Energy Storage

IEEE Berkshire Section – Lee, MA

Michael I. Henderson

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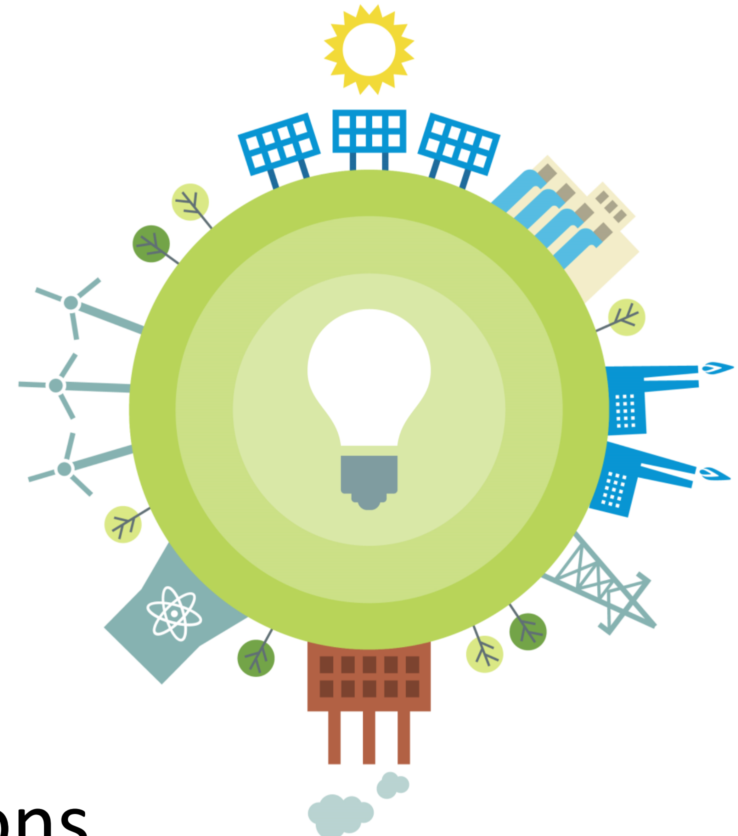
Overview of Presentation

- The Changing Grid
- Introduction to Storage and Key Drivers
- Scenario Analysis
- Applications of Battery Energy Storage Systems
- Summary and Conclusions

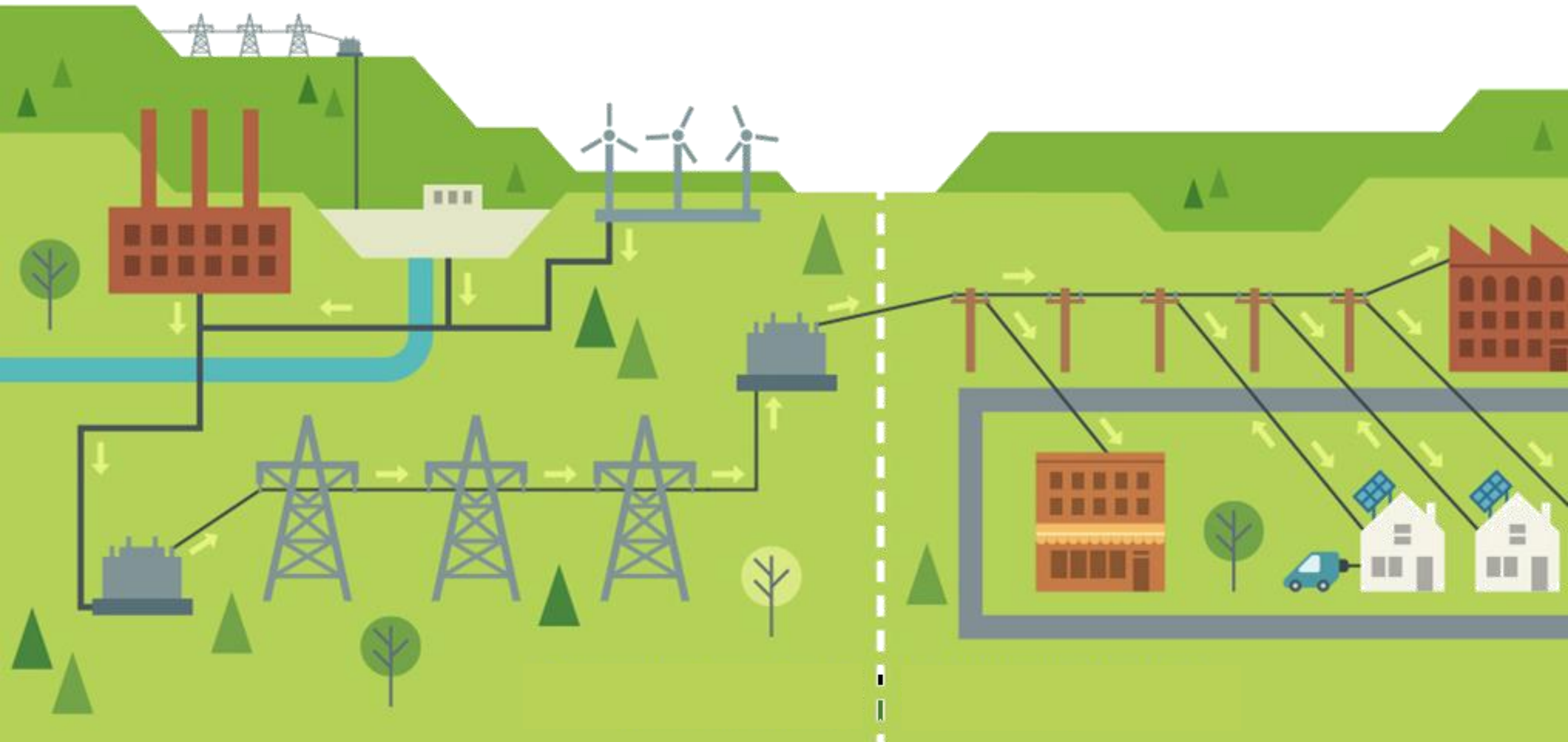


The Changing Grid

Electric Grid Will Look Very Different in the Near Future

State Policies Encourage the Development of EE, Renewables, and Storage

"Hybrid" grid with grid-connected and distributed resources, and a continued shift toward natural gas and renewable energy



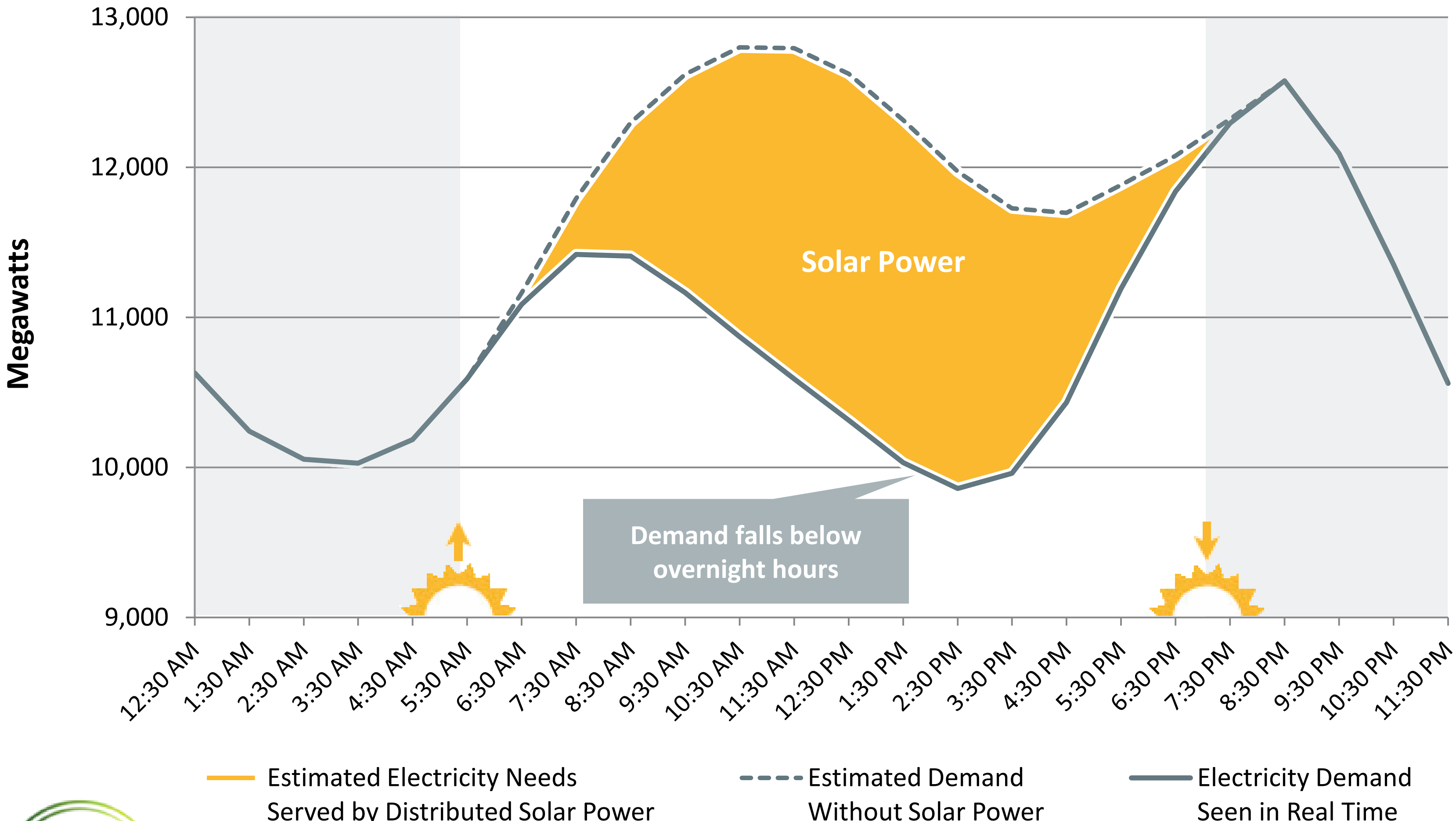
New England Has Significant Wind Potential, but Resources Are Remote from Load Centers

- The ISO identified zones with up to 12,000 MW of onshore and offshore wind potential in a 2009 study for the New England Governors
- Most of the proposed wind resources are located in northern New England
- Transmission would be required to connect potential wind resources to load centers
- New England tariff structure looks to the wholesale power markets to attract new resources; new resources are responsible for funding their interconnection to the transmission network
- Once interconnected, resources have open access to the New England regional network, and compete for use of the network based on their energy offer price

Source: ISO Generator Interconnection Queue (January 2016)
FERC Jurisdictional Proposals Only

Historic Dip in Midday Demand with Record-High Solar Power Output on April 21, 2018

At 1:30 p.m., behind-the-meter solar reduced grid demand by more than 2,300 MW



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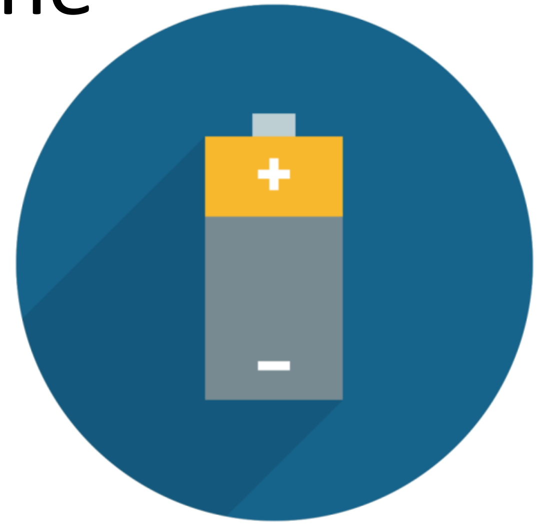
New Energy Storage Technologies Are Coming On Line

- **20 MW** of grid-scale battery storage projects have come on line since late 2015
- More than **800 MW** of grid-scale energy storage are requesting interconnection
- New England has a successful history of operating the region's two large pumped-storage facilities, which can supply **1,800 MW** of power within 10 minutes for up to 7 hours

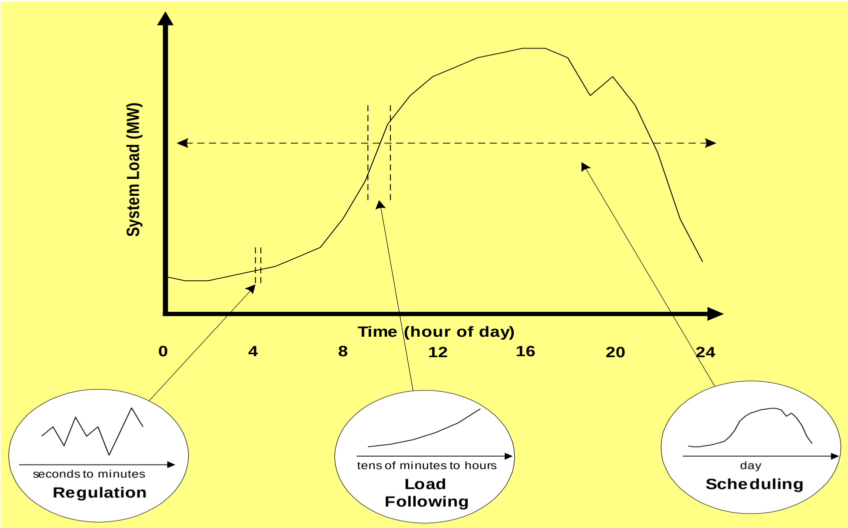


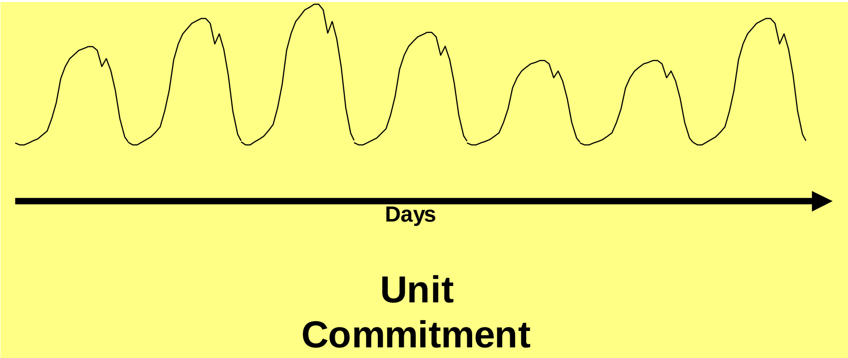
The Lines Between Transmission and Distribution Are Blurring

- Increasing number of generating resources located on the distribution network (e.g. wind turbines, solar arrays, microgrids, CHP)
- Demand resources playing larger role in traditional "transmission level functions" (e.g. energy, reserves and emergency response)
- Regional Power System Control entities need more granular locational and capacity information for both demand and supply resources located on the distribution network
- Operations and planning analyses require situational awareness of supply resources located within a region, regardless of whether they are connected to the transmission or the distribution system

Introduction: Key Drivers and Storage

Time Frames of Variable Resource Impact





Typical U.S. terminology:

- **Regulation** – seconds to a few minutes – similar to variations in customer demand
- **Load-following** – tens of minutes to a few hours
- **Scheduling and commitment of generating units** – hours to several days

Source: www.neo.ne.gov/renew/wind-working-group/milligan_wind-integration-nppd.ppt

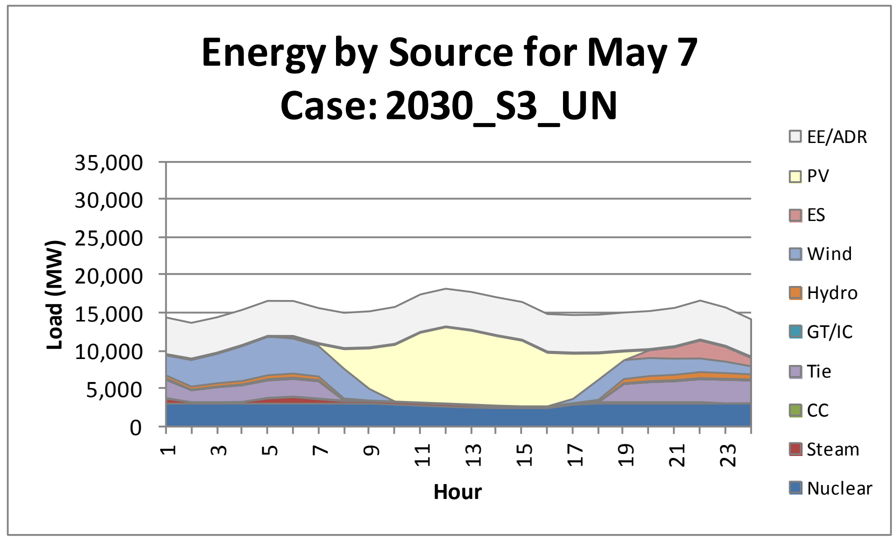
Variable (Intermittent) Resources

- Challenges
  - Load following
  - Frequency control
  - Operating reserves
  - Voltage support
  - Load shifting
  - Power quality
- Smart Grid to the rescue?
  - Demand resources
  - Storage
  - Flexible Alternating Current Transmission Systems (FACTS)

Technical Challenges with Renewable Integration

Scenario Analysis: Sample Results

- The large-scale addition of asynchronous resources (EE, PV, wind, and HVDC imports) poses physical challenges
  - Special control systems may be required, especially to stabilize the system, provide frequency control, ramping, and reserves
  - Protection system issues resulting from lack of short circuit availability could require major capital investment
  - Power quality, voltage regulation



- Opportunity for fast-responding resources (e.g., storage)

System Drivers:

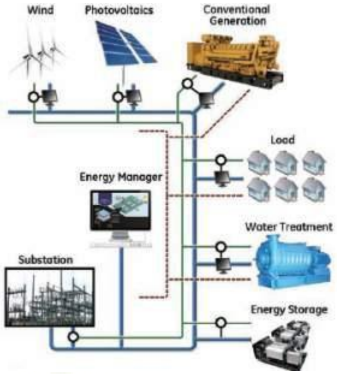
Generation, Transmission, Distribution, & Customers

- **System Need: Increase system resiliency and reliability and improve economic performance**
- Reduce uncertainty of system performance for the integration of variable resources (wind and photovoltaics)
- Supply energy, capacity, and ancillary services that mitigate the adverse effects of variability of net load and intermittent resources
- Improve resource efficiency and environmental impacts by reducing emissions and infrastructure expansion required
- Provide financial arbitrage
- Reduce congestion and defer system upgrades
- Facilitate maintenance of generation, transmission, and distribution facilities, many of which are severely aged

Why Storage?

Lowering Greenhouse Gases

Integrating renewable generation



Making the grid resilient, reliable, and economic

Old and New Storage Technologies

- Chemical and biological
  - Oil
  - Gas
  - Coal
  - Wood
  - Horse power
- Electrochemical
  - Batteries
- Mechanical
  - Hydro
  - Compressed fluids, such as steam or air
  - Flywheels
  - Springs
- Thermal
  - Hot and cold

Current Types of Storage

Battery Storage

Electrical energy is stored for later use in chemical form. Many different battery chemistries are available. Example: 20 MW A123 Li-ion battery storage plant in Johnson City, New York

Pumped Storage Hydro

Electricity is used to pump water to an upper reservoir during off-peak hours. Stored electrical energy is released during on-peak hours. Example: 1,500 MW Castaic plant near Los Angeles, California

Compressed Air Energy Storage

Electricity is used to compress air which is stored in tanks or underground caverns. Compressed air is used in gas turbines to produce electricity when needed. Example: 115 MW CAES plant in McIntosh, Alabama

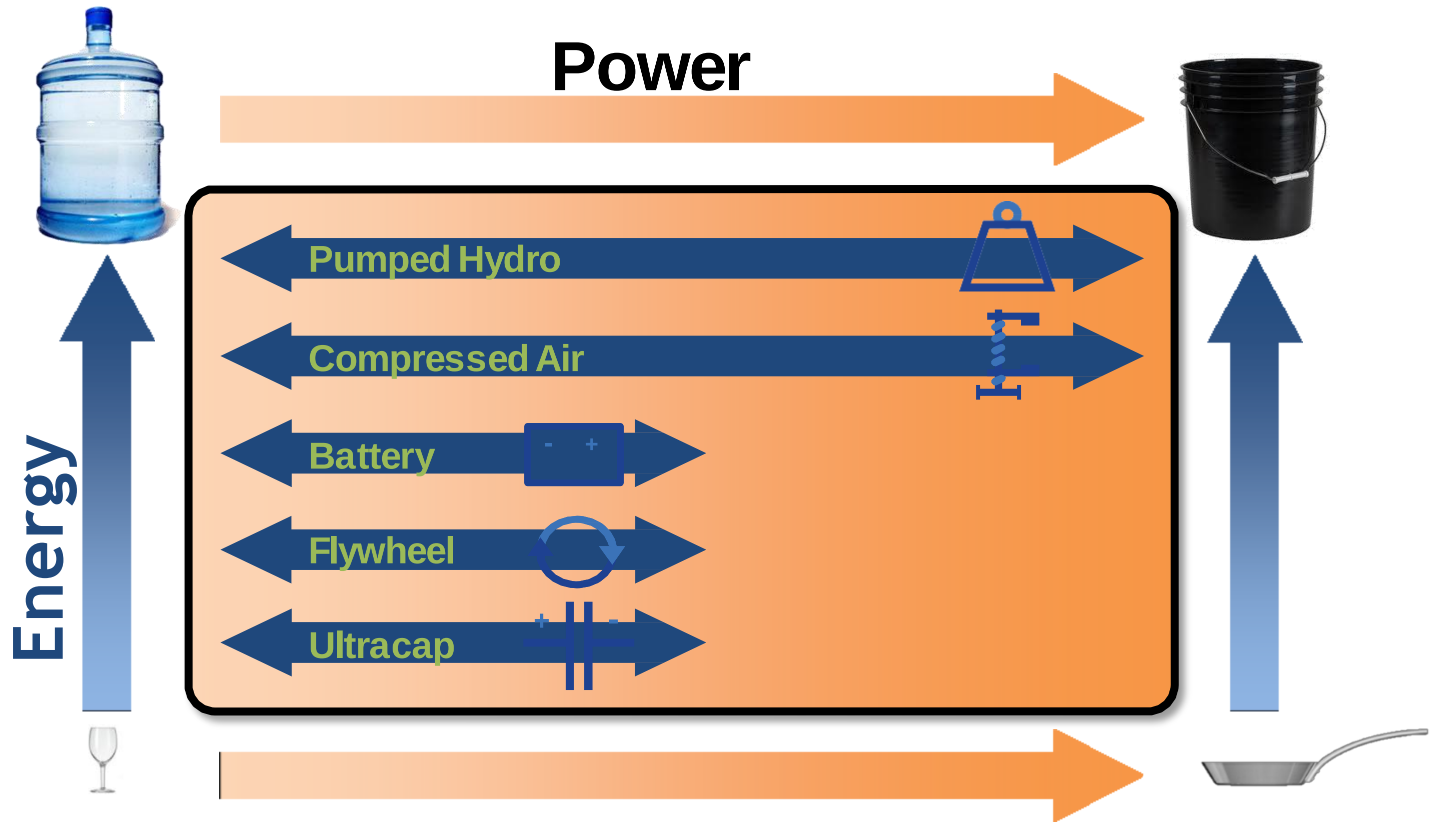
Flywheel Energy Storage

Electricity is stored as rotational energy. Energy is extracted by converting the kinetic energy to electrical energy by slowing the flywheel. Example: 20 MW Bacon flywheel project in Stephentown, New York.

Thermal Energy Storage

Electricity is used to make ice during off-peak hours The stored ice is used in a cooling system to offset electricity consumption during peak hours. Example: 12 MW thermal storage, Napa Valley Community College, California.

Energy or Power?



Application defines the power & energy needed
... Each storage medium has a "sweet spot"

One Size Doesn't Fit All!

Application	Description	CAES	Pumped Hydro	Flywheels	Lead-Acid	NaS	Li-ion	Flow Batteries
Off-to-on peak intermittent shifting and firming	Charge at the site of off peak renewable and/ or intermittent energy sources; discharge energy into the grid during on peak periods	◑	◑	○	●	●	●	●
On-peak intermittent energy smoothing and shaping	Charge/discharge seconds to minutes to smooth intermittent generation and/or charge/discharge minutes to hours to shape energy profile	○	◑	◑	●	●	●	●
Ancillary service provision	Provide ancillary service capacity in day ahead markets and respond to ISO signaling in real time	◑	◑	◑	◑	◑	◑	◑
Black start provision	Unit sits fully charged, discharging when black start capability is required	◑	◑	○	●	●	●	●
Transmission infrastructure	Use an energy storage device to defer upgrades in transmission	○	○	○	●	●	●	●
Distribution infrastructure	Use an energy storage device to defer upgrades in distribution	○	○	○	●	●	●	●
Transportable distribution-level outage mitigation	Use a transportable storage unit to provide supplemental power to end users during outages due to short term distribution overload situations	○	○	○	◑	●	●	●
Peak load shifting downstream of distribution system	Charge device during off peak downstream of the distribution system (below secondary transformer); discharge during 2-4 hour daily peek	○	○	○	●	●	●	●
Intermittent distributed generation integration	Charge/Discharge device to balance local energy use with generation. Sited between the distributed and generation and distribution grid to defer otherwise necessary distribution infrastructure upgrades	○	○	○	●	◑	◑	◑
End-user time-of-use rate optimization	Charge device when retail TOU prices are low and discharge when prices are high	◑	◑	○	◑	◑	◑	◑
Uninterruptible power supply	End user deploys energy storage to improve power quality and /or provide back up power during outages	○	○	◑	●	●	●	●
Micro grid formation	Energy storage is deployed in conjunction with local generation to separate from the grid, creating an islanded micro-grid	○	○	○	●	●	●	●

Definite suitability for application ● ; Possible use for application ◑ ; Unsuitable for application ○

Source: Grid Energy Storage, US DOE, December 2013

Measures of Success

- For Reliability and Economics
  - More efficient use of capacity from transmission and distribution resources
  - Intelligent devices that automate monitoring and respond to emergency situations
  - Efficient production, movement and consumption of electricity
- For the Environment
  - Reduction in Greenhouse Gases
  - Greater penetration of renewables
- For Consumer Control
  - Transparent electricity usage and prices
  - Opportunities for consumers to supply energy, capacity, and ancillary services

Scenario Analysis

Planning Is Complex – Flexibility Is Key

- Markets and bid strategies increase variability
  - Unit dispatch
  - Unit commitment
  - Ancillary services
  - Network flows
- Market power issues
  - Load pockets
  - Dependency on generating units affect transfer limits
- Independent owners make decisions for capital investment
  - Resources
  - Load serving entities
  - Transmission owners
- Public policies, technology, and physical changes
  - Wind and solar
  - Environmental constraints
  - Distributed resources
  - Transmission

Planning Complexities Storage as a Hedge?

- Policy and regulation
- Commitment to long term investment
- Projecting new “smart grid” resources
- Reliability performance
- Modeling is difficult
  - Load forecasting
  - Resource adequacy
  - Mix of resources and economic dispatch
  - Transmission system topology and limits
- Command and control versus distributed control
- Control interactions and performance
- Power quality and load characteristics
- Interconnection requirements

Wholesale Markets

- Generator, Load Reducer, or Load?
- Capacity
- Energy
- Ancillary Services
  - Regulation
  - Reserves
  - Voltage

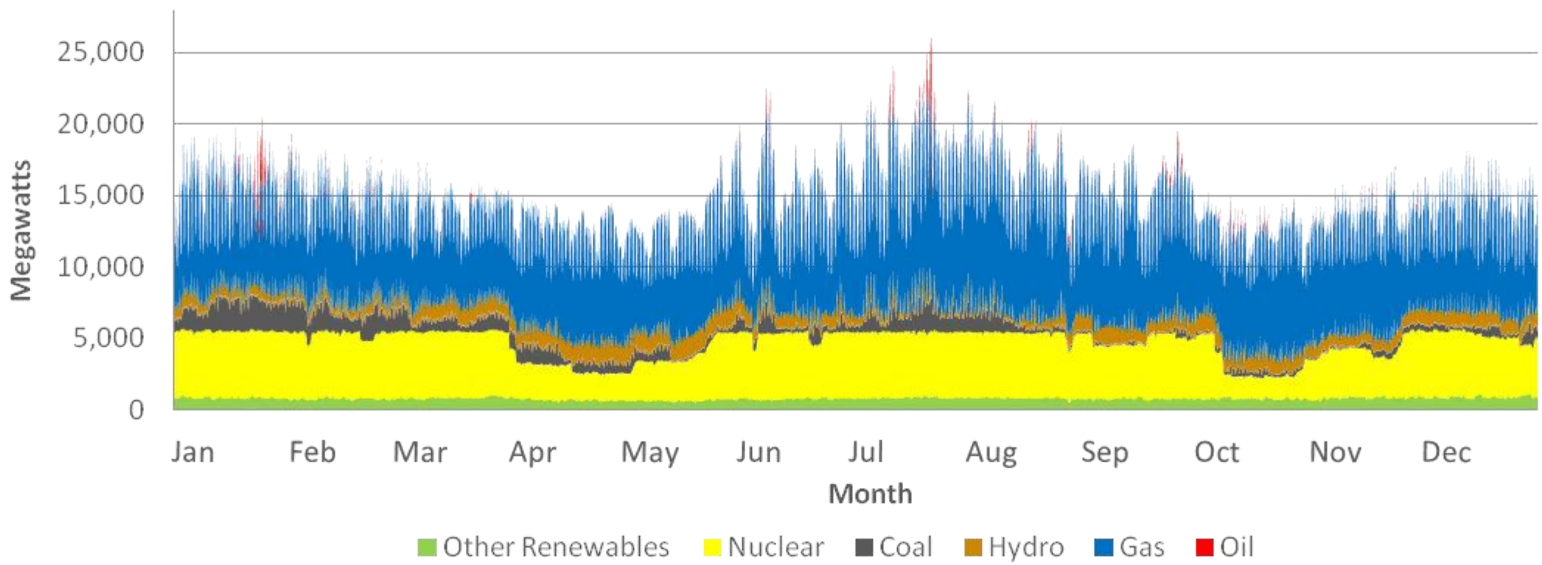
Options for the Participation of Energy-Storage Devices in Markets

When Storage Device is Supplying Electricity	Market				Size Requirements and Aggregation	
	Energy	Capacity[a]	Reserve[b]	Regulation	Maximum Output	Aggregation
Load reducer/retail supplier	Avoids paying or sells at retail cost	Capacity tag[c]	No	ATRR[d]	N/A	N/A
Settlement-only generator	Real-time wholesale price taker	Yes	No	ATRR[d]	<5 MW	N/A
Generator	Real-time and day-ahead wholesale price setter	Yes	Yes	Yes[e]	≥1 MW	Case by case per OP 14[f]
When Storage Device is Consuming Electricity	**Market**				**Size Requirements and Aggregation**	
	Energy	**Capacity**	**Reserve**	**Regulation**	**Size**	**Aggregation**
Retail load	Retail price payer	Capacity tag[c]	No	ATRR[d]	N/A	N/A
Asset-related-demand (ARD)	Real-time and day-ahead wholesale price payer	Capacity tag[c, g]	No	ATRR[d]	≥1 MW	Yes
Dispatchable-asset-related demand (DARD)	Real-time and day-ahead wholesale price setter	Adjusted capacity tag[c,g,h]	Yes[b]	Yes	≥1 MW	Yes
Demand Response	**Energy**	**Capacity**	**Reserve**	**Regulation**	**Size**	**Aggregation**
Demand-response resource (DRR)[i]	Real-time and day-ahead wholesale price setter	Yes	Yes[b]	ATRR[d]	≥100 kW	Yes[j]

Source: ISO New England

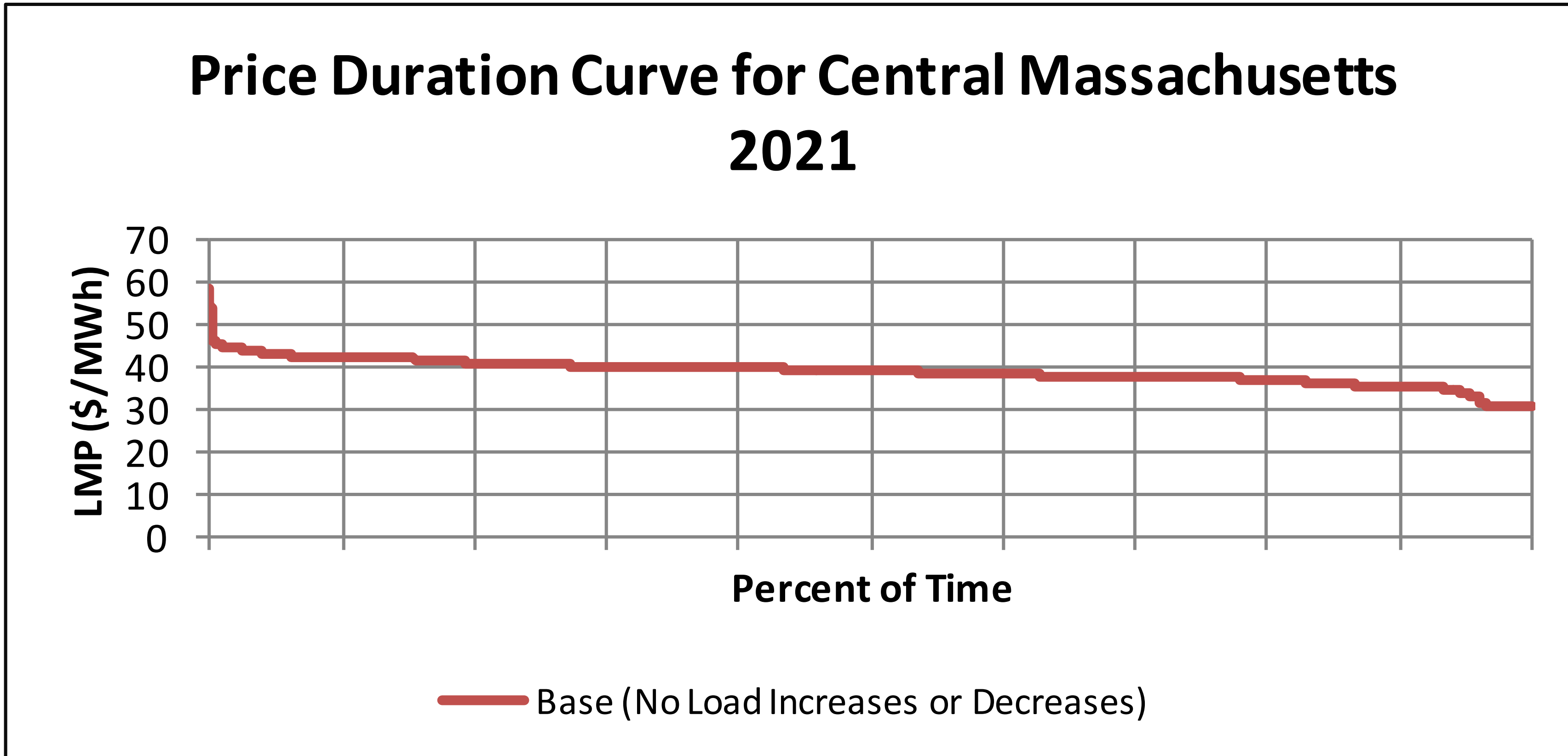
Natural Gas on the Margin

Little difference in peak and off-peak prices?



Prices Can Be Relatively Flat

Scenario Analysis: Sample Results



Rates Manage Retail Demand

- Demand and energy components
  - Capacity of resources
  - Transmission and distribution infrastructure
  - No-load losses
  - Production
    - Fuel adjustment
    - Load losses
- Industrial, commercial, and residential
- Seasonal
- Time of day

Demand Resources

- Opportunities
  - Better use of infrastructure
  - Price elasticity
  - Reliability
  - Environmental emissions
- Challenges
  - Operability
  - Markets
  - Environmental emissions
  - Communications

Active Demand Resources: Challenges and Solutions

- Challenges
  - Increased frequency and amounts of active demand-resource operation
    - Potential fatigue factor
    - Use during the non-traditional shoulder load periods
    - Coordination of DR usage with traditional supply resource maintenance and unanticipated forced outages
  - Control of DR
  - Monitoring performance of DR
  - Cyber Security
  - Forecasting
- Solutions
  - Provide information so that bidders can better anticipate required performance
  - Incorporate DR dispatch in Security Constrained Dispatch
  - Enhance industry structure and the role of Distribution System Operators
  - Coordinate retail structure and rates with wholesale electric markets

Distributed Generation (DG) Interconnection Requirements Affect Transmission System Performance

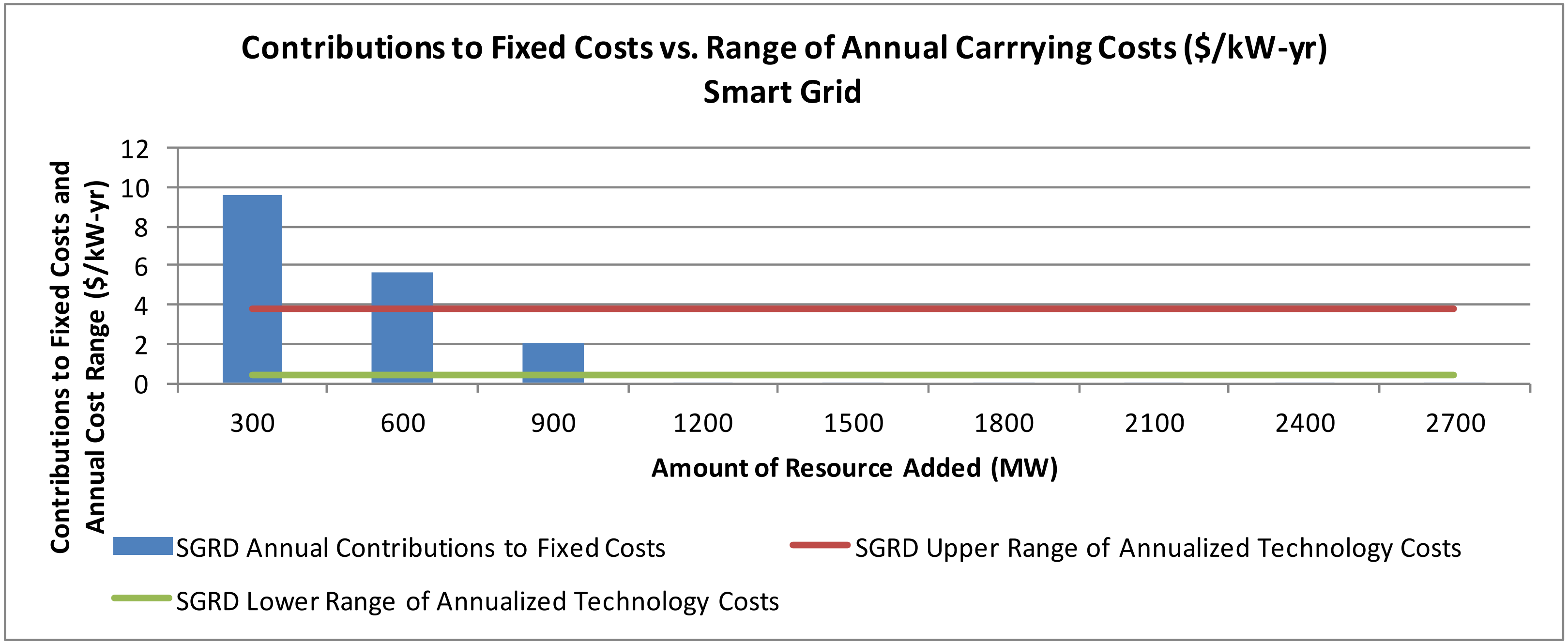
- High/low frequency and high/low voltage ride-through
- Voltage support
- Default and emergency ramp-rate limits
- Reconnect by “soft-start” methods after disconnect
- Communications capability needed to activate/deactivate DG functionalities and parameters, as well as support other DG functionalities that may be needed in the future
- ***Industry groups (IEEE and UL, respectively) are addressing the above issues by developing standards for interconnection and inverter testing***
- ***Storage can play an important role improving system performance***

Scenario Analysis Is a Tool

- Several factors affect scenario development
  - Generation mix, availability, and output
  - Gross and net load
  - Control system settings and failure modes
  - Future system state varies with pricing of fuel, emission allowances, etc.
  - Capital costs for resources, transmission, and demand-side resources
  - Policies affecting resource development
- Tool and study requirements
  - Consider many scenarios
  - Weigh likelihood of expected future system states

As the Amount of Storage Increases, These Resources Have Fewer Opportunities to Recover Their Costs

Scenario Analysis: Sample Results



Applications of Battery Energy Storage Systems

Actual Energy Storage Applications

Flexibility Is Key to Integrating Variable Resources

- Provide capacity
  - Resources
  - Transmission system
  - Distribution system
- Support ancillary services
  - Primary and secondary frequency regulation
  - Reserves
  - Ramping
  - Voltage
  - Black-start
- Improve power quality
- Arbitrage energy prices
- Facilitate operation of microgrids

Potential Applications

Fast Acting vs. Long Duration Storage Solutions

High Power ⟷ High Energy

High Power

Applications:
+ Area Regulation
+ Reserve
+ Renewable Ramping, Enabling Access to Full Energy Value
+ Back Up Power

- Very high Charge/Discharge Rates
- Short Duration (<1hr)
- Many cycles (100s per day)
- Continuous use

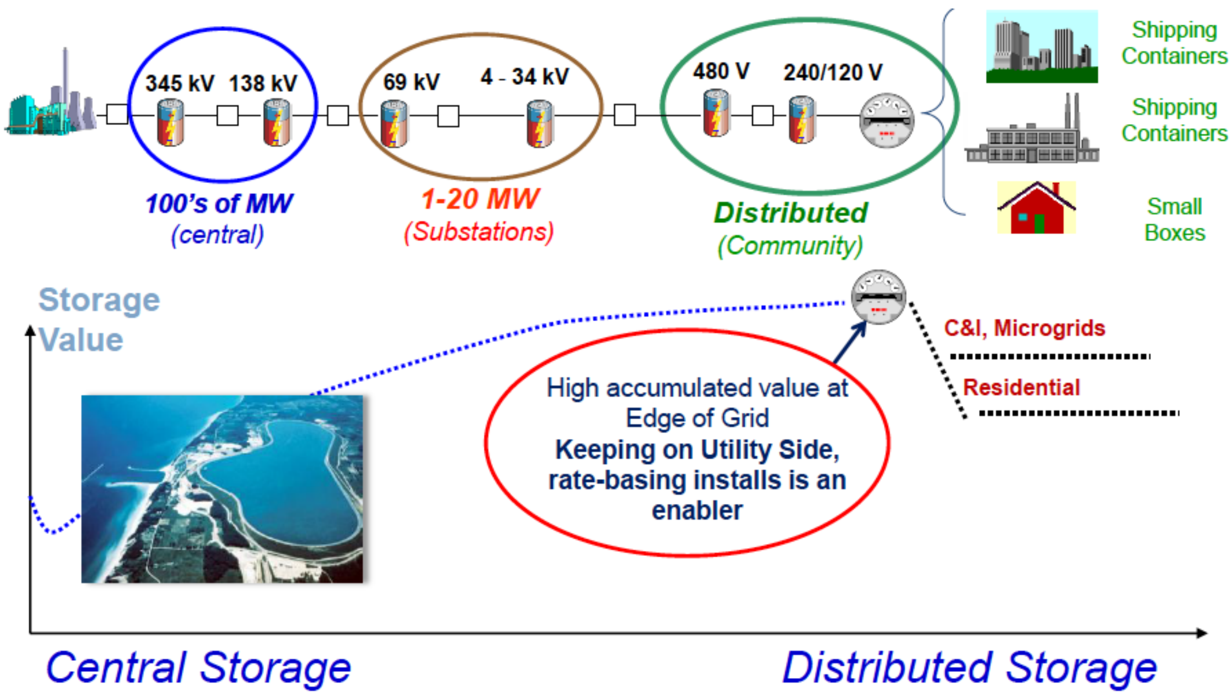
High Energy

Applications:
+ Peak Shifting
+ Renewable time shifting, Adding Incremental Energy Value
+ Renewable Curtailment Recovery
+ Arbitrage
+ T&D Asset Deferral

- Low Charge/Discharge Rates
- Long Duration (2-8 hrs)
- 1-2 cycles per day
- Less frequent use

Source: Center for Commercialization of Electric Technologies

Size and Placement Matter



Source: DTE Energy

Developer Considerations

- **Environmental:** Evaluate Environmental Impact Review process – how likely is a Finding of No Significant Impact?
- **Permitting:** Is a Conditional Use Permit needed?
- **Transmission:** At what voltage can the project connect? Would the battery address a utility need?
- **Construction/Geotechnical:** Battery storage systems are very heavy
- **Land/Title:** Can be an issue in urban areas

Generation Plant Applications

- Improve efficiency for thermal units
- Ancillary services
  - Regulation
  - Ramping rate and speed
  - Reserve
  - Black start
  - Voltage support and control
- Reduced interconnection costs for variable energy resources
- Renewable energy credits
- Market hedge

Transmission System Applications

- Substation protection and control
- Cable pressure
- Flexible Alternating Current Transmission Systems
- Contingency response
  - Thermal
  - Voltage
  - Stability
- Power quality
- Defer infrastructure investment

Distribution System Applications

- Power quality
- Contingency response
  - Thermal performance
  - Voltage performance
- Substations
- Cable pressure
- Defer infrastructure investment
- Community versus home applications
- Microgrids

Mobile Storage

Plug-in Electric Vehicles
Trailers

- Moving Load
- Moving Source

    or

- Stationary Source
- Stationary Load

Storage Applications

Large / Centralized ← Scale of installation → **Small / Distributed**

	Bulk storage	T&D deferral	Renewables integration	Ancillary services	Peak shaving	Backup power
Customer	Utilities, IPPs	Utilities, IPPs	Utilities, IPPs	Utilities, Commercial & Industrial, IPPs	Commercial & Industrial	Residential and Commercial
Monetization scheme	Grid optimization - avoided investment	Deferred grid upgrade investment	Asset optimization	Incremental revenue stream	Savings	Intrinsic value
Catalyst for adoption	Industry maturity, regulatory changes	Industry maturity, regulatory changes	Continued solar+wind development	Market revisions and maturity	Demand charges, TOU pricing rate structure	Resiliency concerns
Technologies deployed	NaS, Flow, Batteries	NaS, Flow, Batteries	NaS, Flow, Batteries	NaS, Flow, Batteries	Batteries	Batteries
Notable deployments	Bosch Braderup ES Facility	Enel Chiaravalle Substation	Invenergy Grand Ridge Wind Farm	AES Angamos Storage Array	Giheung Samsung SDI Project	Drewag Reick

Source: DOE, BatteryUniversity.com, Goldman Sachs Global Investment Research.

Summary and Conclusions

Summary of Storage Application Issues

Provide fast-responding resources at low costs

- Meet system needs, interconnection requirements, and locational requirements
- Sources of revenue and price signals
  - Retail rates versus wholesale markets
  - Capacity
  - Energy
  - Ancillary services
  - Power quality
  - Transmission and Distribution system rates
- Temporal requirements and capabilities
  - Continuous
  - Daily
  - Seasonal
  - Rate of energy discharge and charging

Summary of Storage Application Issues, cont.

- Amount of energy storage and fatigue factors
  - Capital and operating costs
  - Technology
  - Alternative use of energy
- Location
- Reliability of storage and supply technology
- Central versus distributed control
- Control interactions and performance
- Consider competing technologies

The Future – Some Issues

- Low growth in demand for electricity in shorter term
- Uncertain fuel availability and prices
- Expansion of wind generation and photovoltaics increase need for system flexibility
- Changes in public polices, technologies, and costs
- Declining energy-market revenues put upward pressure on capacity prices
- Siting considerations
- Industry restructuring

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“It’s tough to make predictions, especially about the future.”

Yogi Berra

May all of your happy plans be fulfilled!

Thank you for your time and attention!

Questions

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