

Response to DOE RFI#: DE-FOA-0001886

TO: United States Department of Energy, Office of Energy Efficiency and Renewable Energy, Water Power Technologies Office

FROM: Pablo A. Ruiz, James A. Read, Johannes P. Pfeifenberger, Roger Lueken and Judy Chang, The Brattle Group (Main contact: 617-864-7900, Pablo.Ruiz@brattle.com)

SUBJ: **Expanding Hydropower and Pumped Storage's Contribution to Grid Resiliency and Reliability**

DATE: April 4, 2018

We appreciate the opportunity to respond to DOE's Request for Information DE-FOA-0001886. We provide responses to questions under **Topic 3: Current Operations Landscape**.

The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governmental agencies worldwide. Brattle's experts are at the forefront of the latest developments and trends facing the energy industry. We support a wide range of clients in the U.S., Canada, Europe, and the Pacific Rim, including investor-owned utilities, public utilities, electricity and pipeline customers, power generators, transmission organizations, and regulatory agencies.

Resource flexibility is becoming more important on the grid as the share of variable generation resources continues to increase. As a major provider of system flexibility, pumped storage, reservoir, and pondage hydro plants can offer substantial value. Our experience shows, however, that the full value of hydro resources is often not being realized today. Maximizing the value of flexible hydro resources requires a review of the operational constraints, of wholesale market rules and design, and transmission congestion. In previous engagements, we have found opportunities and developed strategies to increase the wholesale market value of existing hydro storage plants by 200% to 500%. Capturing the value of hydro resources requires co-optimization across day-ahead energy, real-time energy, and ancillary services markets. Identifying the optimal utilization across these markets is an analytically challenging problem, one that is much advanced by state-of-the-art optimization software. This optimization can either be implemented by the market operators or, if not, by the market participants to improve how they bid and schedule their resources into the market. In addition, our analyses have found significant potential to add value through physical modifications to plants to increase operational flexibility, and to transmission systems to relieve congestion.

The attached slide-deck report provides additional details relevant to Topic 3. The report includes background information on the value of hydro plants (slides 5-6), a discussion of market rules and software challenges and limitations (slides 7-8), optimized energy and ancillary services market performance (slide 11), additional benefits from making hydro plants more flexible (slide 12), and transmission congestion relief (slide 13).

These comments are submitted solely on behalf of the authors and do not necessarily represent the views of The Brattle Group or its clients.

Maximizing the Market Value of Flexible Hydro Generation

PREPARED BY

Pablo Ruiz

Jamie Read

Johannes Pfeifenberger

Judy Chang

Roger Lueken

March 29, 2018

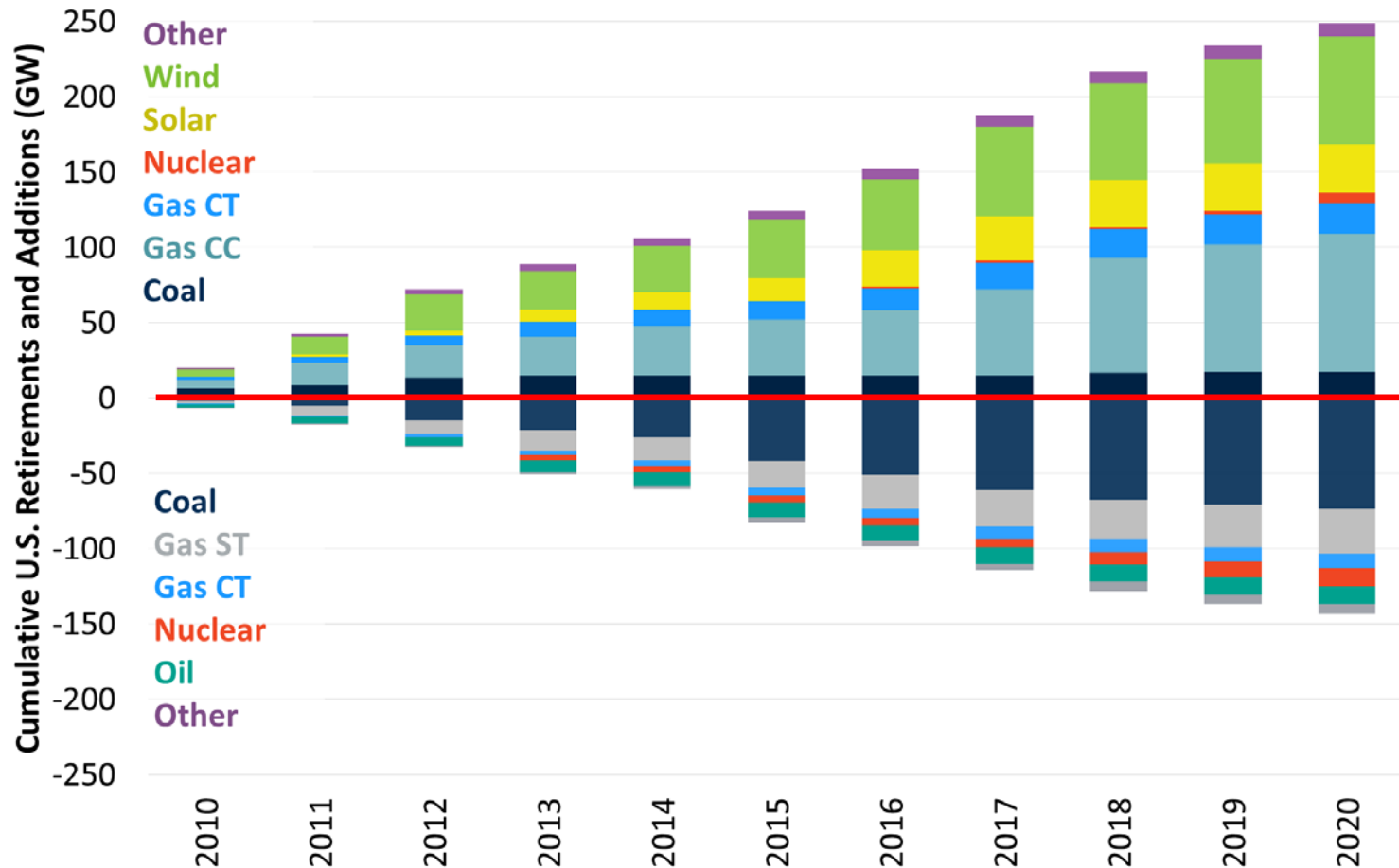


Content

- 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

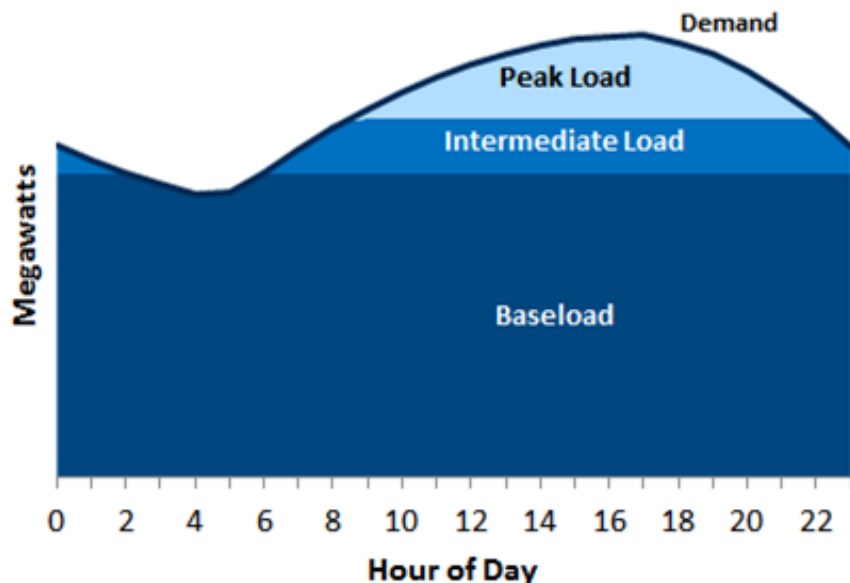
U.S. Retirements and Additions (2010 – 2020)



Changing Supply Mix = Need for More Flexibility

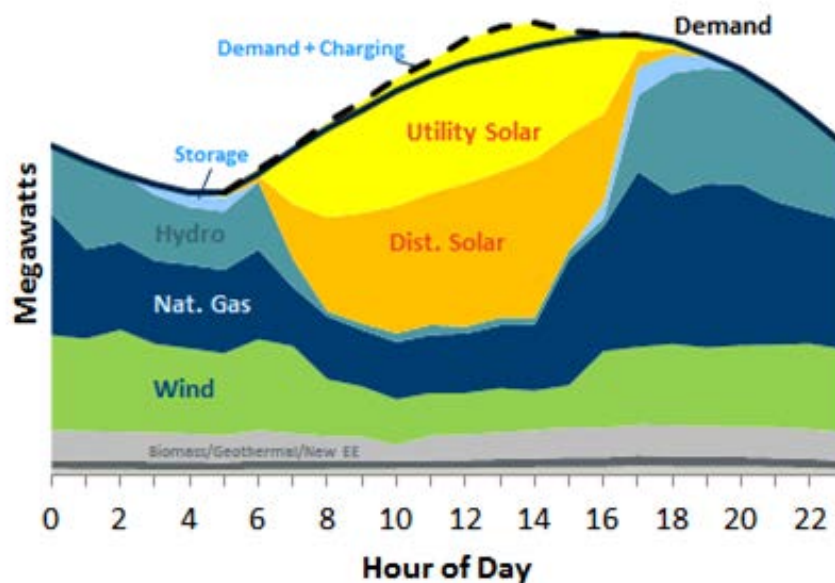
Flexible resources that can respond quickly and efficiently as system conditions change are needed to operate with an increasing share of variable generation. Hydro is uniquely able to provide this flexibility.

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

 = Exhibits Attribute
 = Partially Exhibits Attribute
 = Does Not Exhibit Attribute

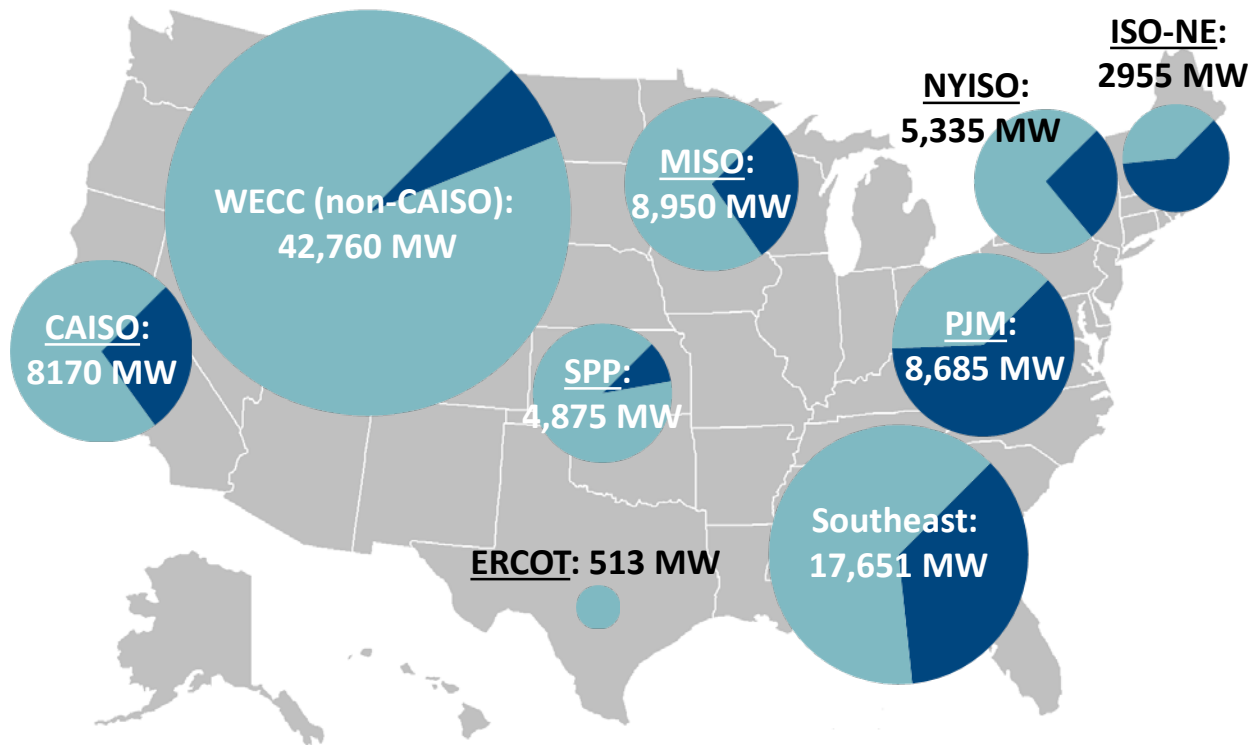
Resource Type	Essential Reliability Services (Frequency, Voltage, Ramp Capability)					Fuel Assurance		Flexibility			Other		
	Frequency Response (Inertia & Primary)	Voltage Control	Regulation	Contingency Reserve	Load Following	Not Fuel Limited (> 72 hours at Eco. Max Output)	On-site Fuel Inventory	Cycle	Short Min. Run Time (< 2 hrs./ Multiple Starts Per Day)	Startup/ Notification Time < 30 Minutes	Black Start Capable	No Environmental Restrictions (That Would Limit Run Hours)	Equivalent Availability Factor
Hydro													
Natural Gas - Combustion Turbine													
Oil - Steam													
Coal - Steam													
Natural Gas - Steam													
Oil/ Diesel - Combustion Turbine													
Nuclear													
Battery/ Storage													
Demand Response													
Solar													
Wind													

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

Pumped Storage: 13.6 GW

Conventional Hydro: 25.5 GW

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.

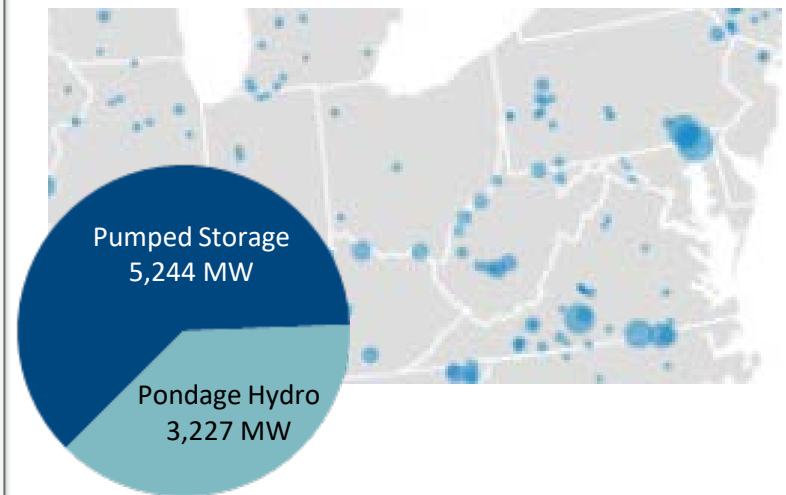
Case Study: PJM

- ✗ *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>

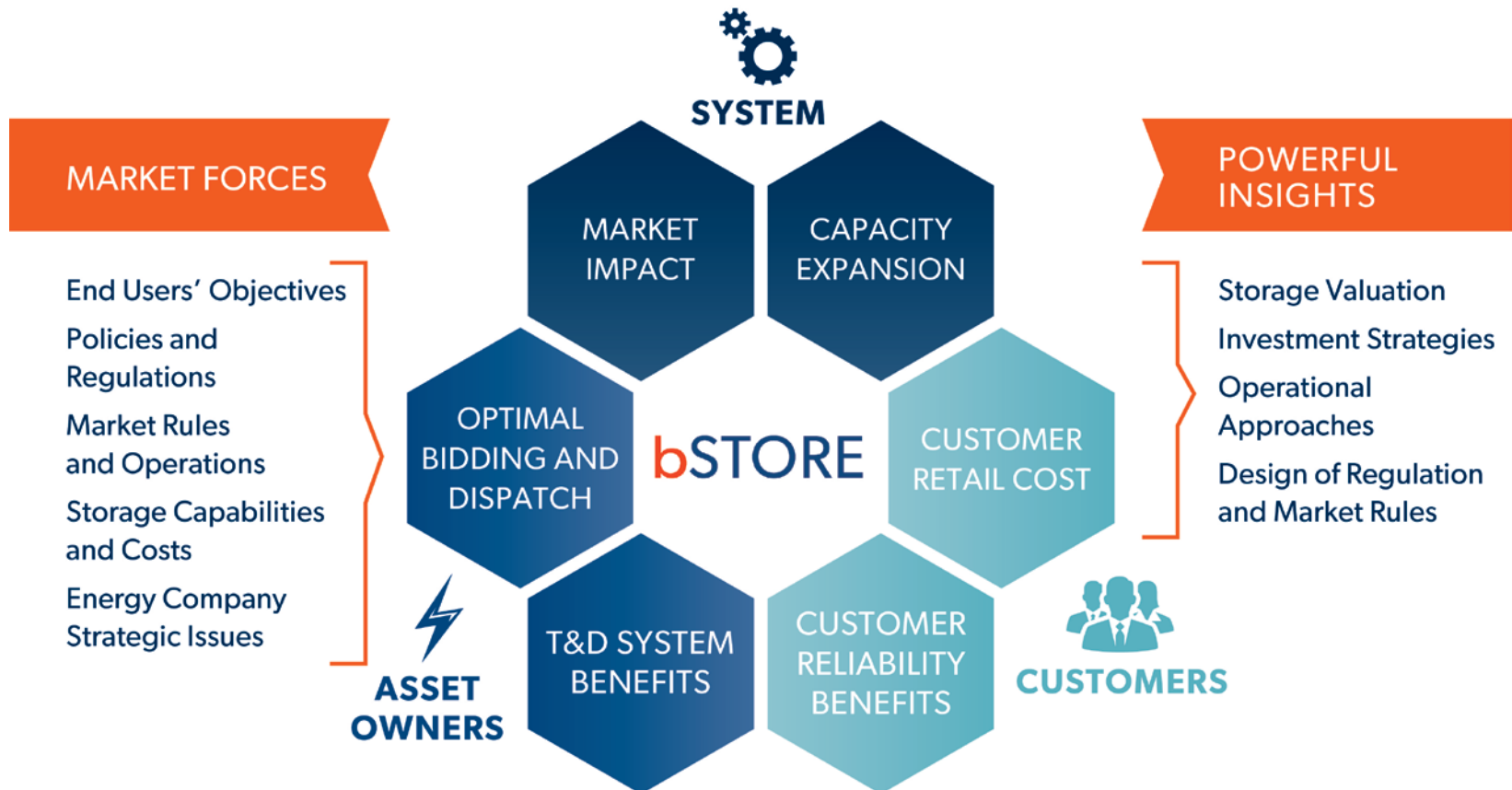
Hydro plants: The Brattle Group analysis based on SNL and other data.

Notes:

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

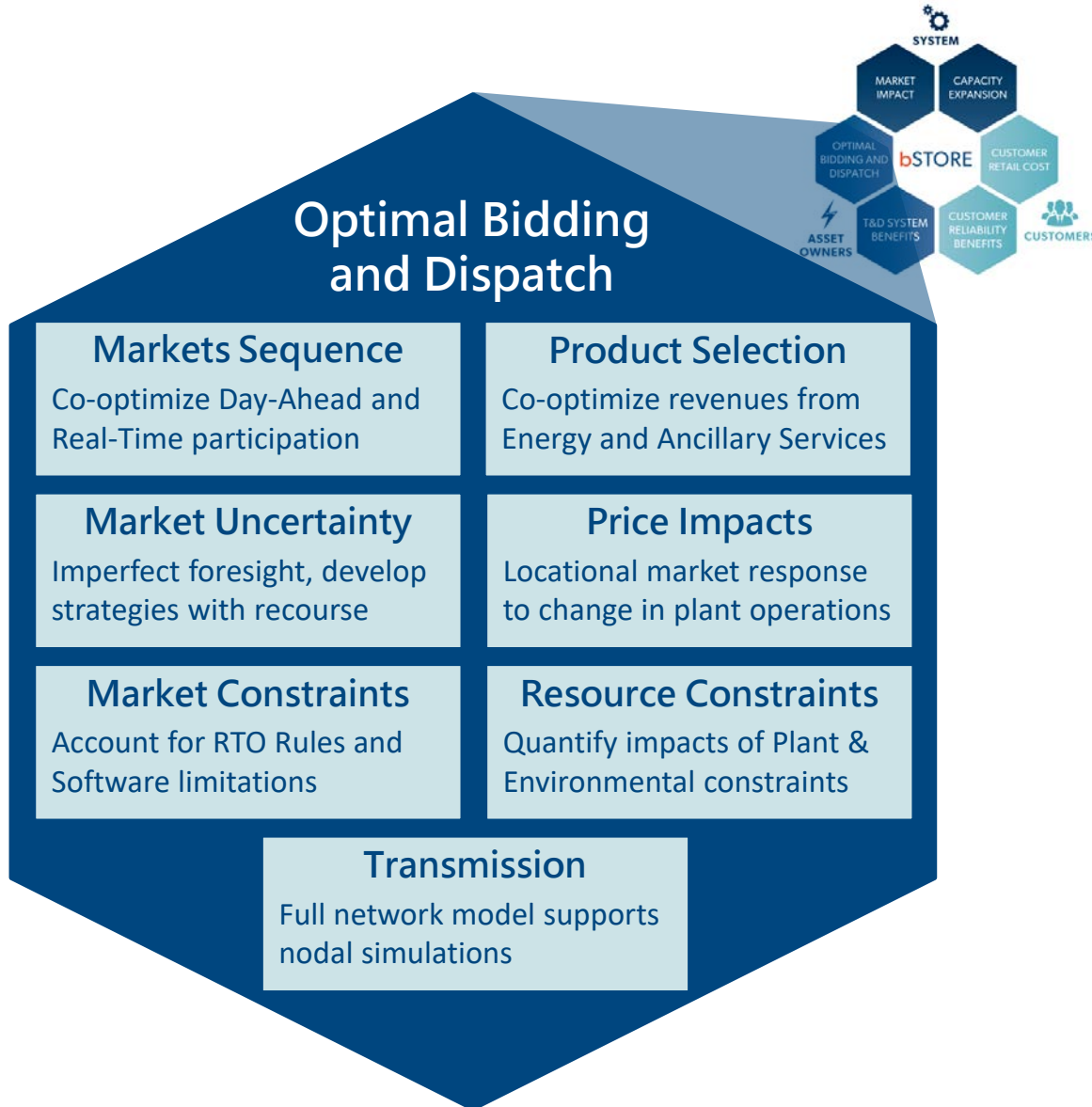
Brattle's bSTORE Storage Modeling Platform

bSTORE MODELING PLATFORM



www.brattle.com/storage

bSTORE Use in Hydro E&AS Market Optimization

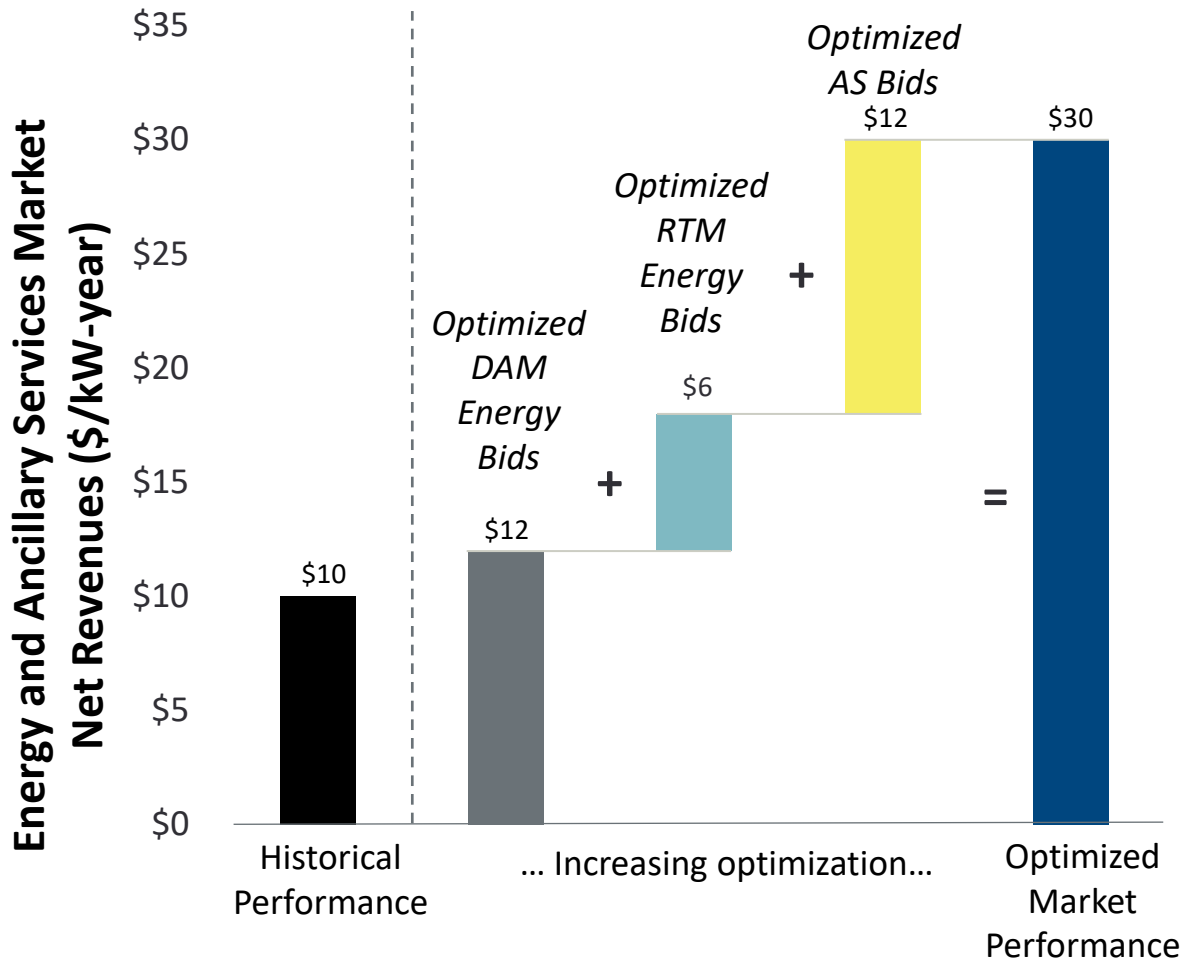


Module Features

- 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

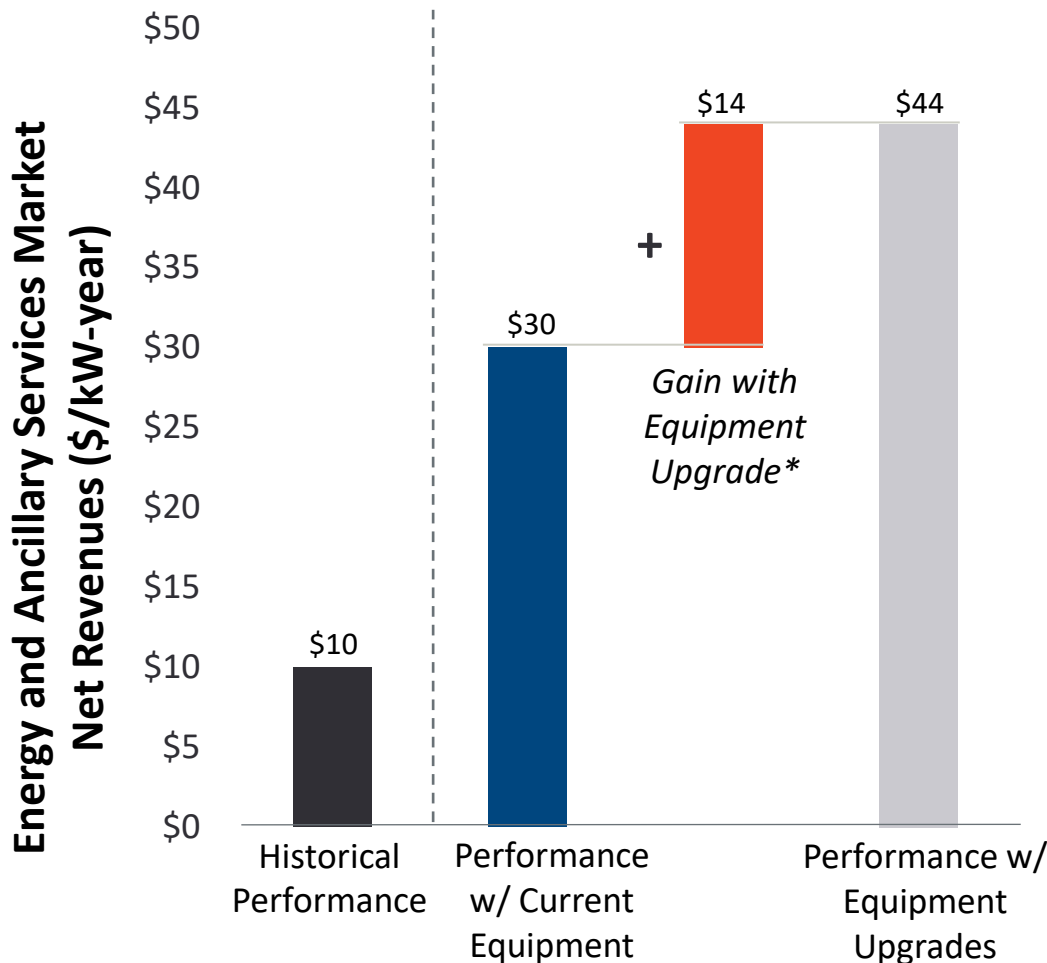


- *Optimized DA Market:* RTO-optimized energy schedule
- *Optimized RT Market:* Price-based offers and bids (imperfect foresight)
- While existing equipment and constraints preserved
- Modeling included market response/elasticity

***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***

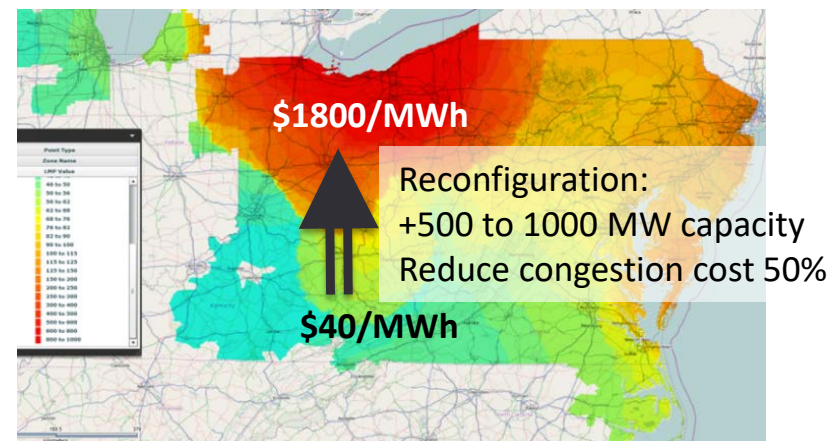
Transmission Congestion Relief Strategies

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



PABLO RUIZ

Senior Associate | Boston, MA

Pablo.Ruiz@brattle.com

+1.617.234.5748



JAMES READ

Principal | Boston, MA

James.Read@brattle.com

+1.617.234.5645



JOHANNES PFEIFENBERGER

Principal | Boston, MA

Hannes.Pfeifenger@brattle.com

+1.617.234.5624



ROGER LUEKEN

Associate | Washington, DC

Roger.Lueken@brattle.com

+1.202.419.3321



JUDY CHANG

Principal and Director | Boston, MA

Judy.Chang@brattle.com

+1.617.234.5630

The views expressed in this presentation are strictly those of the presenter(s) and do not necessarily state or reflect the views of The Brattle Group, Inc. or its clients.

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

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

Offices



BOSTON



NEW YORK



SAN FRANCISCO



WASHINGTON, DC



TORONTO



LONDON



MADRID



ROME



SYDNEY