Maximizing the Market Value of Flexible Hydro Generation

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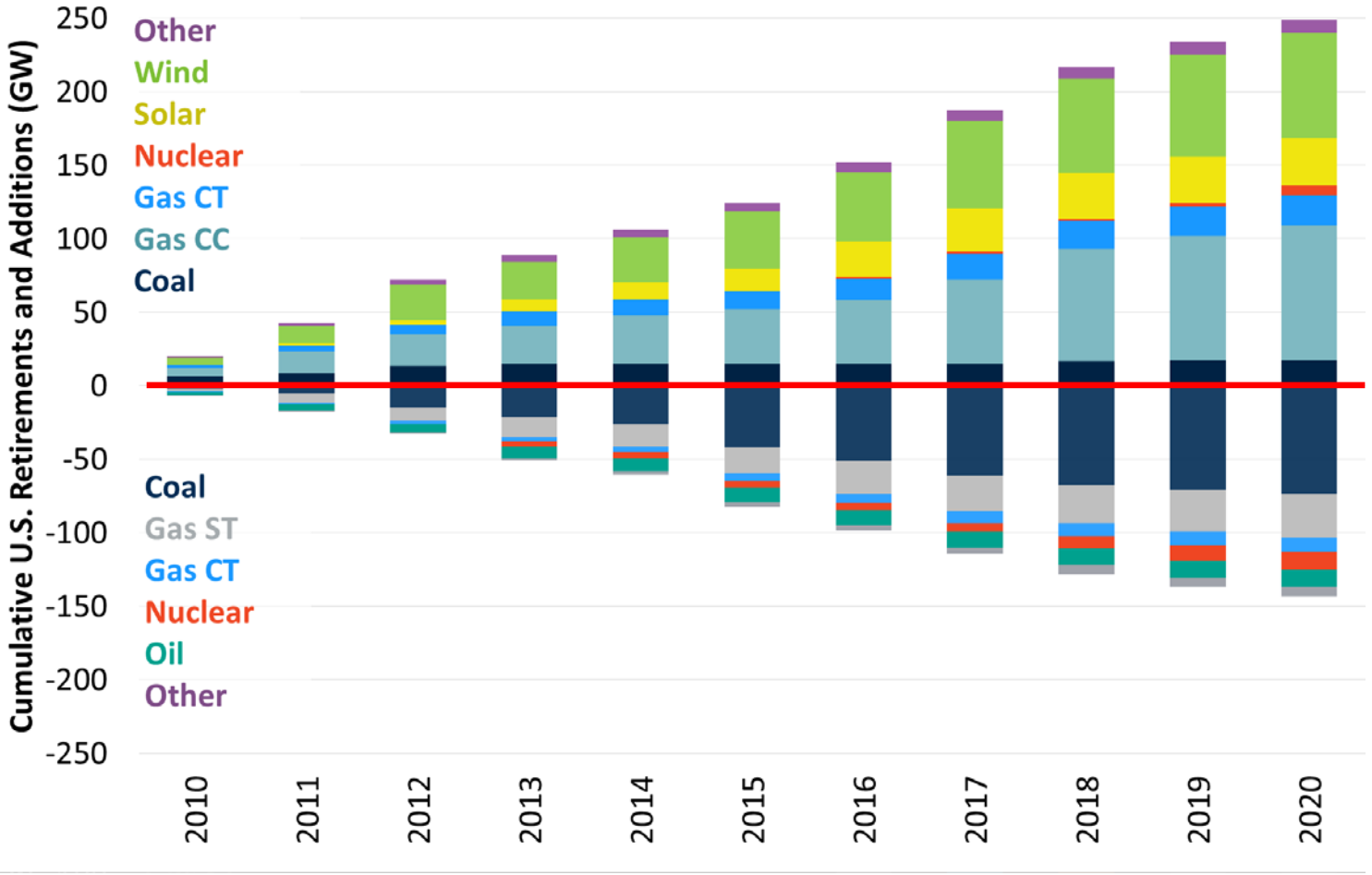
THE Brattle GROUP

Content

- Growing grid flexibility needs
- Hydro resource flexibility
- Factors currently limiting hydro value
- The bSTORE tool for maximizing hydro value
  - Case Study: Optimizing pumped hydro into RTO markets
- Managing transmission constraints

The Resource Mix is Changing Rapidly

U.S. Retirements and Additions (2010 – 2020)

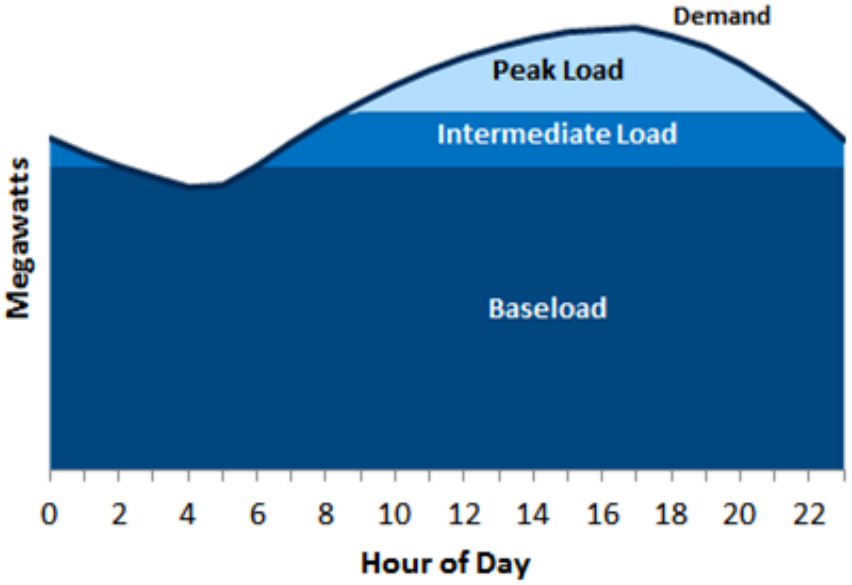


Source: The Brattle Group analysis of data compiled by ABB, Inc., The Velocity Suite

Changing Supply Mix = Need for More Flexibility

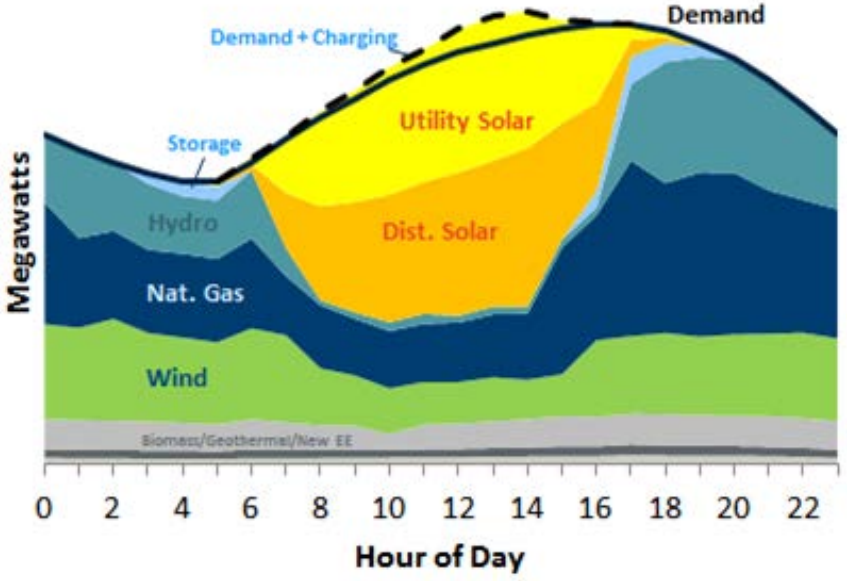
Flexible resources that can respond quickly and efficiently as system conditions change are needed to operate with an increasing share of variable generation. Hydro is uniquely able to provide this flexibility.

Electricity Demand and Traditional Supply Mix



Source: The Brattle Group

Electricity Demand and Supply Mix with High Renewable Generation



Source: The Brattle Group

Complements: Batteries and Flexible Hydro

All storage and flexible resources will be needed to meet the systems' growing flexibility needs cost effectively.

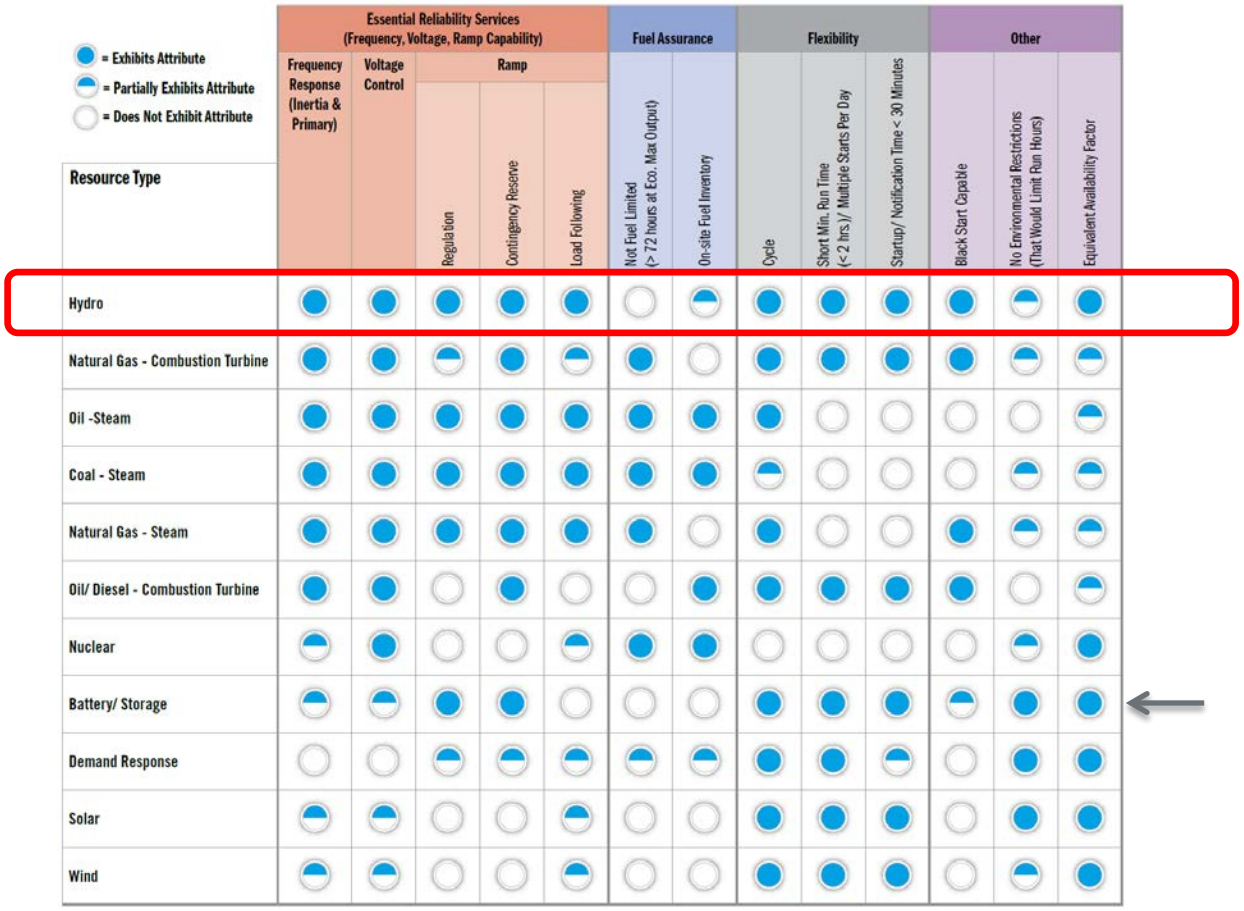
- Where available, flexible hydro plants are successfully employed to balance regional power systems:
  - Daily and seasonal storage to meet peak loads and help integrate large baseload plants (nuclear, coal, run-of-river hydro)
- Battery storage is gaining momentum as markets begin to recognize their capabilities and contribution
  - Brattle Study: 50 GW of battery storage potential at cost of $350/kWh installed
  - Declining battery costs make them suitable to address:
    - Fast regulation and ramping needs
    - Peaking energy and capacity (only up to several hours)
    - Distributed local T&D needs
    - Customer bill savings and outage reduction

Together with battery deployment, increasing the operational flexibility of hydro resources will be a low-hanging fruit to help address growing flexibility needs in some regions.

Hydro is a Major Provider of Op. Flexibility

Flexible hydro plants are becoming more valuable as system needs for reliability and flexibility "attributes" increases.

PJM Generator Reliability Attribute Matrix



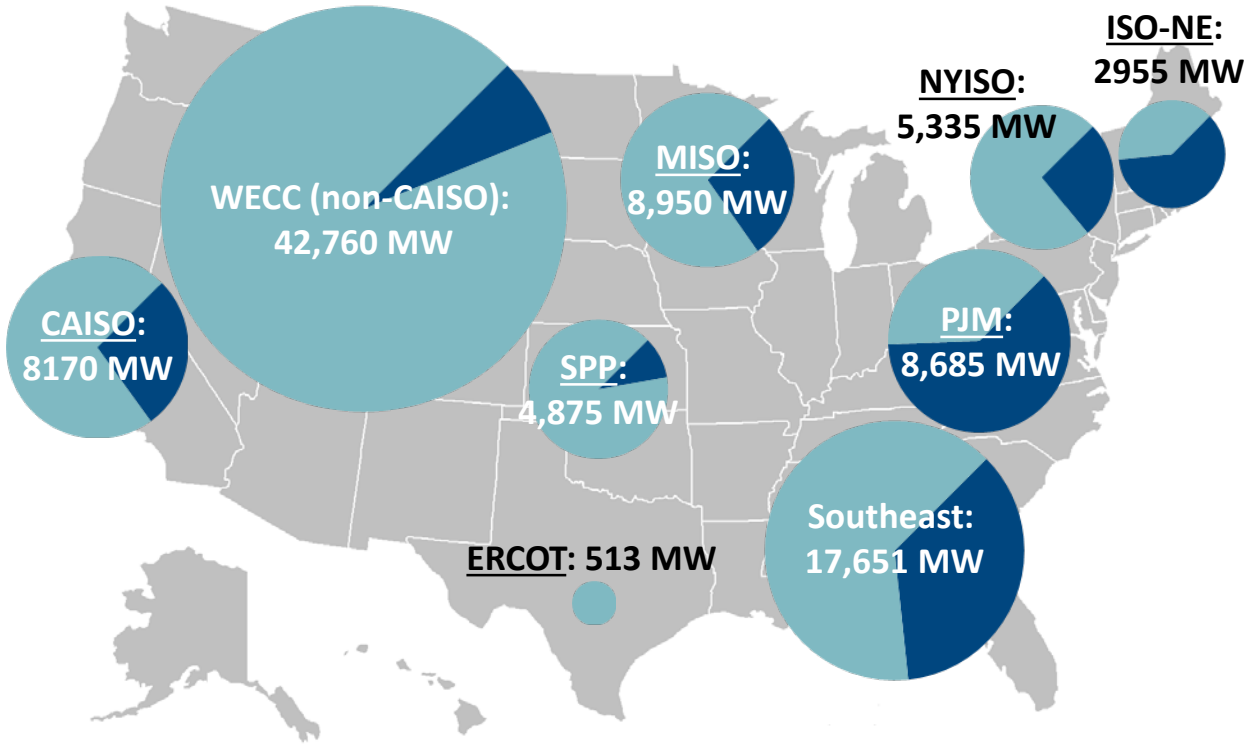
Source: PJM Interconnection, *PJM's Evolving Resource Mix and System Reliability*, page 16, http://www.pjm.com/-/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx .

Where available, existing (and some new) hydro plants are a very cost-effective source of flexibility, although different hydro plants have varying degrees of versatility

In addition to these system flexibility attributes, batteries provide value streams such as local T&D benefits, customer bill savings, and outage reduction

Substantial Existing Large Hydro Resources

Existing Hydro Capacity in U.S. Regional Markets



- The vast majority of conventional hydro resources offer grid flexibility.
- Even pondage hydro plants, sometimes labeled as run-of-river, usually have a dam that enables them to control water flow and generation on an hourly, daily, and occasionally weekly timeframe.

Hydro Storage Capacity in U.S. RTO Areas

Sources and Notes: The Brattle Group analysis based on SNL and other data of existing hydro plants over 25 MW.

Opportunities to Increase Hydro Value

The potential value of hydro plants is rarely realized in the energy and ancillary services markets today.

- *Market limitations*:
  - Market design, rules, optimization systems
  - The U.S. energy markets developed with a focus on thermal resources
- *Bidding and operational practices*:
  - Heuristic procedures developed to address the physical resource constraints
- *Resource constraints*:
  - Pumped-storage hydro: min output, min pump, time to switch, and others
  - Pondage and reservoir hydro: minimum flow constraints, cascading hydro operation, environmental, public safety, and public recreation constraints
- *Transmission congestion*:
  - Some hydro facilities are located in areas subject to frequent transmission limitations

Hydro resource owners will need to re-evaluate these constraints to create additional flexibility that could be offered into the market.

RTO Market Rules and Software Challenges

RTO rules and operational tools often limit hydro resources' market participation and ability to capture their full wholesale market value.

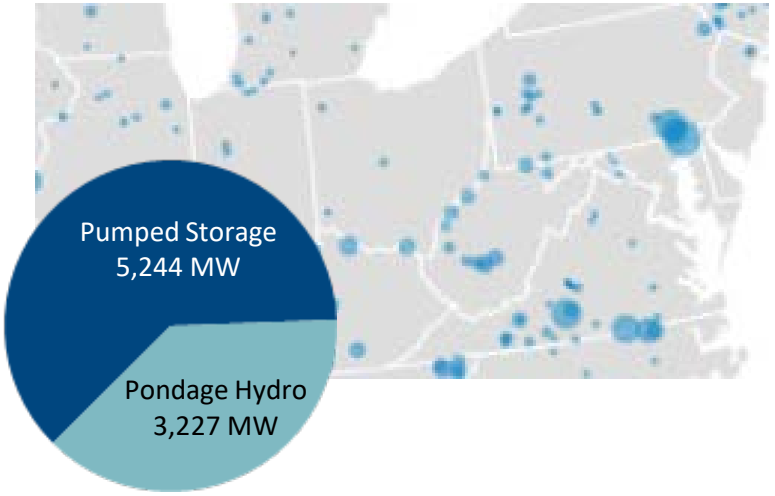
Case Study: PJM

- *Although opportunity costs are generally allowed, it does not appear that they are well-defined or actively used for hydro units.*
- *Pumped-storage hydro can be optimized by PJM in the day-ahead market.*
- *Hydro plants not scheduled by PJM (including all pondage plants) cannot submit price-based offers,* i.e., they must self-schedule.*
- *Market enhancements have not yet focused on hydro plants.*

Potential Improvements

- ***Allow offering hydro energy at a price.***
- ***Optimize hydro scheduling as part of market clearing, including pondage plants.***

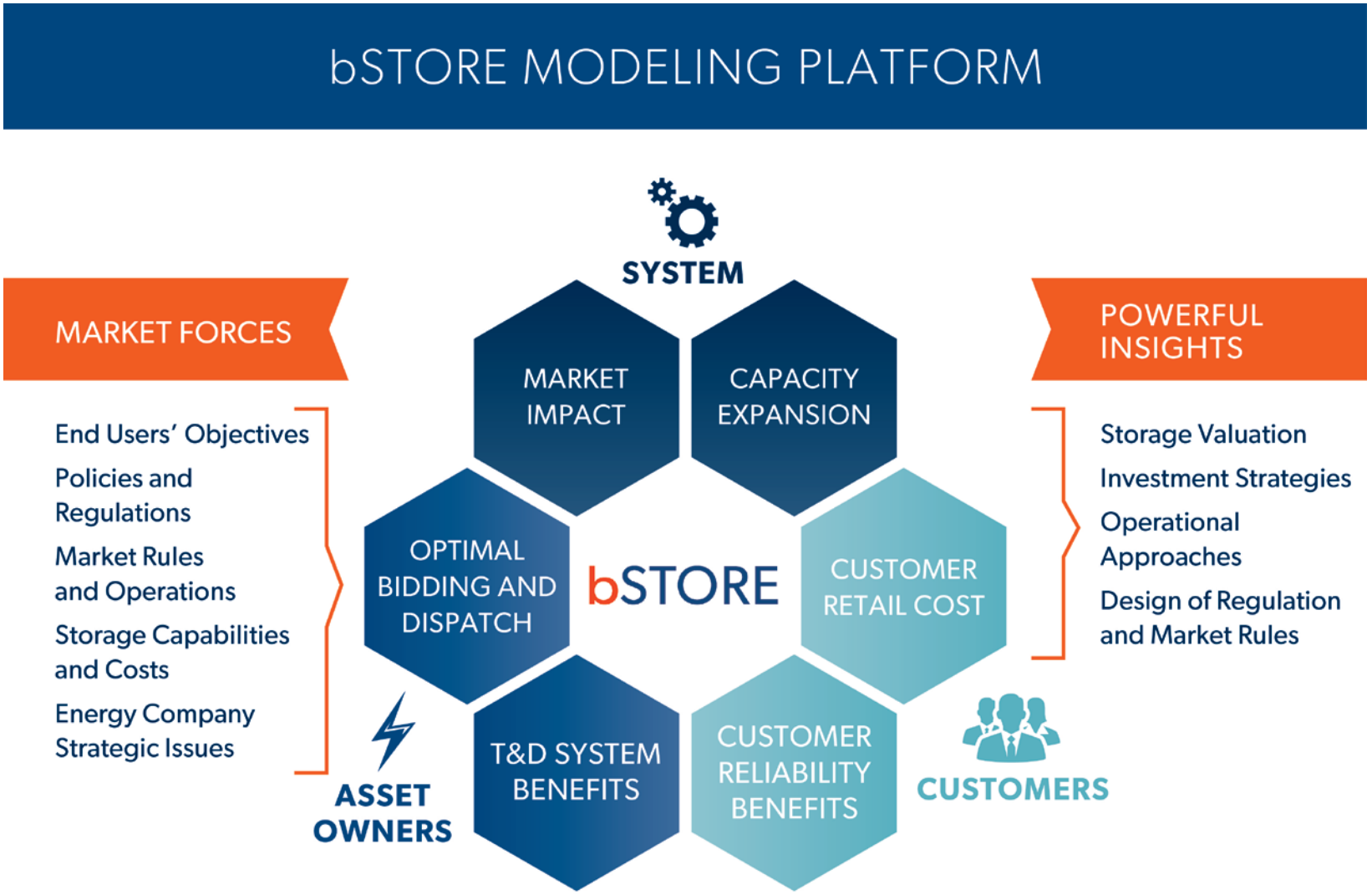
Hydro Plants in the PJM footprint



Sources:
Map: John Muyskens, Dan Keating and Samuel Granados, "Mapping how the United States generates its electricity," *The Washington Post*, updated March 28, 2017, https://www.washingtonpost.com/graphics/national/power-plants/?utm_term=.1ee4dad07383
PJM hydro rules: PJM Operating Agreement, Schedule 1, Section 1.10 Scheduling, http://www.pjm.com/directory/merged-tariffs/oa.pdf
Hydro plants: The Brattle Group analysis based on SNL and other data.

Notes:
** Other resources can submit price-based offers even if they do not have "fuel costs."*

Brattle's bSTORE Storage Modeling Platform



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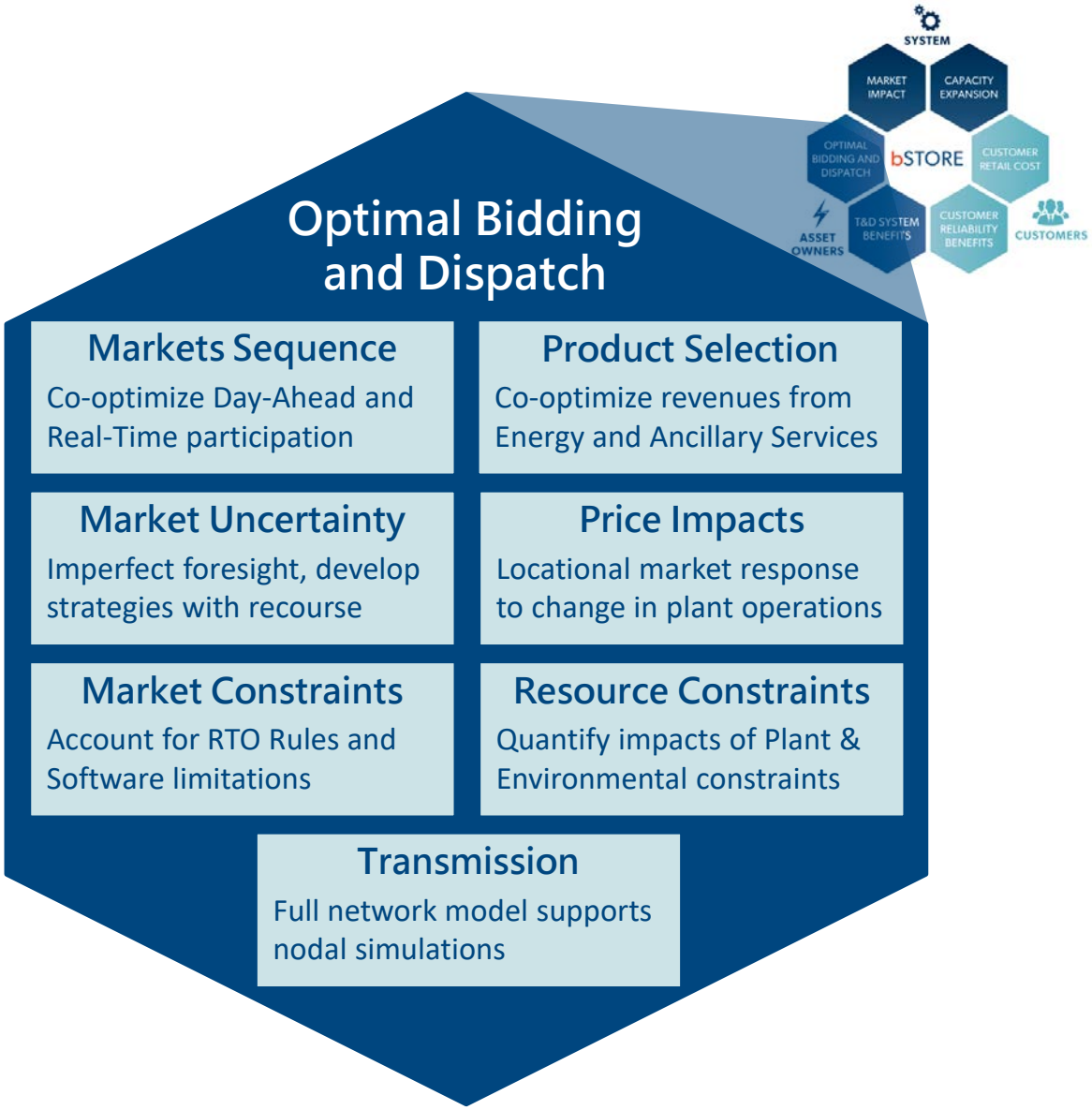
bSTORE Use in Hydro E&AS Market Optimization

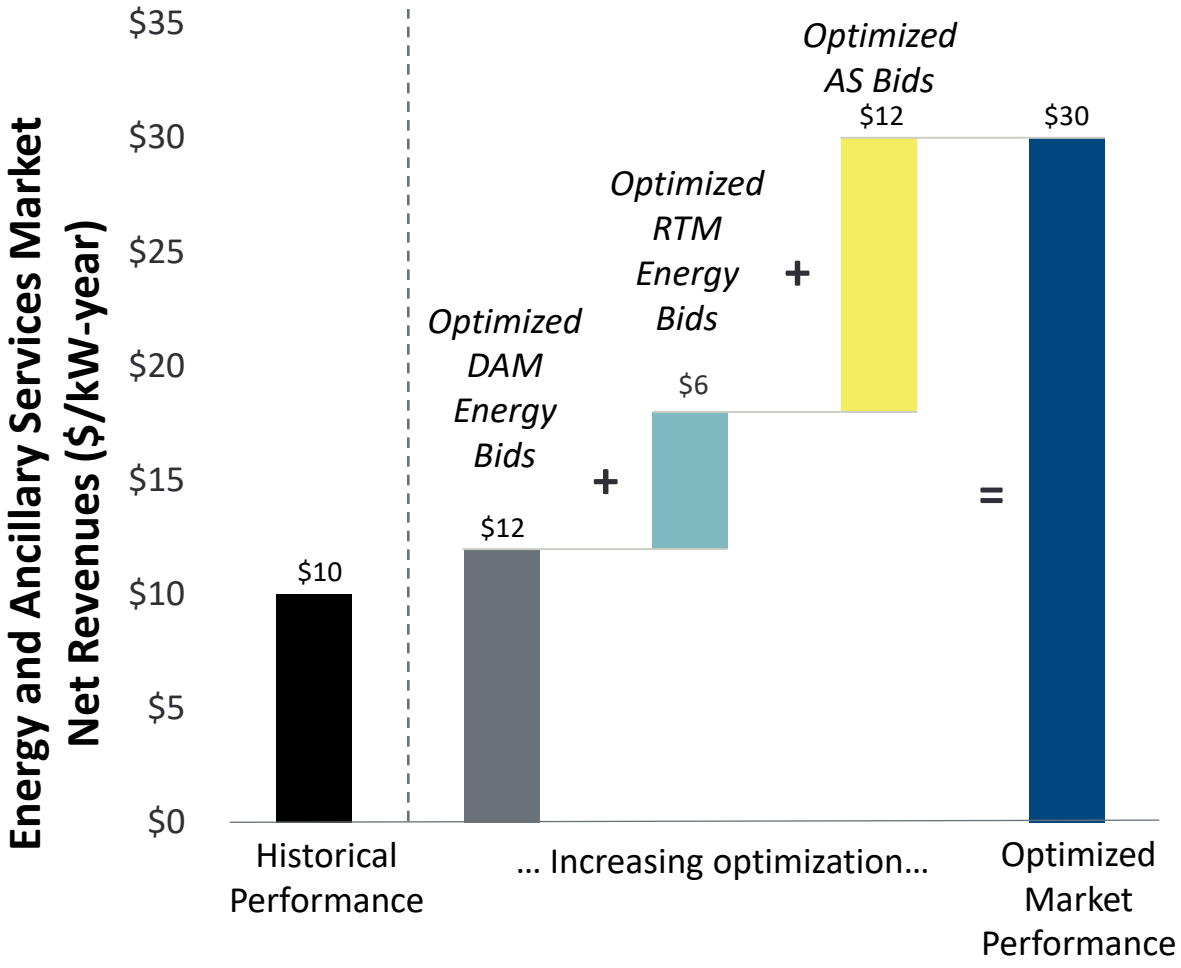


Module Features

- Mixed Integer Programming (MIP) solver as used by RTOs
- Rolling-horizon simulation with look-ahead optimization
- Sequential model of DA, RT and other decision cycles with feedback loops
- Scenario-based & heuristic-based uncertainty modeling
- Hydro modeling
  - Generation constraints
  - Reservoir constraints
  - Cascaded plants w/ delays
  - Value of water: calculate (long-horizon problems) or specify (short-horizon)

Optimized Pumped Hydro E&AS Performance

***Illustrative Example*: Pumped Storage Hydro plant operating in an RTO market**

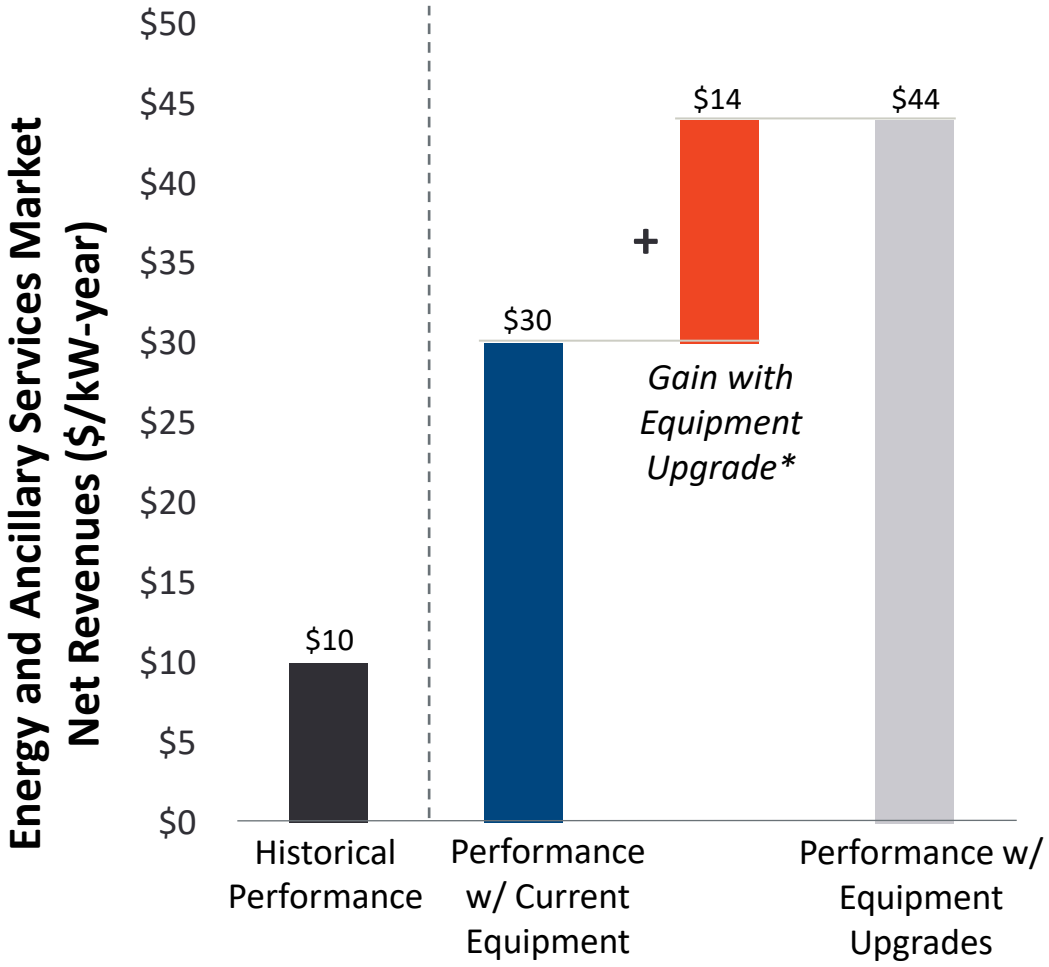


- *Optimized DA Market*: RTO-optimized energy schedule
- *Optimized RT Market*: Price-based offers and bids (imperfect foresight)
- While existing equipment and constraints preserved
- Modeling included market response/elasticity

Optimized Performance: 2-3x of Historical Performance

Impact of Equipment Upgrades

Equipment upgrades can further increase the value of hydro plants.



- Legacy plants may be subject to costly constraints:
  - Time to switch pump/generate modes can be too long
  - Limits AS and RT energy market opportunities
- Equipment upgrades to enable fast mode switching enables substantial AS and RT market gains

Performance with Upgrades:

4-5x of Historical Performance

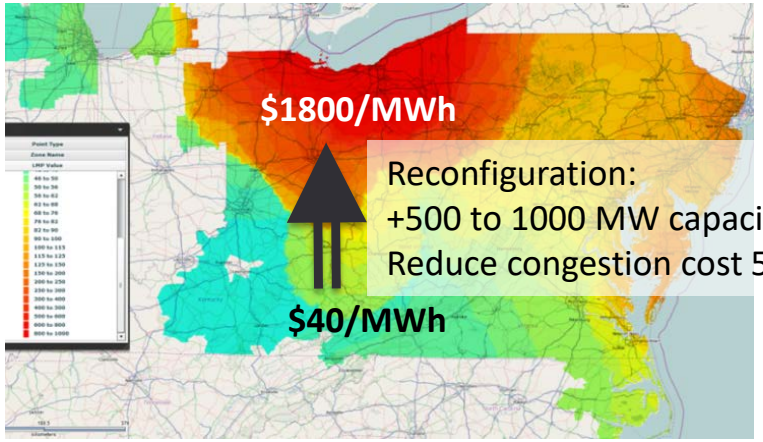
Transmission Congestion Relief Strategies

Congestion affecting hydro storage projects can usually be relieved cost-effectively employing advanced transmission technologies.

- Congestion is often seen by the plant owner as an erratic price signal
- Advanced transmission technologies provide cost effective and timely means to relieve plant congestion under these conditions
  - *Transmission reconfigurations (topology control/line switching)*
  - *Power flow control devices*
  - *Dynamic line ratings*

Case Study: PJM

- ✓ *Extreme peak conditions with outages*
- ✓ *Reconfiguration can increase transfer capacity by **5% to 10% (500-1000 MW)***
- ✓ ***50% reduction in congestion cost***
- ✓ *Similar impacts for more localized congestion in PJM, SPP, MISO, ERCOT*

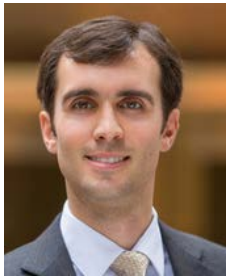


PJM Real Time Prices, 18/7/2013, 15:30 (pjm.com)

Conclusions

- Resource flexibility is becoming more important on the grid
- As the major provider of system flexibility, pumped, reservoir, and pondage hydro plants can offer a significant value.
- Our experience shows that the full value potential of hydro resources often is not realized today.
- Maximizing the market value of flexible hydro resources requires a review of the constraints that a plant faces with respect to operations, market design, market rules, and transmission congestion.
- In our engagements we found opportunities and developed strategies to increase the market value of existing hydro storage plants by 200% to 500%.
  - If not optimized by RTO, this requires co-optimization of bidding (or self scheduling) into day-ahead energy, real-time energy, and ancillary services markets, considering uncertainty.
  - Our analyses also found significant additional value offered by plant modifications that increase operational flexibility.

Contact Information



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About The Brattle Group

The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governmental agencies worldwide.

We combine in-depth industry experience and rigorous analyses to help clients answer complex economic and financial questions in litigation and regulation, develop strategies for changing markets, and make critical business decisions.

Our services to the electric power industry include:

- Climate Change Policy and Planning
- Cost of Capital
- Demand Forecasting Methodology
- Demand Response and Energy Efficiency
- Electricity Market Modeling
- Energy Asset Valuation
- Energy Contract Litigation
- Environmental Compliance
- Fuel and Power Procurement
- Incentive Regulation
- Rate Design and Cost Allocation
- Regulatory Strategy and Litigation Support
- Renewables
- Resource Planning
- Retail Access and Restructuring
- Risk Management
- Market-Based Rates
- Market Design and Competitive Analysis
- Mergers and Acquisitions
- Transmission

Brattle's Storage Experience

Asset Valuation

- Valuing and sizing renewables + storage facilities
- Valuing storage across multiple value streams
- Developing bid/offer strategies to maximize value
- Accommodating storage into IRPs
- Supporting due diligence efforts of investors

Market Intelligence

- The state and federal policy landscape
- Electricity market fundamentals and opportunities
- Storage cost and technology trends
- Current and emerging business models

Policy, Regulatory, and Market Design

- Wholesale market design
- Market and regulatory barriers
- Utility ownership and operation models
- Retail rate implications of distributed storage
- Implications of storage on wholesale markets

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Additional Reading

"Getting to 50 GW? The Role of FERC Order 841, RTOs, States, and Utilities in Unlocking Storage's Potential," Roger Lueken, Judy Chang, Johannes P. Pfeifenberger, Pablo Ruiz, and Heidi Bishop, February 22, 2018

"Battery Storage Development: Regulatory and Market Environments," Michael Hagerty and Judy Chang, Presented to the Philadelphia Area Municipal Analyst Society, January 18, 2018

"U.S. Federal and State Regulations: Opportunities and Challenges for Electricity Storage," Romkaew P. Broehm, Presented at BIT Congress, Inc.'s 7th World Congress of Smart Energy, November 2, 2017

"Stacked Benefits: Comprehensively Valuing Battery Storage in California," Ryan Hledik, Roger Lueken, Colin McIntyre, and Heidi Bishop, Prepared for Eos Energy Storage, September 12, 2017

"The Hidden Battery: Opportunities in Electric Water Heating," Ryan Hledik, Judy Chang, and Roger Lueken, Prepared for the National Rural Electric Cooperative Association (NRECA), the Natural Resources Defense Council (NRDC), and the Peak Load Management Alliance (PLMA), February 10, 2016

"Impacts of Distributed Storage on Electricity Markets, Utility Operations, and Customers," Johannes P. Pfeifenberger, Judy Chang, Kathleen Spees, and Matthew Davis, Presented at the 2015 MIT Energy Initiative Associate Member Symposium, May 1, 2015

"The Value of Distributed Electricity Storage in Texas - Proposed Policy for Enabling Grid-Integrated Storage Investments," Ioanna Karkatsouli, James Mashal, Lauren Regan, Judy Chang, Matthew Davis, Johannes P. Pfeifenberger, and Kathleen Spees, Prepared for Oncor, March 2015

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