Energy Storage for the Electric Grid

vermont electric power company

VELCO

VSPC meeting

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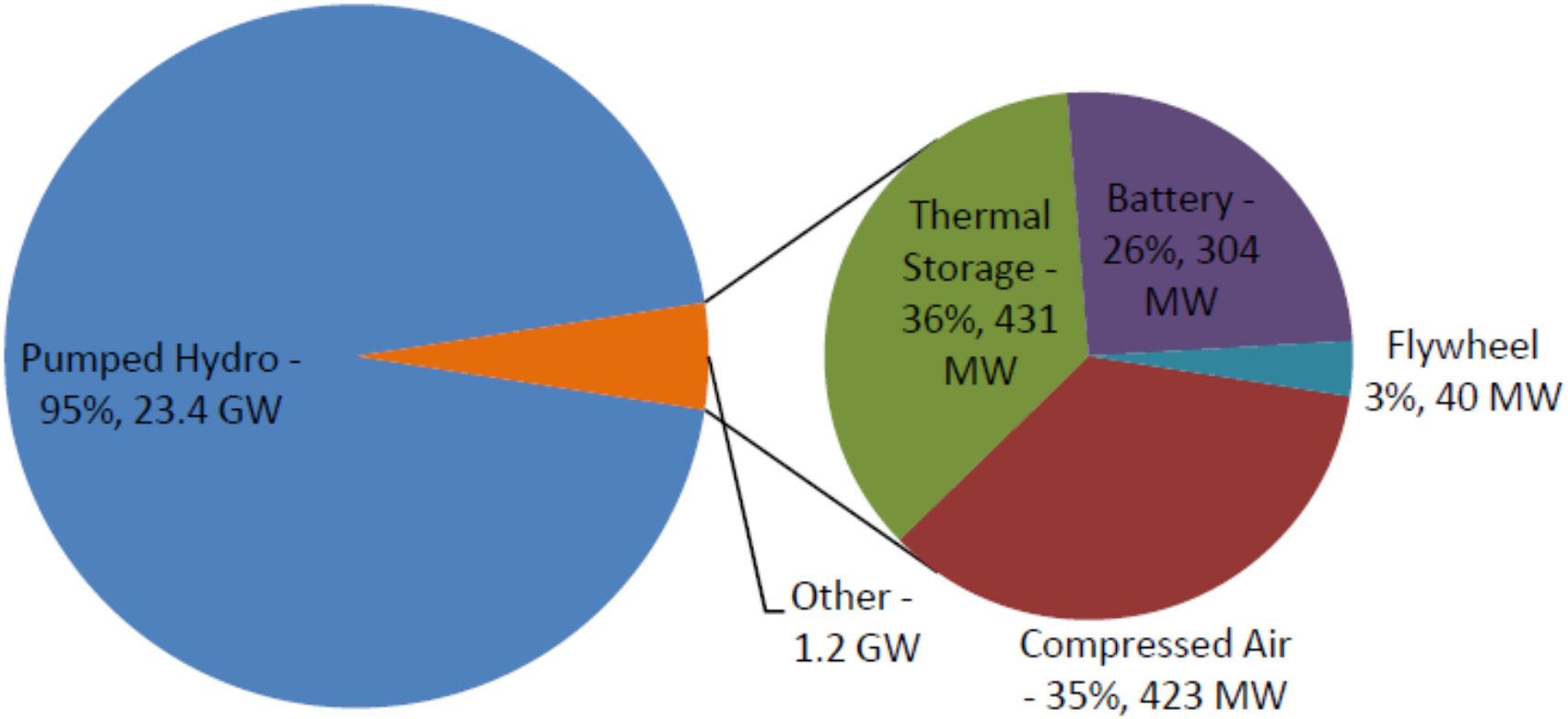
Storage: the Holy Grail

- Generation (supply) matches load (demand) exactly all the time
- Benefits of holding energy inventory
  - Greater operational flexibility
    - Lower cost and carbon content by dissociating instantaneous production from instantaneous sale of energy
  - Greater grid resiliency
    - Reliably serve load during outage events and severe weather events
- Barrier is cost, which is dropping fast
  - Seeing similar cost progression as solar PV
  - Regulations and standards have not caught up
- Significant research to lower cost
  - Increase energy density
  - Increase round-trip efficiency
  - Increase service life
  - Reduce interconnection costs

Storage basics

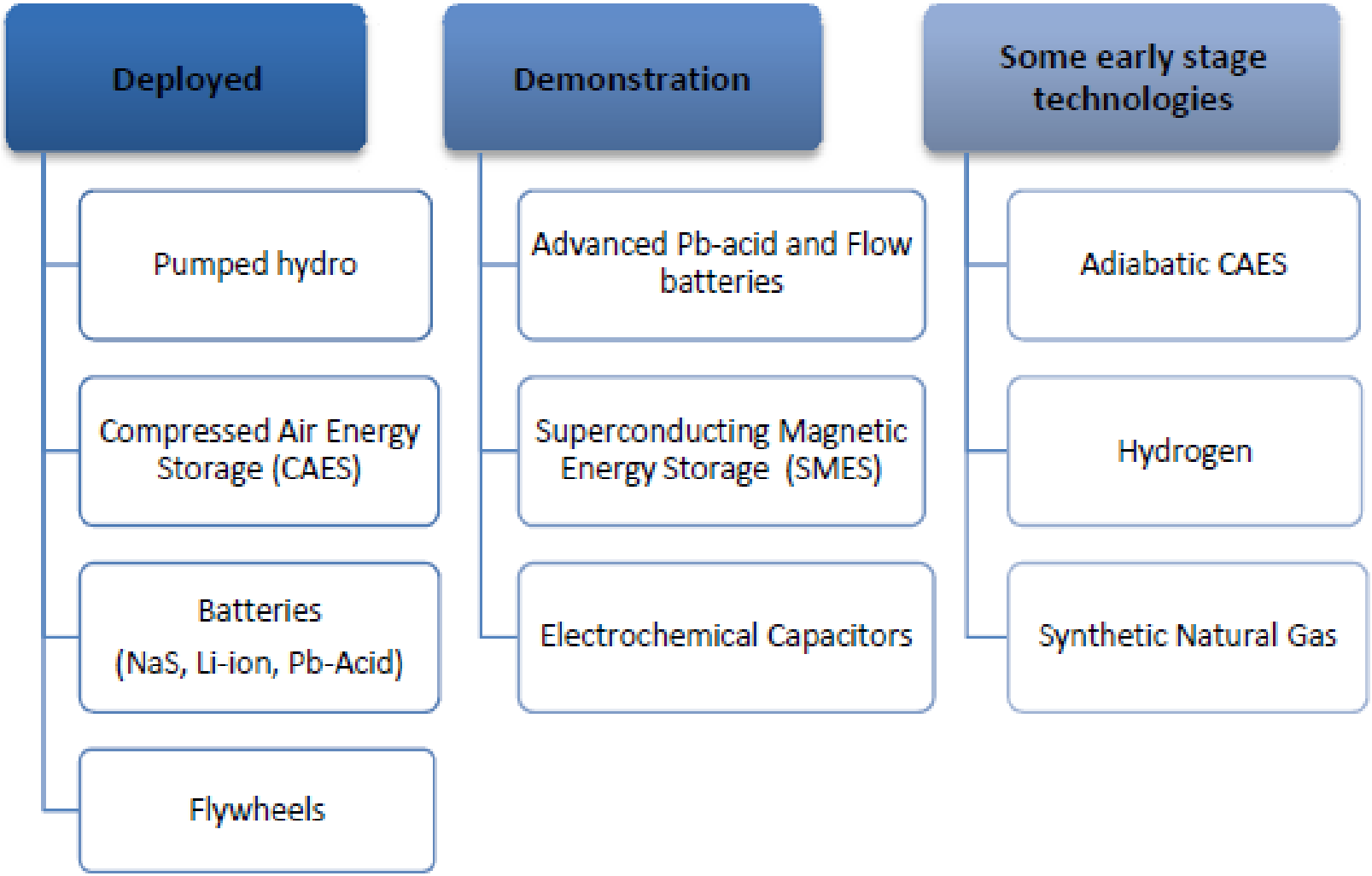
- Storage system includes
  - Storage mechanism
    - Battery, flywheel, reservoir, etc
  - Charging and discharging system
    - Inverter, motor/generator set, etc
  - Monitoring and control
- Wide variety of technologies
  - Lead acid battery and other electrolytes
  - Pumped hydro
  - Flywheel
  - Compressed air
  - Super capacitor
  - And so on
- Selection of technology depends on application
  - Power or energy
  - Speed of response
  - Frequency of operation

US grid storage projects
(includes announced projects)



This slide and the next two slides are from a DOE paper on electric energy storage
http://energy.gov/sites/prod/files/2014/09/f18/Grid%20Energy%20Storage%20December%202013.pdf

Maturity of storage technologies



http://energy.gov/sites/prod/files/2014/09/f18/Grid%20Energy%20Storage%20December%202013.pdf

Applications of energy storage

Bulk Energy Services
Electric Energy Time-Shift (Arbitrage)
Electric Supply Capacity
Ancillary Services
Regulation
Spinning, Non-Spinning and Supplemental Reserves
Voltage Support
Black Start
Other Related Uses

Transmission Infrastructure Services
Transmission Upgrade Deferral
Transmission Congestion Relief
Distribution Infrastructure Services
Distribution Upgrade Deferral
Voltage Support
Customer Energy Management Services
Power Quality
Power Reliability
Retail Electric Energy Time-Shift
Demand Charge Management

http://energy.gov/sites/prod/files/2014/09/f18/Grid%20Energy%20Storage%20December%202013.pdf

Energy storage in the New England markets

- Contact ISO-NE for market opportunities
- Grid-scale storage can participate in
  - Energy, Capacity, Reserves and Regulation markets
- ISO-NE needs visibility of storage assets
- Storage can participate as a
  - Generator when injecting power into the grid
  - Load when taking power from the grid
  - Or both

Summarized from ISO-NE paper:
http://www.iso-ne.com/static-assets/documents/2016/01/final_storage_letter_cover_paper.pdf

Options for the Participation of Energy-Storage Devices in the ISO New England Markets

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

Table from ISO-NE paper. See the notes on next slide.
http://www.iso-ne.com/static-assets/documents/2016/01/final_storage_letter_cover_paper.pdf

Notes for the table on the prior slide

(a) Developers seeking to participate in the capacity market should refer to the FCM participation guide at www.iso-ne.com/markets-operations/markets/forward-capacity-market/fcm-participation-guide.

(b) The North American Electric Reliability Corporation requires one-hour sustainability to provide operating reserves.

(c) The Regulation Market is generally cleared hourly; resources selected to provide regulation service are evaluated and compensated on the basis of their ability to perform for the entire hour. *See Market Rule 1*, Sections III.14.8(b)(iv) and III.14.3(c).

(d A capacity tag is the energy consumption of an individual customer or group of customers represented as a percentage of total New England energy consumption during the hour of the annual system coincident peak in the year before the capacity commitment period. Capacity tags are used to allocate FCM costs.

(e) ATRR refers to an alternative-technology regulation resource, which can consist of an aggregation of sites <1 MW across the system that sum to at least 1 MW.

(f) Claimed capability audit values for energy storage must equal the mean net real power output demonstrated over the duration of the audit, as reflected in the hourly revenue metering data. The claimed capability audit duration for energy storage is two hours.

(g) A generator must be at least 10 MW to provide regulation service.

(h) OP 14 refers to ISO's Operating Procedure #14, *Technical Requirements for Generators, Demand Resources, Asset-Related Demands, and Alternative-Technology Regulation Resource*, www.iso-ne.com/static-assets/documents/rules_proceds/operating/isone/op14/op14_rto_final.pdf.

(i) The capacity tag is zero for ARDs exclusively associated with ATRRs following automatic generation control dispatch instructions.

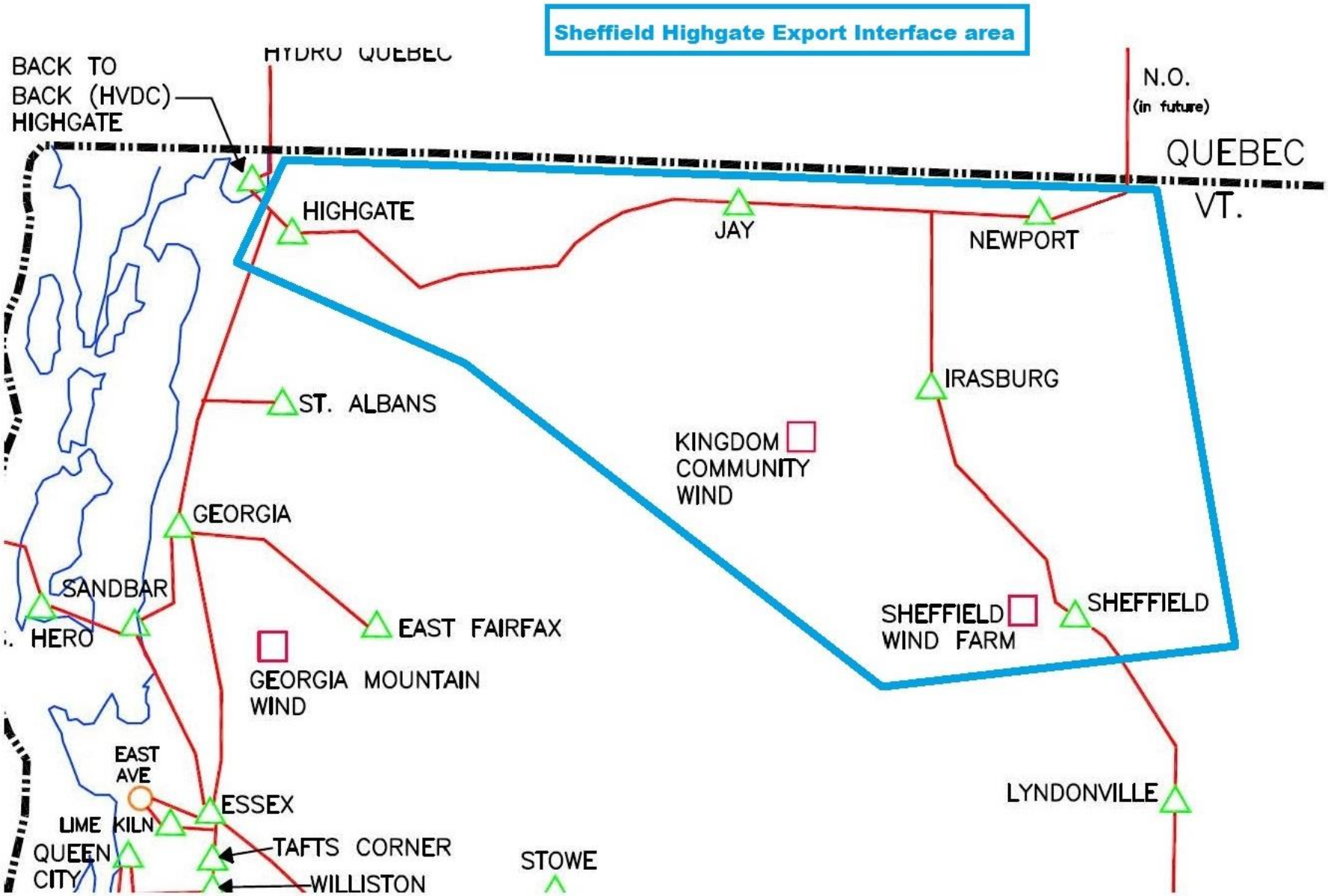
(j) A dispatchable asset-related demand capacity tag is set to a minimum consumption limit (firm load), which is zero for a storage asset.

(k) The full implementation of demand response into the energy market is scheduled for June 1, 2018, at which time demand-response resources will also participate in the reserve market. Demand-response resources will be able to aggregate, except for facilities providing ≥5 MW. A single facility providing ≥5 MW can be a demand-response resource, but it must participate individually and cannot be aggregated with others resources.

(l) A demand-response regulation resource can participate directly in the Regulation Market. Alternatively, an ATRR can be located behind the retail delivery point of a demand-response asset provided that the device supplying regulation service is registered separately from the asset, is individually telemetered and directly receiving an automatic generation control signal, and is compliant with all the ATRR requirements.

VELCO performed a high-level study of the time shift application

- Time shift of renewable energy in northern VT
  - Store energy that would be curtailed due to transmission constraints
  - Deliver that energy at a later time
- Did not perform a detailed study of storage as a wholesale market asset or as a reliability resource
- Quanta technology conducted study
  - Significant support from GMP
  - Studied 18 months of production data and system operator notes
  - Evaluated effects of future solar PV on curtailments

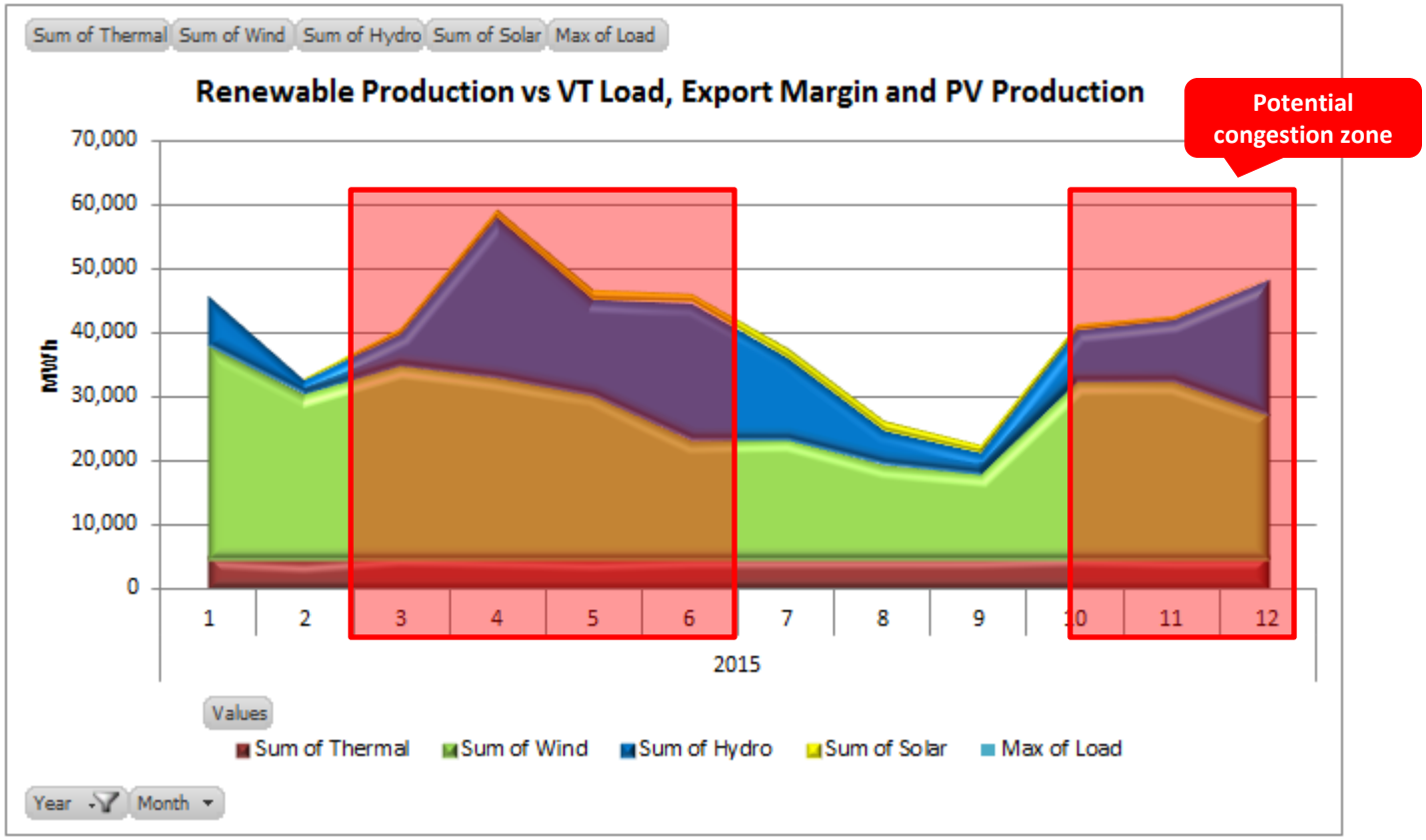

Sheffield Highgate Export Interface area
BACK TO
BACK (HVDC)
HIGHGATE
HYDRO QUEBEC
N.O.
(in future)
QUEBEC
VT.
HIGHGATE
JAY
NEWPORT
IRASBURG
ST. ALBANS
KINGDOM
COMMUNITY
WIND
GEORGIA
SANDBAR
HERO
EAST FAIRFAX
GEORGIA MOUNTAIN
WIND
SHEFFIELD
WIND FARM
SHEFFIELD
EAST
AVE
ESSEX
LIME KILN
QUEEN
CITY
TAFTS CORNER
WILLISTON
STOWE
LYNDONVILLE

Implications of export limits

- Reliability to load is always maintained
- Generation is limited 36% of the time
  - Limit AKA curtailment = the plants are directed to be offline or to stay below a certain output level
  - 87% of those limit events relate to ISO-NE dispatch orders
    - Other limits relate to sound, weather, service
    - Limits vary frequently, sometimes several times a day
    - Lost production occurred 13% of the time during limit events
    - Energy storage can only address these lost production events

Quantifying curtailment

What other factors could be contributing to curtailment?

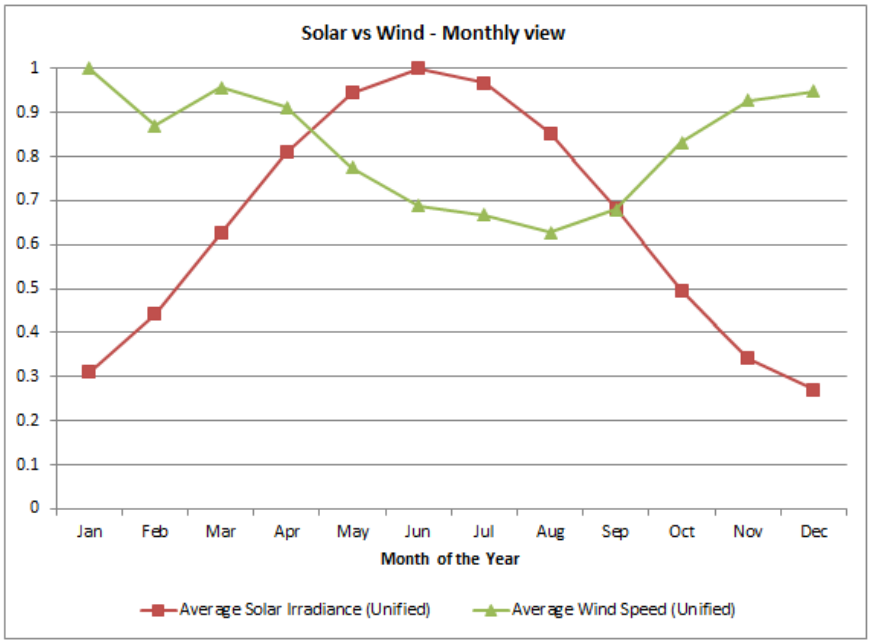


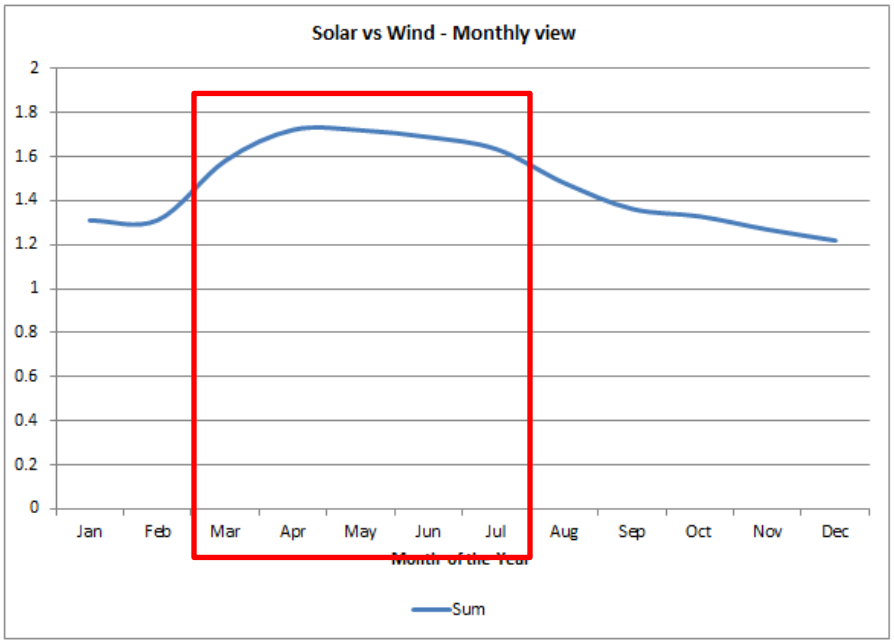
Findings of Quanta storage study

- Storage device would remain idle for long periods
  - Not enough energy charge/discharge transactions to offset installed cost of storage, using very rough cost assumptions
  - Payback periods of tested storage scenarios were in hundreds of years range
  - Financial performance can be improved with participation in wholesale markets
- GMP and others may investigate storage further
  - Opportunities may still exist for viable storage projects
- Future solar PV improves financials for storage
  - More energy to manage
  - Solar PV and wind are somewhat complementary

Quantifying curtailment

Solar versus Wind – Monthly view





In a capacity constrained system there is a higher likelihood of conflict in March to July

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Quantifying curtailment

Solar versus Wind – Hourly view