hogan, "Electricity Market Design and the Green Agenda," *IEEE PES GM*, 2020.

Price Formation

Key Questions



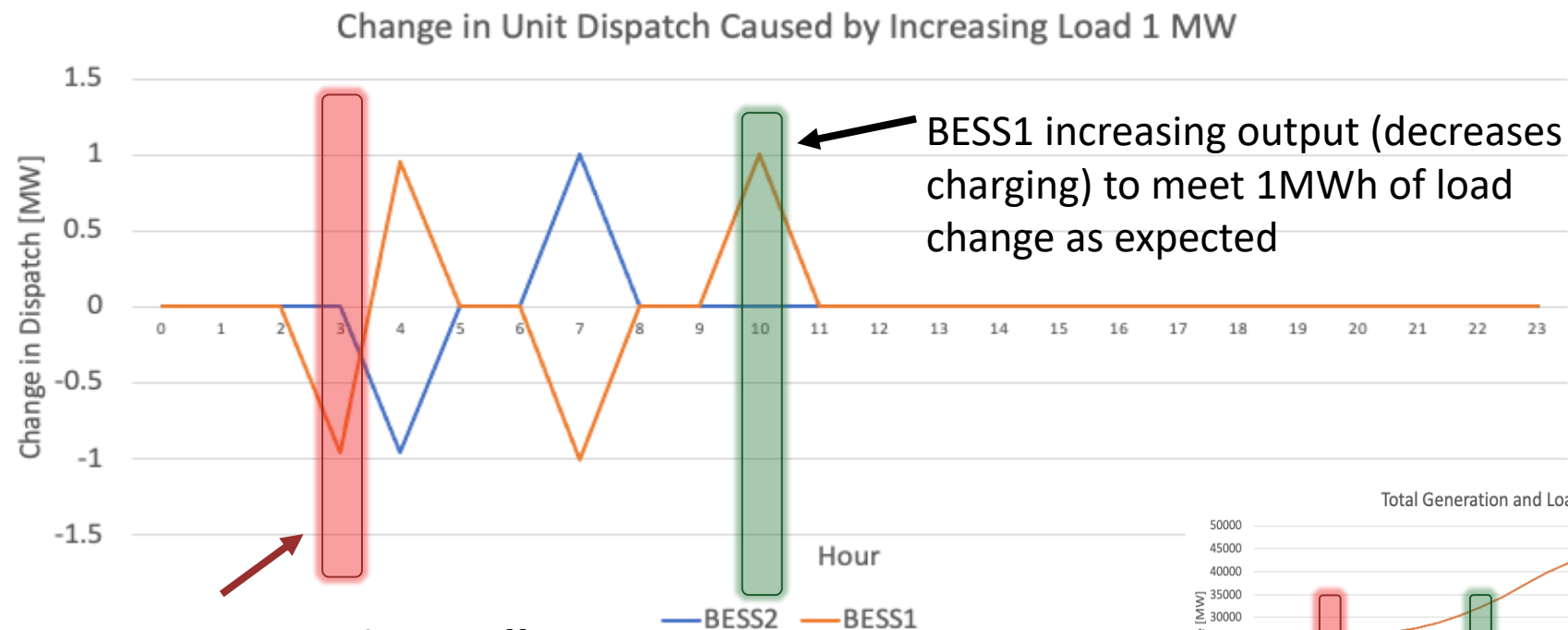
What is the marginal cost?

What is the value of energy to consumers?

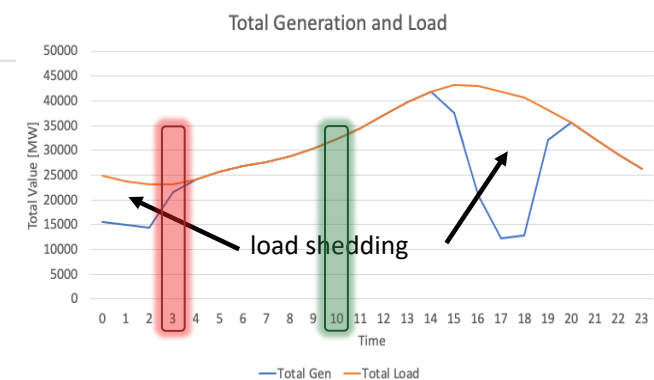
What is the cost / value of operational attributes?

How do retail customers understand and react?

Evaluating determination of price – Capacity Constrained



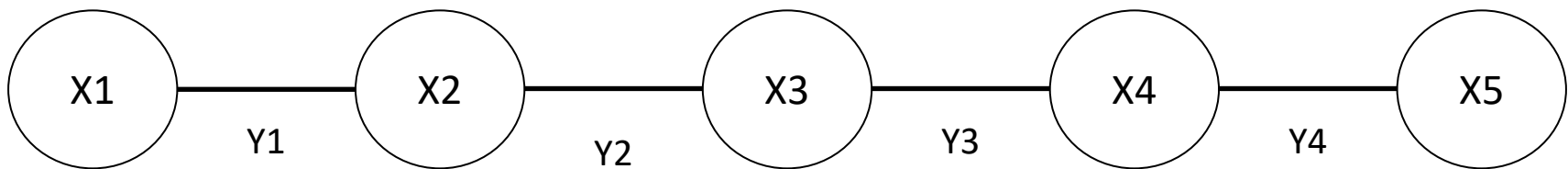
BESS1 must reduce its output at 3:00, to have sufficient energy for 10:00 and end of day, further exacerbating a load shedding event that was occurring during 3:00



- Shortage pricing observed at 10:00 due to shortage at 3:00!

Analogy of Storage and Transmission Pricing

The way that storage impacts price formation, especially with large amounts of storage, and dominant zero-fuel-cost resources, is analogous to how transmission impacts on locational prices. There are important differences, however. The conceptual view below can be used for either case. Because of the unique way in which power flows as defined by Kirchoff’s laws, we encourage readers to instead think of zonal, transportation-based flow with a radial network structure.



Concept	X	Y	If all Yn are limitless (ignoring losses)	Other price differences
Locational Pricing	Zones	Transmission Interface Constraints	All locations have the same price (based on marginal resource across all zones)	Transmission losses
Temporal Pricing	Intervals	Energy Storage SOC constraints	All intervals have the same price (based on marginal resource across all intervals)	Storage round-trip efficiency losses

How do Energy Storage Resources Impact Wholesale Electricity Prices in Future Systems with 100% Zero Fuel Cost (ZFC) Resources?
EPRI, Palo Alto, CA: 2022. 3002024549.

\$0/MWh prices when there is no curtailment, shortage pricing when there is no shortage

OK, so now what?

Prices will always be zero! With some spikes!

Prices will not look too dissimilar from today!



Research, analysis and simulation can better prepare us



Together...Shaping the Future of Energy®

