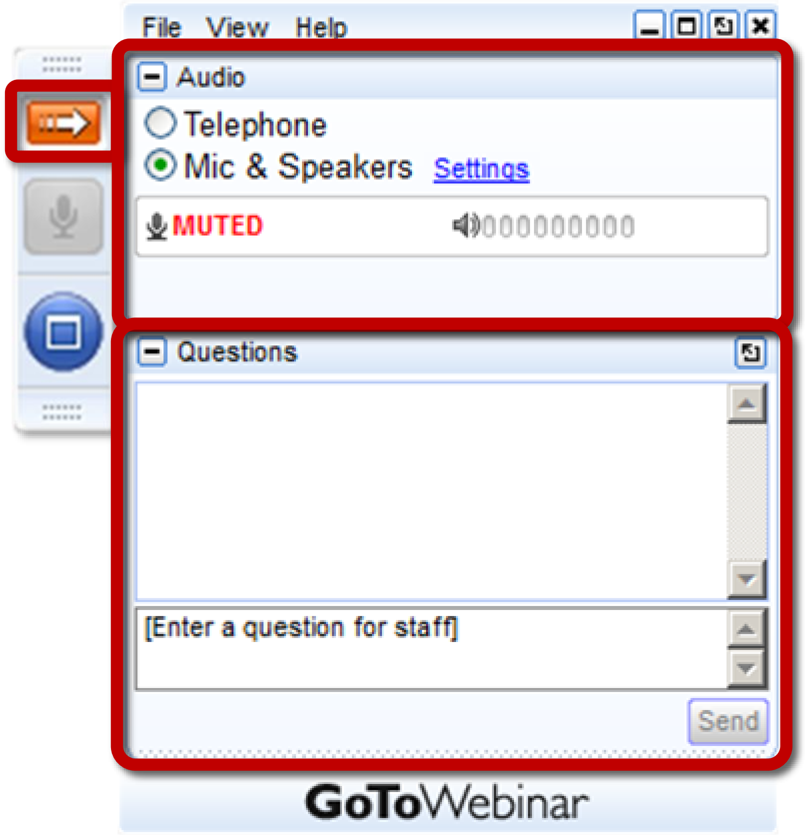
DOE-OE Energy Storage Technology Advancement Partnership (ESTAP) Webinar

Nantucket Island Energy Storage: Batteries for Reducing Peak and Deferring Infrastructure Investment

October 9, 2020

Webinar Logistics



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DOE-OE Energy Storage Technology Advancement Partnership

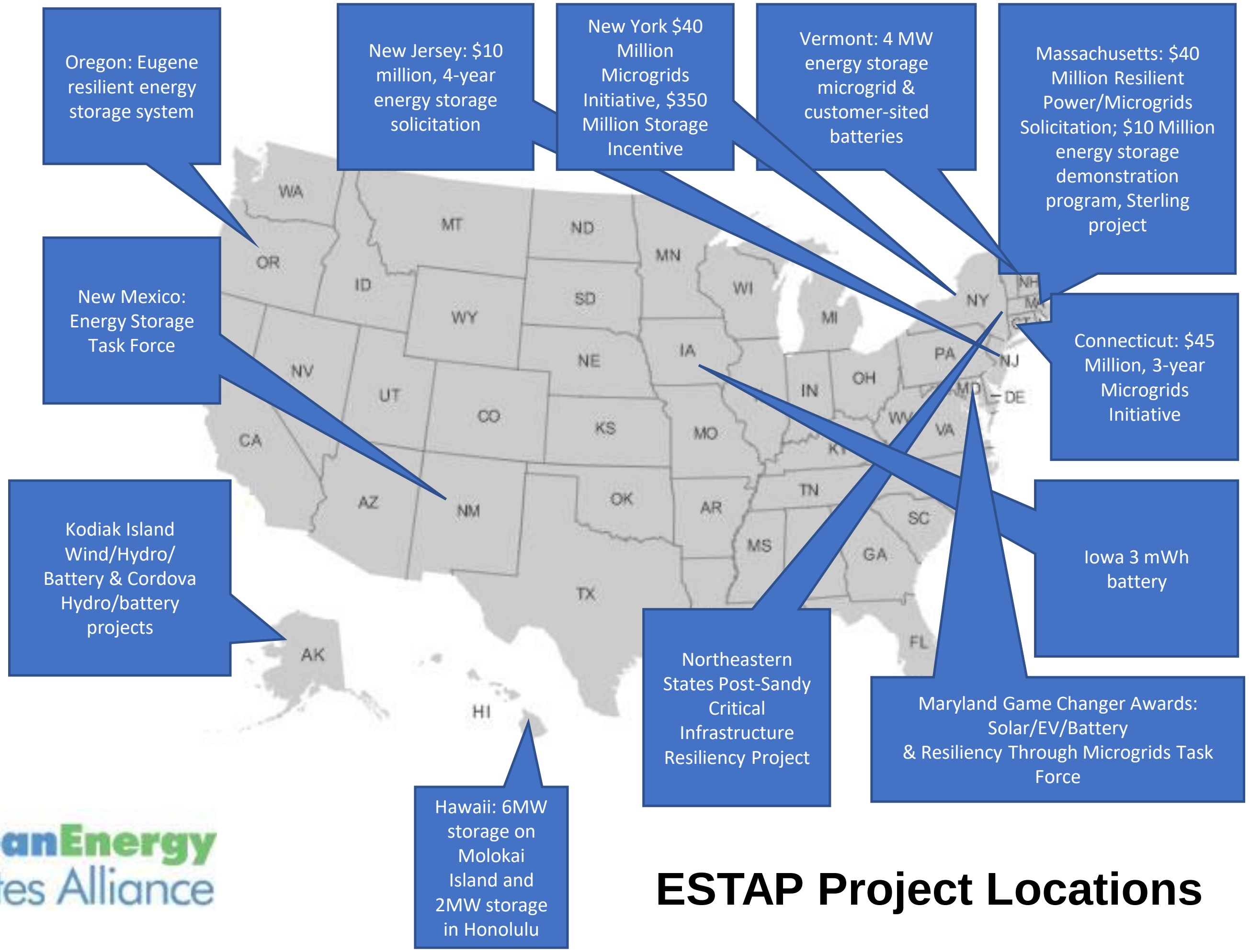
The Energy Storage Technology Advancement Partnership (ESTAP) is a US DOE-OE funded federal/state partnership project conducted under contract with Sandia National Laboratories.

ESTAP Key Activities:

1. Facilitate public/private partnerships to support joint federal/state energy storage demonstration project deployment

2. Disseminate information to stakeholders
    - ESTAP listserv >5,000 members
    - Webinars, conferences, information updates, surveys.

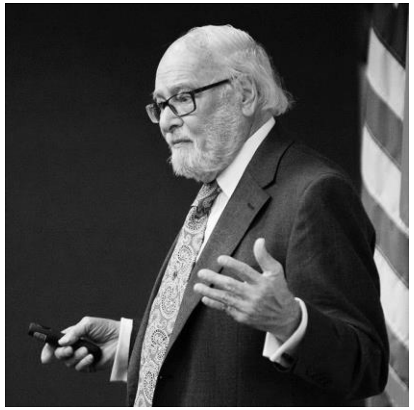
3. Support state energy storage efforts with technical, policy and program assistance



ESTAP Project Locations

U.S. DEPARTMENT OF ENERGY | Sandia National Laboratories | CleanEnergy States Alliance

Thank You!



Dr. Imre Gyuk
Director, Energy Storage Research,
U.S. Department of Energy

U.S. DEPARTMENT OF ENERGY

Dan Borneo
Engineering Project/Program Lead,
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Sandia National Laboratories

Clean Energy States Alliance

State of California Energy Commission

Connecticut Green Bank

Department of Energy & Environment

Energy Trust of Oregon

IPA Illinois Power Agency

Governor's Energy Office (Maine)

Maryland Energy Administration

Massachusetts Clean Energy Center

EGLE Michigan Department of Environment, Great Lakes, and Energy

mn Commerce Department

New Hampshire Public Utilities Commission

New Jersey Board of Public Utilities (BPU) | New Jersey's cleanenergy program — njcleanenergy.com

New Mexico emnrd Energy, Minerals and Natural Resources Department

New York State of Opportunity | NYSERDA

State of Rhode Island Office of Energy Resources

SMUD — Powering forward. Together.

Vermont Clean Energy Development Fund — Public Service Department

DMME Virginia Department of Mines Minerals and Energy

State of Washington Department of Commerce — Innovation is in our nature.

OEI Wisconsin Office of Energy Innovation

Connecticut Energy Environment

Illinois Commerce Commission (ICC)

Inclusive Prosperity Capital

DOER Massachusetts Department of Energy Resources

MassDEP

NREL National Renewable Energy Laboratory

Commissioner Stephanie Garcia Richard — New Mexico State Land Office

OPC-DC Office of the People's Counsel — Advocacy | Education | Protection

Oregon Department of Energy

Prairie Island Indian Community — In the State of Minnesota

Rhode Island Commerce Corporation

Smart Electric Power Alliance

www.cesa.org

Today's Webinar Speakers

Dr. Imre Gyuk
Director, Energy Storage Research, U.S. Department of Energy

David Bianco
Principal Engineer, National Grid

Patrick Balducci
Chief Economist, Pacific Northwest National Laboratory

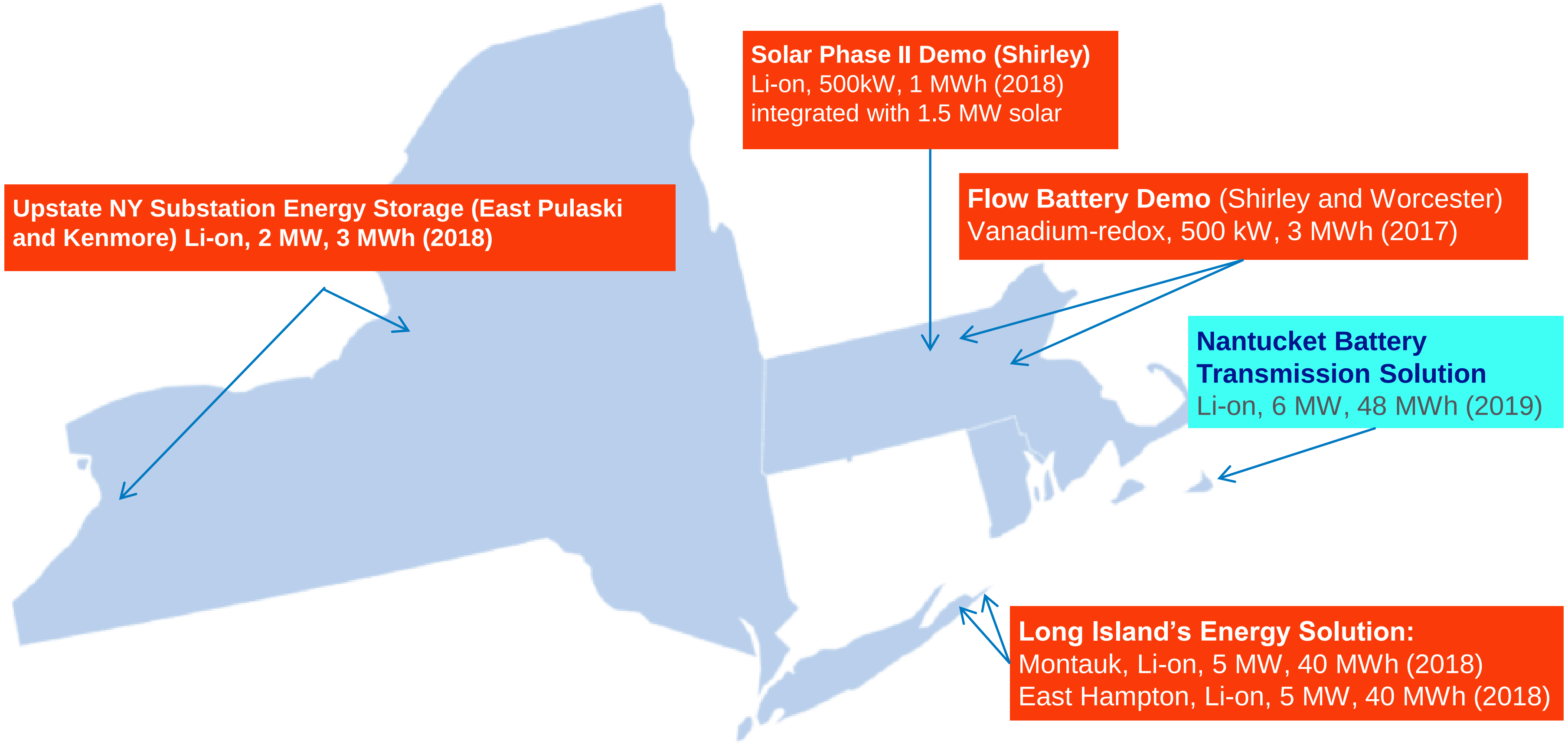
Val Stori
Project Director, Clean Energy States Alliance (moderator)

Nantucket, Massachusetts –

Battery Energy Storage System BESS

nationalgrid

National Grid’s Energy Storage Solutions:
Multiple projects



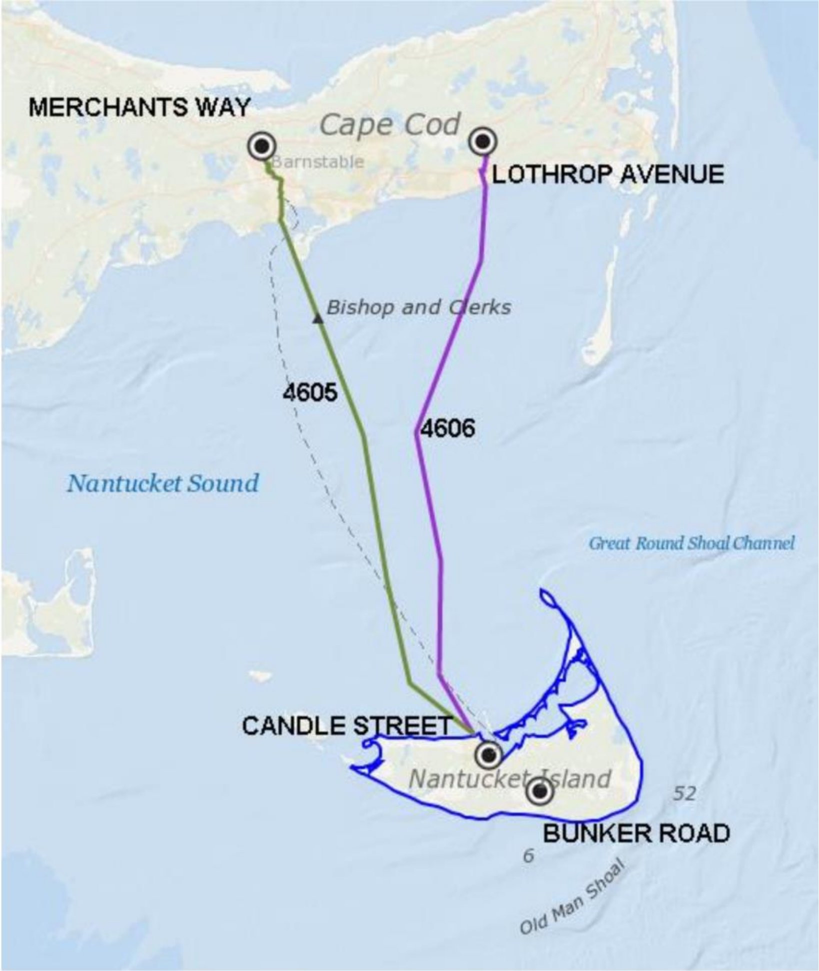
Nantucket Island

- 26 miles off the coast of Cape Cod, MA
- Fed via two under sea cables
- ~12,000 year around customers;
  ~50,000+ during summer peak
- Existing Oil-fired Combustion Turbines for lack of supply to island (Emergency use)

Nantucket Load Growth

Summer Peaking

- Summer peaking area limited by summer equipment ratings.
- Load growth : 2008-2013 (4%), 2014 (6%), 2015 (3%), 2016 (3%), 2017 (2%), 2018 – 2034 (1.7%)
- **Issue :** N-1 Condition, if one undersea cable fails during peak, remaining cable will be overloaded
- **Solution :** upgrade existing (diesel) Combustion Turbine Generator (CTG) & new Battery Energy Storage System (BESS) on island
- **Value Streams :** Deferred investment of undersea cable & pilot market participation in ISO-NE



Storage : As Non Wires Alternative (NWA)

- Understand techno-economics of different

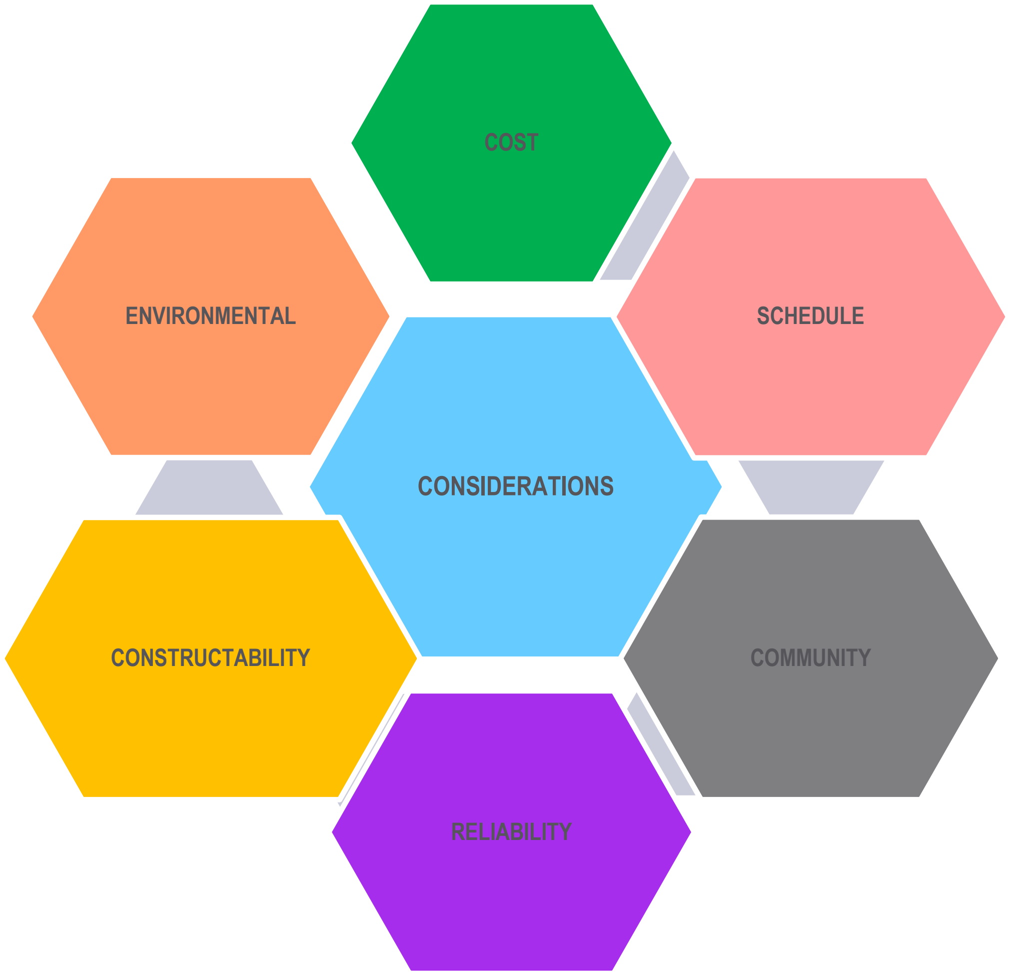
  energy storage applications

- Compare energy storage against conventional Distribution & Transmission solutions

- Recognize economics as key decision variable

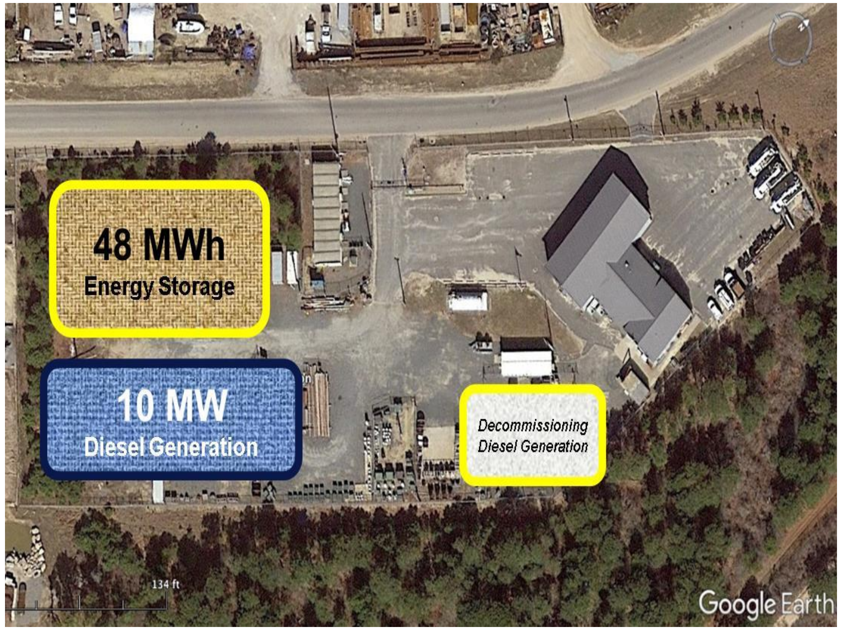
Considerations

- N-1 Reliability, if one cable failed
- Local & ISO interconnection studies
- Coordination of control
- Balancing Reliability and Market Need
- Utility ownership
- Land availability



Hybrid Option: Combustion Turbine + Storage

- Defers need of third undersea cable
- Avoids Major expense of the undersea cable
- Provides N-1 contingency relief for loss of supply
- Provides T&D benefits (e.g., voltage, PF and other ancillary services)
- Provides effective, efficient, and environmentally sustainable solution



DOE Support

PNNL supported various Economic and Technical Studies. Results can be found at :

https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-28941.pdf

Deferral of a third undersea cable confirmed, and identified the benefits of using the system to support local reliability and market operations.

- Capacity
- Regulation
- Spinning Reserves
- Volt-VAR optimization, Conservation Voltage Reduction
- Outage Mitigation

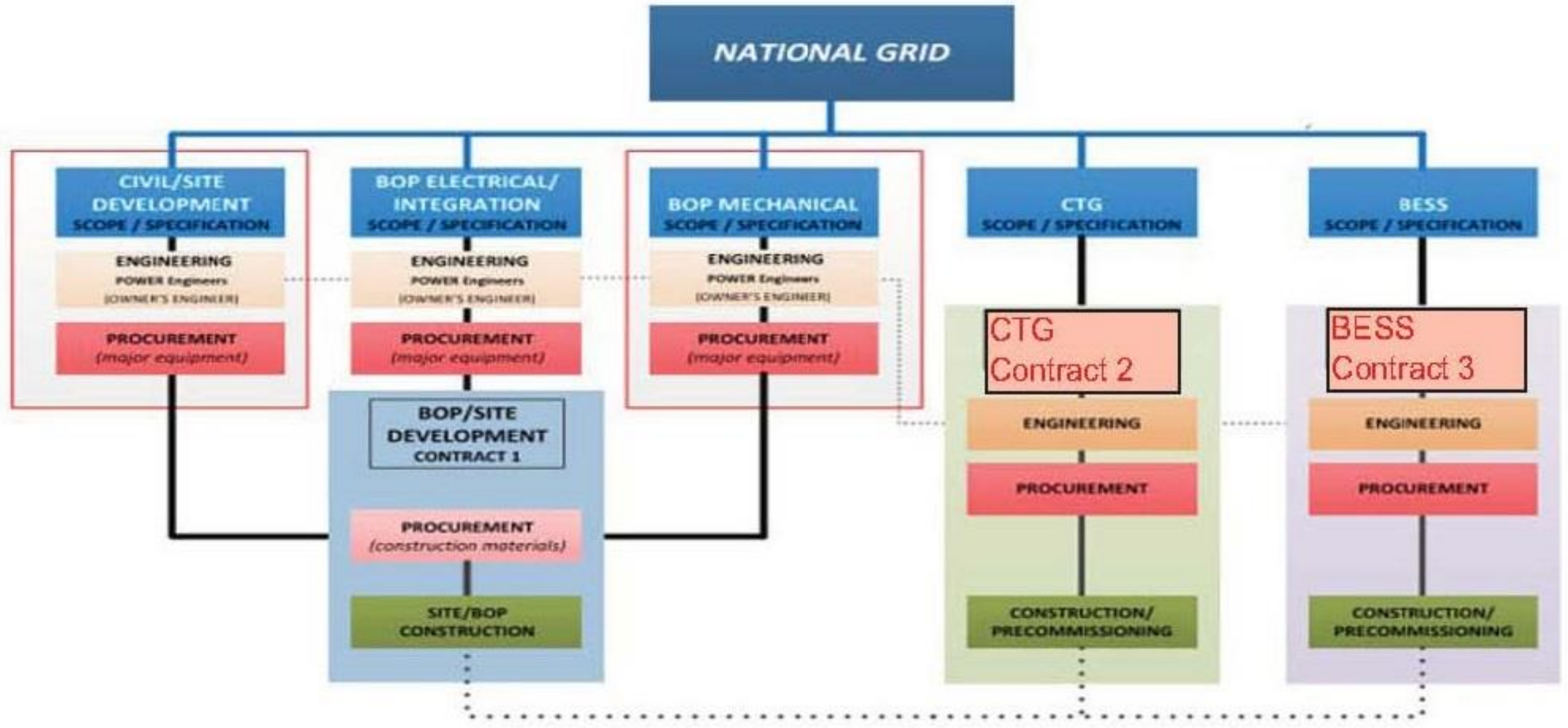
BESS Selection Process Differentiators

- Open to all technologies-technology neutral
- Footprint
- Configuration (Enclosed building/Outdoor)
- Pre-Qualifications (Supplier Capabilities/Experience)
- Island Logistics
- Technical and Commercial terms
- Schedule
- Site Interfaces

Preliminary Engineering

- Interconnection Studies on local Distribution System
- Two 26 mile radial undersea cables from mainland (weak system)
- Large DER (CTG & BESS) – control modes
- Coordinate control of CTG, BESS, LTC’s, line caps, line VRs
- Parallel Operation of CTG and BESS, avoid violations
- Inverter modeling (PSSE, Aspen, PSCAD)
- Balancing Reliability and Market needs
- Peak Shave - forward predictions of weather, load and grid considerations

Project Delivery Strategy



Construction-Logistics

Labor resource - Lodging

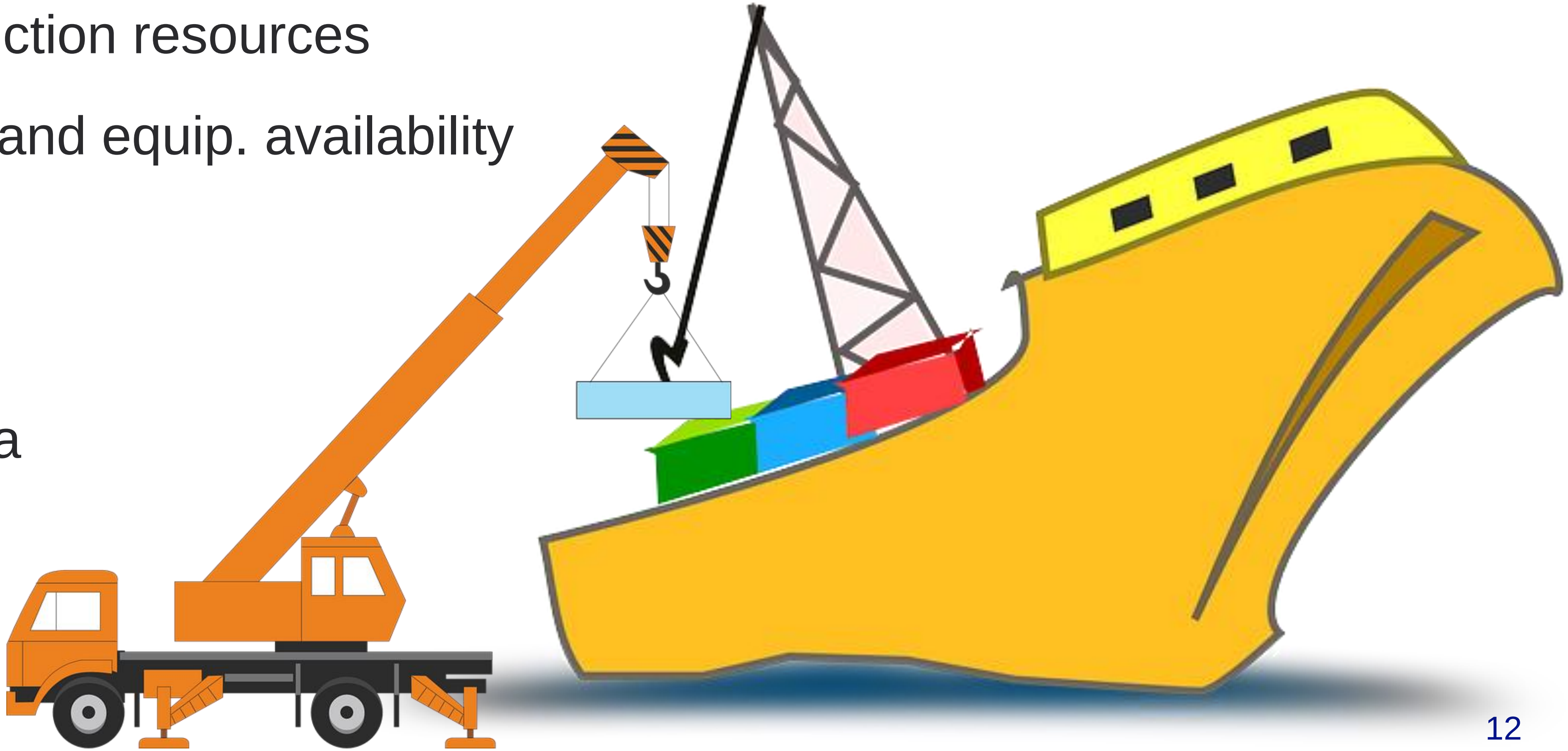
Logistics of construction resources

On Island vs Off Island equip. availability

Mainland staging

Ferry availability

Island laydown area



Commissioning

- Ownership & Delivery Model – drives approach
- Start project with Commissioning & Acceptance in mind (Tech Specs!)
- Utilize EPRI / ESIC and IEEE standards
- Can take a Day or a Month, system dependent
(takes longer than anticipated)
- Consider forms of supply & load available (Generation & Load Banks)
- Baselines test results help alleviate later operational problems
- Trains personnel, ensures safe and operational system

Challenges

- Developing comprehensive technical and contracting specifications
- Forming a project delivery structure, for a supplier/utility team that works
- Paralleling maturity of design, procurement, construction and testing phases
- Coordinating a wide degree of stakeholders
- New technology integration during Engineering, Construction & Commissioning
- Deploying large equipment and logistics in a remote area

Challenges (*continued*)

- Understanding large DER interconnection issues (Hybrid, CTG and BESS)
- Industry models such as PSS/E, CYME, Aspen need upgrades to model DER appropriately
- Remote IT monitoring requirements for CTG and BESS diagnostics, maintenance and warranty needs

Final thoughts….

- Islands cause unusual and unique needs
- Peak seasonal demand created supply risk
- Sequencing of Major Suppliers vs. Balance of Plant adds to an already complex scenario in a remote area
- Remote Radial lines create an application for storage satisfying Reliability
- National Grid has deferred the need to build a third undersea cable

Questions?

nationalgrid

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An Economic Assessment of the Nantucket Island Energy Storage System

Patrick Balducci, Chief Economist

Pacific Northwest National Laboratory

CESA-ESTAP Webinar

Online Conference

October 9, 2020

Support from DOE Office of Electricity

ENERGY STORAGE PROGRAM

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Other contributing authors: Kendall Mongird, Vanshika Fotedar, Di Wu, Tom McDermott, Alasdair Crawford, Xu Ma, Bilal Bhatti, Bishnu Bhattarai, and Sumitrra Ganguli

Project Overview

Nantucket Island

- Located off the southeast coast of Massachusetts
- Small resident population of 11,000
- Transmission capacity constraints in summer where population can swell to over 50,000

Project Description

- Nantucket Island's electricity is supplied by two submarine cables with a combined capacity of 71 megawatts (MW) and two small on-island combustion turbine generators (CTGs) with a combined capacity of 6 MW
- Rather than deploying a 3rd cable, National Grid is replacing the two CTGs with:
  - A single, large CTG with a maximum capacity of 16 MW, and
  - A 6 MW / 48 MWh Tesla Li-ion battery energy storage system (BESS)

Nantucket Supply Cables

Project Synopsis and Objectives

Objective

1) Evaluate the technical and financial (market and non-market) benefits of energy storage on Nantucket Island
2) Evaluate its impact on the Nantucket Island distribution system
3) Develop control strategies to maximize financial benefits while achieving resilience goals

Phases

***Phase 1:* Preliminary Economic Analysis** → ***Phase 2:* Distribution System Impact Analysis** → ***Phase 3:* Final Assessment & Controls Development**

1) Use Case Definition, Preliminary Economic Analysis
2) Distribution System Impact Analysis, Install BESS
3) Controls Development and Final Evaluation

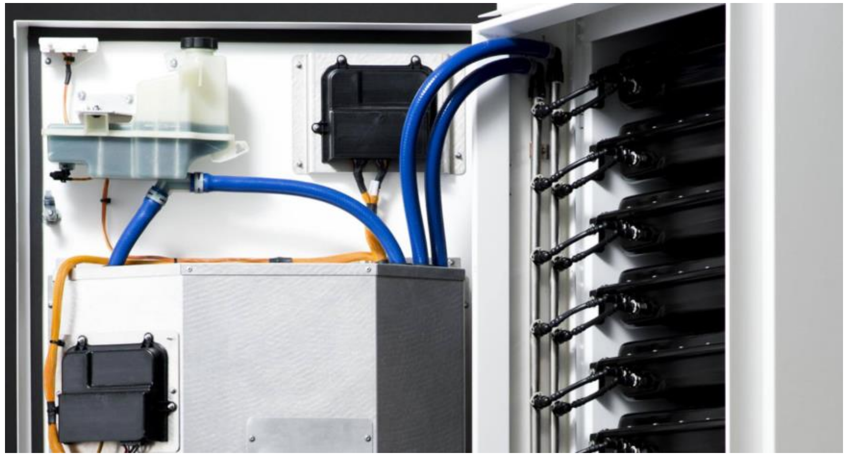
Team

- **PNNL:** Brings expertise in energy/economics/environment system analysis and modeling
- **National Grid:** Brings deep operational experience and required utility data / test sites
- **U.S. Department of Energy**: Program management by Dr. Imre Gyuk
- **Virginia Tech:** Distribution system analytical support

Nantucket Island Economic Use Cases

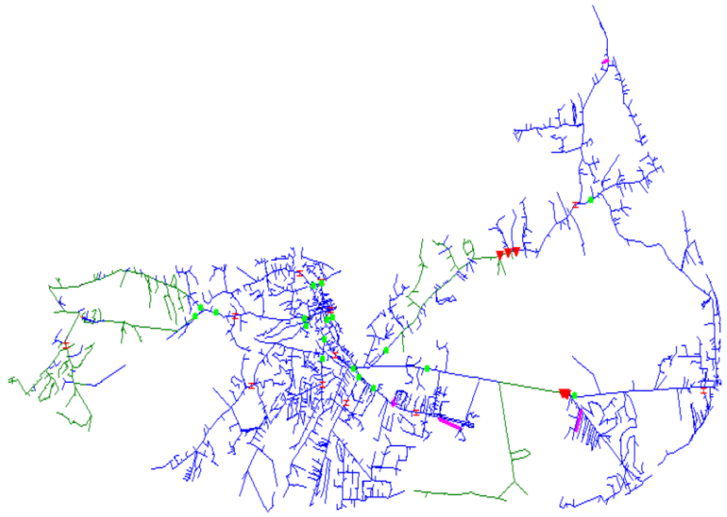
Use cases evaluated:

- Non-market operations
  - ✓Transmission deferral
  - ✓Outage mitigation
  - ✓Conservation voltage reduction (CVR)/Volt-VAR optimization
- Market operations
  - ✓Forward capacity market
  - ✓Arbitrage
  - ✓Regulation
  - ✓Spinning reserves



Tesla Powerpack 2 Lithium-ion Energy Storage System - Exterior and Interior

Distribution System Integration

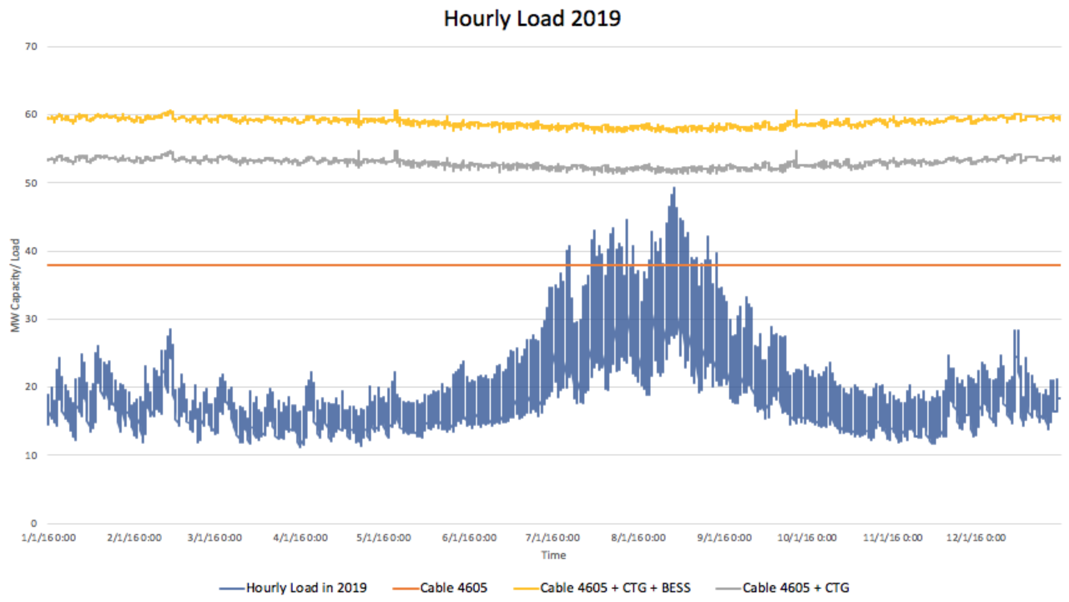


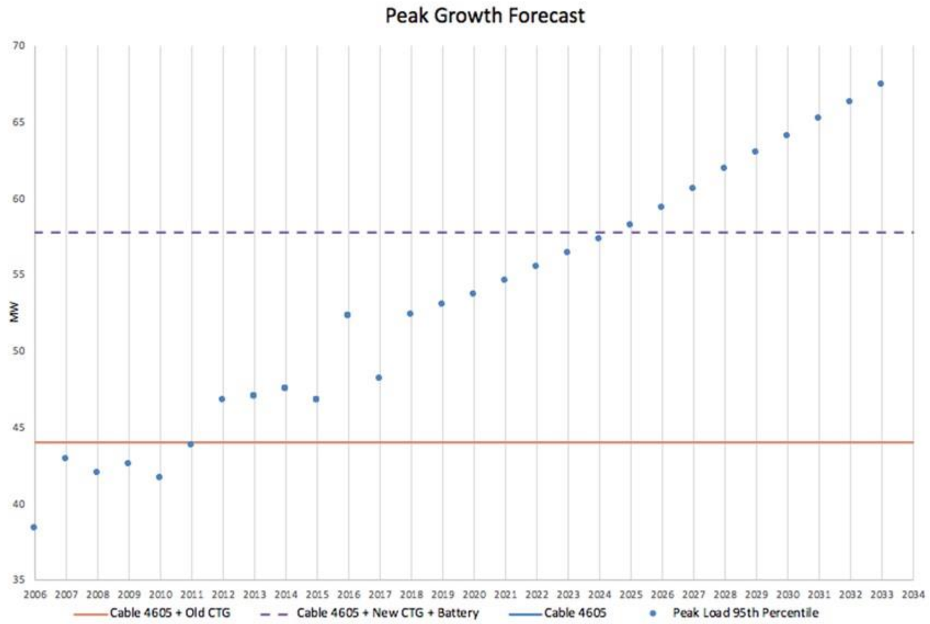
Nantucket Island Distribution System

- BESSs do not operate in isolation and must therefore be integrated into the existing grid
  - Modeled and simulated integration of storage systems to identify and mitigate negative system impacts
  - Converted existing data and models to GridLab-D and OpenDSS
  - Added battery and inverter controls to the models
  - Evaluated battery integration under normal conditions to include feeder volt/var control, battery state of charge (SOC) management, dispatch requirements with respect to existing distributed energy resources (DER), and the impact on reliability metrics
  - Recommended operating practices and settings as needed, covering the battery, other DERs, and feeder volt/var equipment
- Results woven back into the economic assessment

Non-Market: Transmission Deferral

- PNNL performed an extensive load analysis in order to define the N-1 contingency window
- Historic load data demonstrates that load peaks each year in the July/August period
- If transmission cable 4606 were to fail during the peak load season, the island faces a threat of power outage and would not be able to support even current energy demand
- Adding the battery and CTG defers the installation of a third cable by 13 years – $109.5 million in net present value (PV) benefits





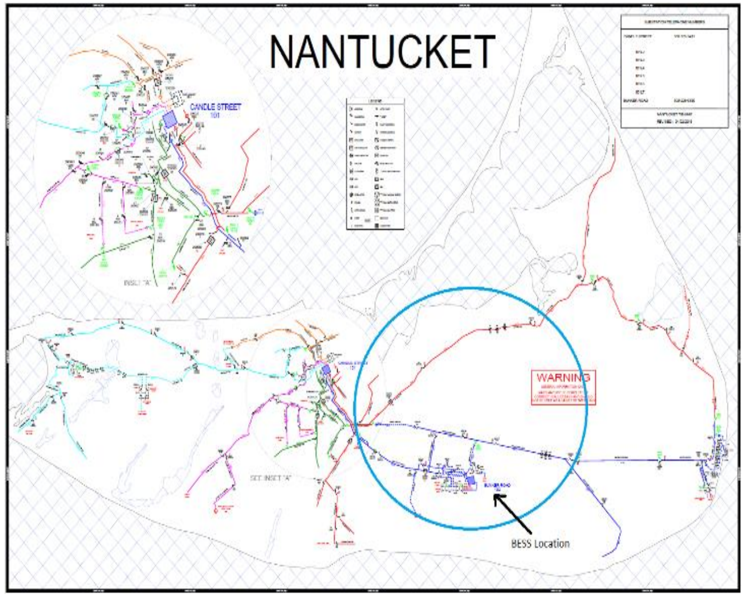
Non-Market: Outage Mitigation

- Outage data
  - Obtained from National Grid for multiple years - 704 outages over 11 years, averaging 64 annually
  - All outages with secondary/service, transformer, and fused branch in the description were eliminated because the BESS could not address them
  - Outage start time and duration also collected
- Customer and load information
  - Number of customers affected by each outage obtained from utility
  - Customer outages sorted into customer classes
- Outage mitigation evaluated using both historical outages and distribution system model; 50% SOC floor established

Annual Savings in Value of Lost Load

Response Time	Without Reconductoring	With Reconductoring
1 Hour	$783,124	$876,157
5 Minutes	$909,293	$1,011,754
1 Minute	$920,382	$1,023,523

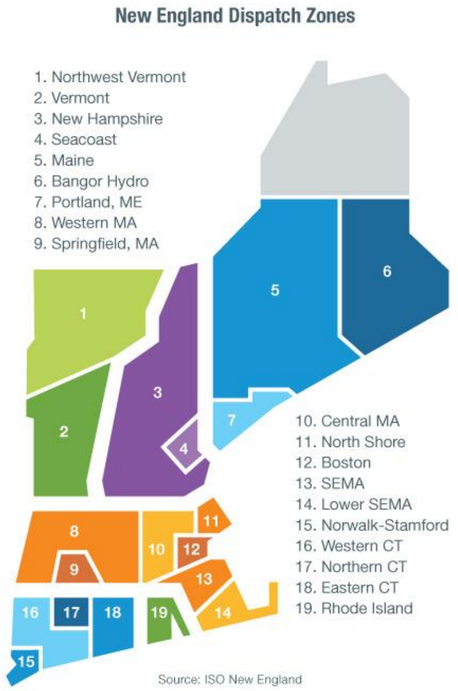
Modeled Outage on Nantucket Island

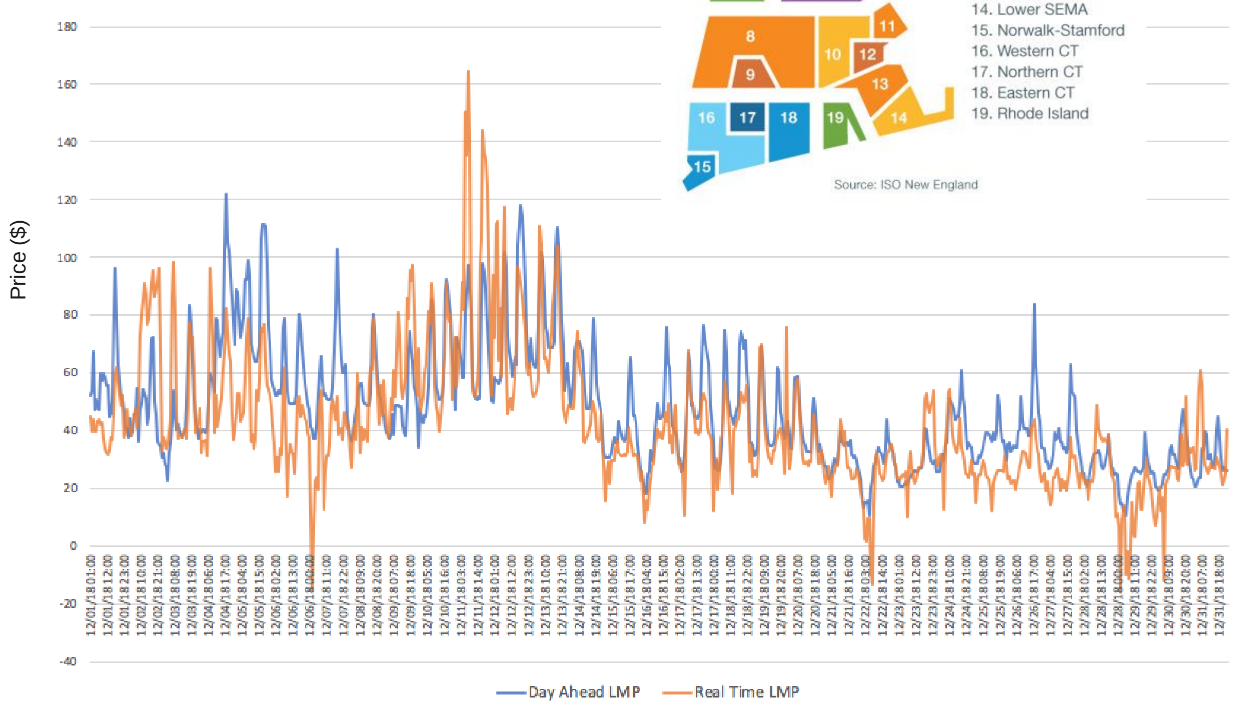


ISONE Market: Energy Arbitrage

- Nantucket BESS modeled as a continuous storage facility – forward capacity, spinning reserve, energy arbitrage and frequency regulation (CTG not bid in market due to emissions/noise concerns)
- Market rules enable National Grid to adjust price bids based on local opportunity costs – higher prices, economic min/max altered when BESS is required for local operations
- For arbitrage, PNNL collected hourly and real-time market data on clearing prices

Key Lesson: While one of the first recognized use cases for energy storage, arbitrage typically yields a small value.





ISONE Market: Energy Arbitrage

- Daily operation of the BESS is based on forecast prices while revenue results from market clearing prices. Imperfect foresight includes impacts of forecast error
- After testing several models, the two best approaches that were used to generate final predictions for DAM LMP and RTM LMP were **ARIMA and GBM.** We used the ARIMA-fed GBM method

GBM - The Gradient Boosting Machine, or GBM, is a machine learning tool where a weak model is iteratively upgraded into a strong one by minimizing the negative gradient of the loss function

ARIMA - The ARIMA(p,d,q) models are a general form of time series model capable of modeling **A**uto**R**egressive, **I**ntegrated, and **M**oving **A**verage time series data.

- Revenues higher in the RTM relative to the DAM, even when accounting for forecast error
- While GBM yielded the most precise estimates statistically, use of DAM LMP as predictor of RTM LMPs yielded highest revenue due to its ability to identify high price days

Results by Year and Prediction Method for Arbitrage Only ($)

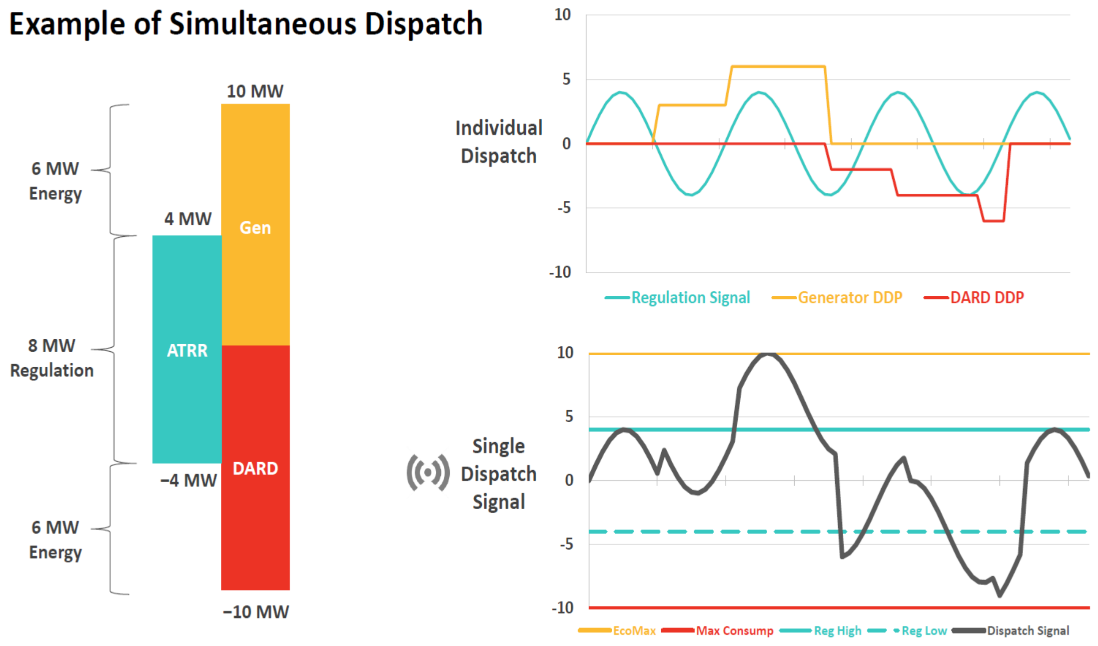
Market/Prediction Method	2016	2017	2018	Average
GBM Prediction of DAM LMP	110,058	95,585	133,560	113,068
Yesterday DAM LMP as Predictor of DALMP	101,746	87,453	123,486	104,228
GBM Prediction of RTM	137,519	124,620	85,866	116,002
DAM LMP Prediction of RTM	154,096	131,988	107,506	131,197

Note: After performing co-optimization routine and imposing cycling limitations, arbitrage revenue virtually eliminated.

ISONE Market: Frequency Regulation

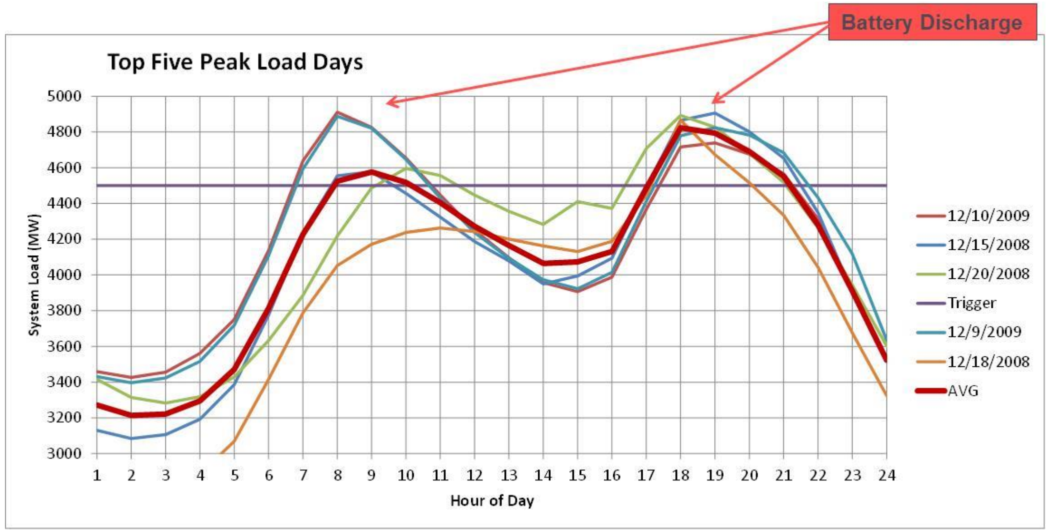
- The electric power system must maintain a near real-time balance between generation and load. The BESS can provide second-by-second adjustment in output power to maintain grid frequency
- Within the ISO-NE market, regulation follows an energy-neutral automatic generation control (AGC) signal; we assume a 95% performance score based on literature review
- The Nantucket BESS can simultaneously provide energy, regulation, and reserve services
- Regulation prices obtained from the ISO-NE market database for the time period 2016-2018. Regulation prices represent systemwide regulation pool prices
- Regulation provides <u>78% of total market benefits</u> for the BESS

Key Lesson: Performance of battery storage in providing frequency regulation is exceptionally high. Batteries represent an efficient resource for providing frequency regulation; however, market prices can be driven downward as a result, undermining the profit potential to storage operators in the process.



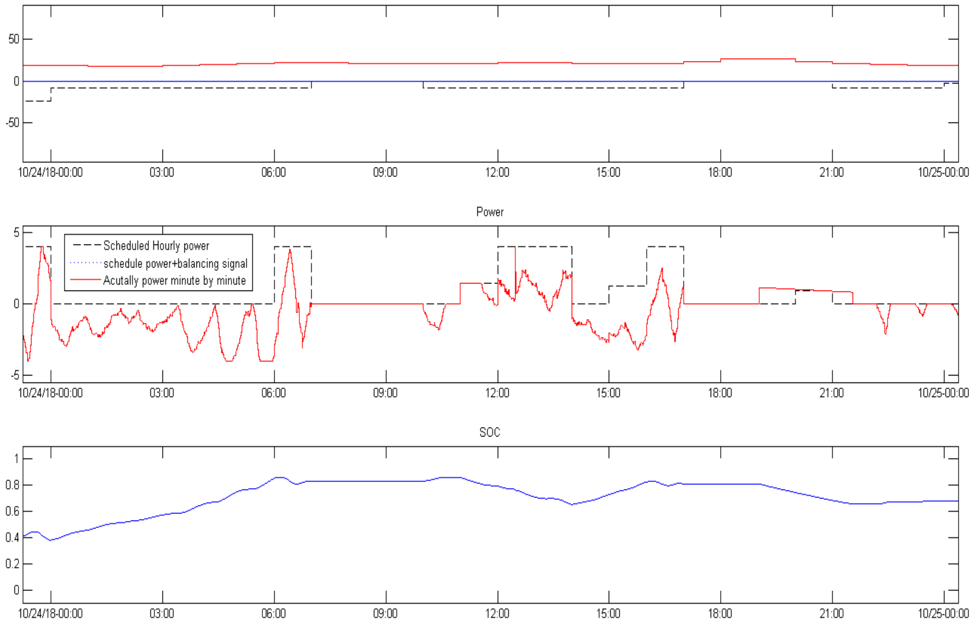
ISONE Market: Forward Capacity Market

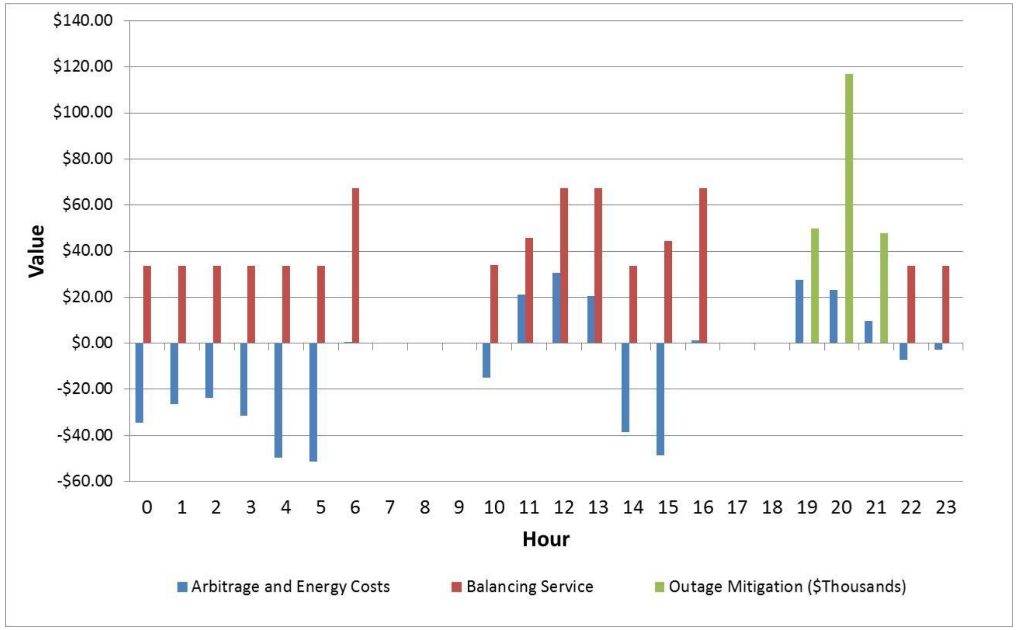
- Forward capacity market (FCM) auction is held three years in advance for each period
- BESS would be bid in for a year-long capacity commitment, spanning from June-May of the following year
- To obtain the capacity value, the BESS must be bid into the ISO-NE energy market on the day of the shortage event
- To mirror the units with capacity supply obligations (CSOs), PNNL relied on historic events called in the ISO-NE market
- The capacity payment is equal to the CSO and the net regional clearing prices
- There is also an additional payment/penalty component which is dependent on BESS performance during events
- 50% SOC floor established



Time Period	FCM Net Regional Clearing Price ($/kW-month) Actual	Forecast
2019-2020	7.03	
2020-2021	5.30	
2021-2022	4.63	
2022-2023	3.80	
2023		5.81
2024		6.40
2025		7.02
…		…

Bundling Services: How To Do It Optimally



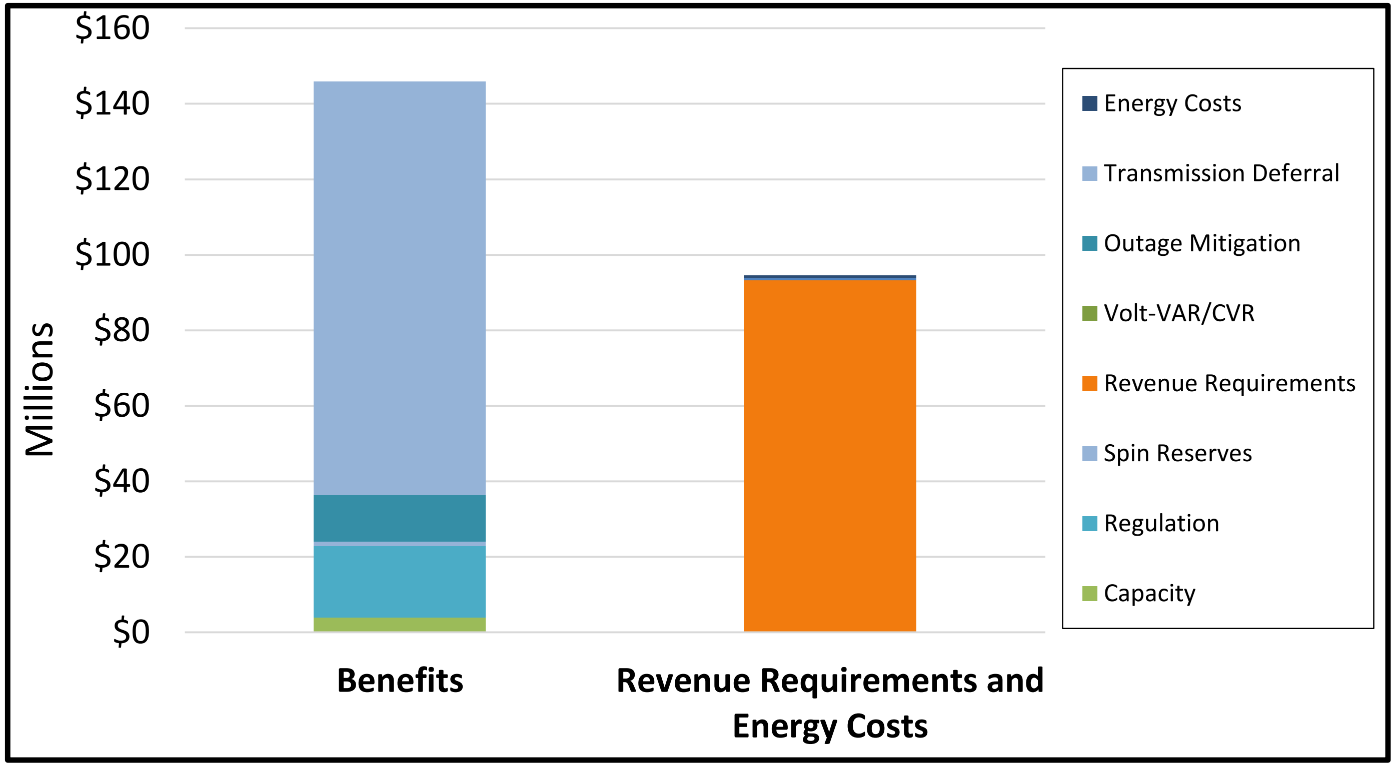


Key Lesson: A valuation tool that co-optimizes benefits is required to define technically achievable benefits.

- Multi-dimensional co-optimization procedures required to ensure no double counting of benefits
  - BESSs are energy limited and cannot serve all services simultaneously
  - By using energy in one hour, less is available in the next hour
- Energy storage valuation tools are required; we use our battery storage evaluation tool (BSET)

Nantucket Island Base Case Results

- Total 20-year PV of BESS and CTG operations at $145.9 million exceed revenue requirements and energy costs at $93.9 million with a return on investment (ROI) ratio of 1.55
- Benefits largely driven by transmission deferral use case – $109 million (75%) in PV terms
- An additional $18.8 million results from regulation services, which comprise 12.9% of total benefits
- Regulation service dominates the application hours, with the BESS engaged in the provision of this service 7,900 hours each year



Benefits of Local and Market Operations (Base Case) vs. Revenue Requirements

Conclusions

- National Grid decision to avoid installation of 3rd cable by deploying a CTG and BESS appears sound
  - Value of local operations ($122 million) exceeds the $93.3 million in revenue requirements for the systems, yielding an ROI ratio of 1.30
  - Market benefits are estimated at $24.0 million in PV terms over life of BESS; regulation provides $18.8 million (78%) of total benefits, followed by capacity at $4.1 million (16.9%) and spinning reserves at $1.2 million (5.0%); energy arbitrage value negligible due to cycling constraints
  - The total 20-year PV of BESS and CTG operations estimated at $145.9 million exceeds revenue requirements and energy costs at $93.9 million with an ROI ratio of 1.55
- Nantucket Island's load patterns enable year-round participation in ISO-NE market; ability to predict when load enters N-1 contingency will be key
- Distribution system modeling offered insights into local Volt-VAR/CVR and outage mitigation benefits
  - The value of reducing the large-scale outages affected by BESS and CTG operations could yield annual savings in excess of $1 million; reducing customer minutes of interruption up to 46%
  - The distribution model quantifies the benefits of additional investments in reconductoring and automated switching

Pacific Northwest NATIONAL LABORATORY

Looking Forward

- Accomplishments
  - Final report, Nantucket Island Energy Storage System Assessment (PNNL-28941) https://www.sandia.gov/ess-ssl/wp-content/uploads/2019/09/Nantucket-Report_Final.pdf
  - PNNL has developed a distribution system network model for Nantucket Island
  - PNNL published the results of two study elements:
    - A combined look ahead and real time optimization scheme will be proposed to schedule BESS real and reactive power dispatch
    - A modular optimal power flow concept which coordinates the application layer of emerging storage and generation technologies with the grid operation layer
- Next Steps
  - PNNL is aiding in development of real-time control systems and will be monitoring economic operations over multiple years to determine if predicted benefits are ultimately realized
  - PNNL will publish the results of additional study elements:
    - Findings of the economic assessment
    - Transactive system for sustained operation when one or two 46-kV cables are out of service
    - Adaptive voltage regulation for storage inverters to avoid limits on real power ramping

Nantucket Island BESS/CTG ribbon cutting ceremony on October 8, 2019

Acknowledgments

Dr. Imre Gyuk, DOE – Office of Electricity

Jack Vaz, Joseph Henry, Terron Hill, David Bianco, Ben Carron, Babak Enayati, and Tim Martin of National Grid

Mission – to ensure a resilient, reliable, and flexible electricity system through research, partnerships, facilitation, modeling and analytics, and emergency preparedness.

https://www.energy.gov/oe/activities/technology-development/energy-storage

Q/A and Further Information

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https://energystorage.pnnl.gov/

Grid Scale Energy Storage:

Projects in Massachusetts

IMRE GYUK, DIRECTOR,
ENERGY STORAGE RESEARCH, DOE-OE

MA Legislative Activity

Target: 200MW by 2020, 1000MW by 2025

HB 2496: Storage is Green Energy Technology!

H4857 directs MA Dept. of Energy Resources
To develop proper valuation of ES for Planning

$200M+ in Grants to 26 Projects

DOE-OE Storage Program Is Building and Validating Business Cases through Innovative Pilot Projects:

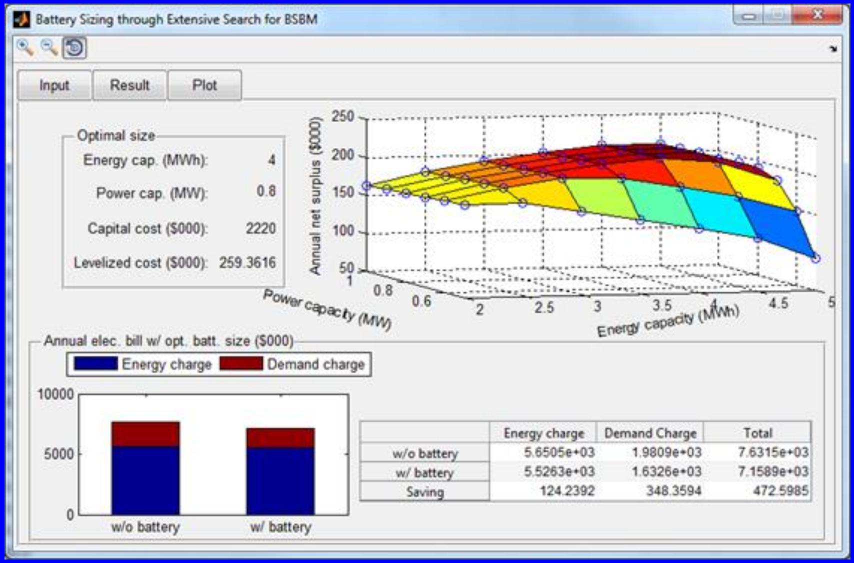
Resilience, Sustainability, Grid Stability

QuESt a Tool for Valuation– Sandia/DOE
(Deregulated Utilities)

- QuESt: An open source Python tool for Energy Storage evaluation
- QuESt Valuation: Stacking services in an electricity market
- QuESt BTM: Bill reduction for time-of-use/net metering customers
- QuESt: Data Manager: Data Acquisition

Sandia.gov/ess-ssl/tools/quest

Battery Storage Evaluation Tool (BSET) – PNNL/DOE (Vertically Integrated Utilities+)



- **<u>BSET:</u>** Evaluation and sizing tool for utility-owned and behind-the-meter ES systems:
- Desktop application with GUI.
- Co-optimization to capture multiple value streams including avoided costs.
- Optimal storage sizing based on value streams and cost parameters.

availabletechnologies.pnnl.gov/technology.asp?id=413

Sterling, MA: Microgrid/Storage Project

Sterling Municipal Light Department. / DOE-Sandia

$1.5M Grant from MA Community Clean Energy Resiliency Initiative (Dept. of Energy Resources) + DOE

2MW/2hr storage with existing 3.4 MW PV to provide resiliency for Police HQ and Dispatch Center. Li-ion batteries provided by NEC.

Sterling, MA, October 2016

Sterling, MA, December 2016

2016 Dec. till 2017 Nov.
Actual Savings:

- Arbitrage $11,731
- Monthly Peaks $143,447
- Annual Peak $240,660
- Total $395,839

Sean Hamilton

Chart: Carina Kaainoa

Dec. 2016 - April 2019: 1 million Avoided Cost!

Visitors: Germany, Switzerland, Denmark, Sweden, England, Ireland, Australia, Japan, Malaysia, Taiwan, Brazil, Chile, ... Thailand

Northampton Muni – National / DOE / PNNL

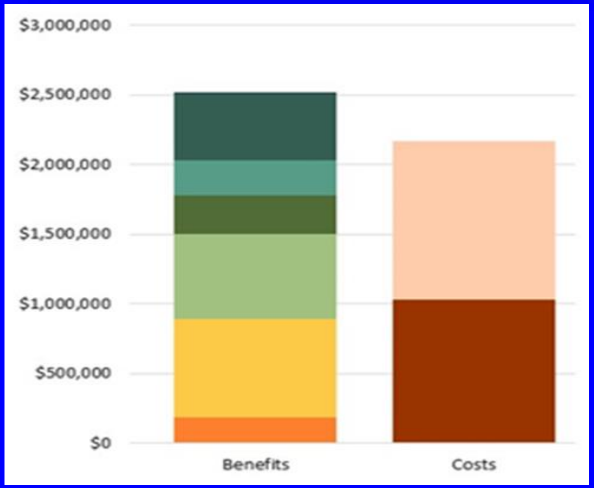
- Microgrid islands 3 campuses during outage
  - Northampton Dept. of Public Works
  - Smith Vocational and Agricultural High School
  - Cooley Dickinson Hospital

- Multiple grid assets to improve resiliency
  - 386 kW PV, Diesel, Biomass,
  - Energy storage: 441 kW / 1 hour

- Total 20-year benefits $2.5 million
  Costs $2.2 million, **ROI: 1.16**.

Modeled Use Cases for Storage:

PV Energy Payment Reduction
PV Recovery
Outage mitigation
Installed Capacity Tag (ICAP) reduction
NationalGrid Demand Response Program
Demand charge reduction



Energy Storage System Economic Results

Something to think about:

Energy Storage Value
Depends highly on
Local Regulatory Structure
and this Structure
may change in time!

This webinar was presented by the DOE-OE Energy Storage Technology Advancement Partnership (ESTAP)

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Upcoming Webinars

Financing Resilient Power in Underserved Communities: Moving Forward with Distributed Solar+Storage Projects
Tuesday, October 20, 2-3:30pm ET

The Costs and Benefits of Offshore Wind Transmission Options
Friday, October 23, 2-3pm ET

Should a Carbon Tax Be Part of the Strategy for Achieving 100% Clean Energy?
Wednesday, November 18, 3-4pm ET

Learn more and register at: www.cesa.org/webinars