

# Maximizing Storage Value in Regional Markets and the QuEST App



PRESENTED BY

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Planning for energy storage can be a tricky process

Before commissioning a system, you want to get an idea of what it could do

- What are the value streams?
- What system size?
- How will it operate?

A number of factors can significantly affect the potential of a system

- Pricing structures
- System configurations
- Load Requirements

Sandia helps many entities determine value to help planning efforts

- Analyses of regional markets for specific applications
  - NY State VDER Program
- The QuEST tool streamlines analyses for common scenarios



NY State has undertaken an ongoing process to change compensation for distributed energy

- Value of Distributed Energy Resources (VDER)
- Replaces net metering
- Assigns value to when and where energy is produced

Multiple values that can stack depending on time and location

- Day Ahead LBMP
- iCap - Value for beneficial production capacity
  - 3 Alternatives that provide value for different production times
- E – Environmental Component
- DRV – Demand reduction value
  - Production during 10 annual peak hours
- LSRV – locational system relief value
  - Extra incentive for generation in certain areas
- MTC – market transition credit
  - Fudge factor to make people happy





Multiple options can be selected for capacity VDER pricing

## Alternative 1

- Fixed monthly \$/kWh price for all generation
- Price set monthly
  - Typically higher in summer and fall months
- ES in a DC-tied configuration increases this value by delivering clipped DC power

## Alternative 2

- Fixed monthly \$/kWh for generation between 2pm and 6pm weekdays
- Only available during summer months (June-August)
- Much higher rate than Alt 1 in most areas
- ES value for AC-tied and DC-tied

## Alternative 3

- Monthly \$/kW value for generation during coincident peak hours
- Potential ES value as peak hours are typically from 4-8pm

Focus on Alternatives 2 and 3

Three candidate Community Distributed Generation (CDG) projects considered

- 3 different locations
- 3 different project sizes (sized for the needs of the area?)

Estimate additional value that could be obtained with energy storage systems

- AC-Tied, separate inverter
- DC-Tied, shared inverter
  - Clipped DC power at the inverter can be used to charge the batteries

Subject to transmission limits, PV potential, etc.

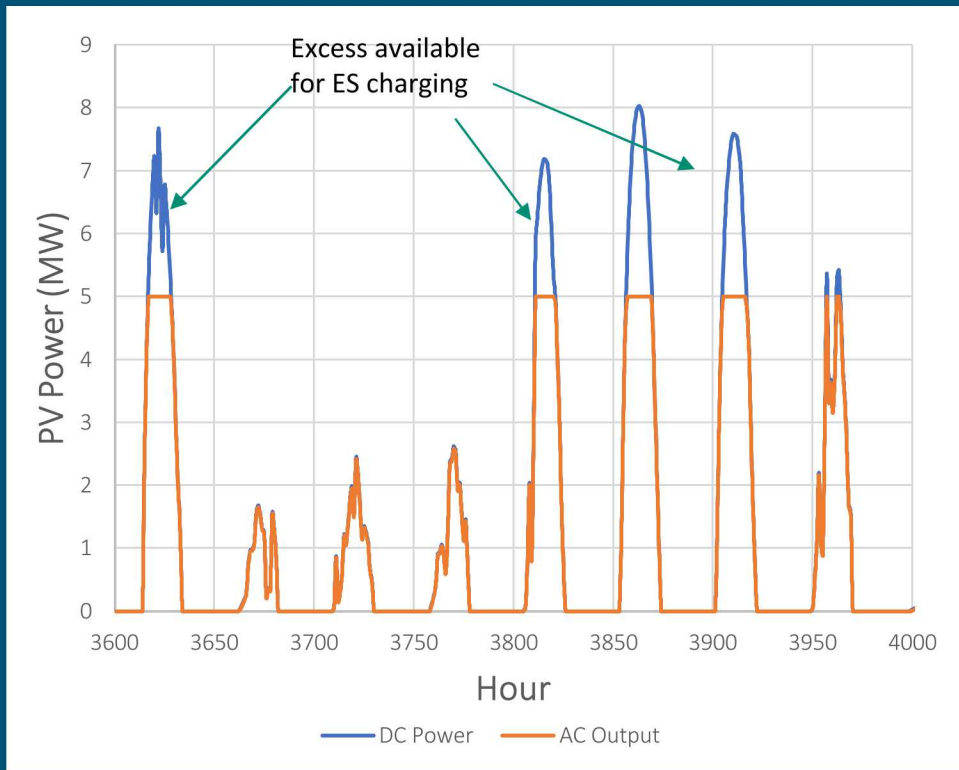
Optimized battery dispatch schedule using Python/PYOMO

- Open source tools

	A	B	C
Service Territory	ConEd Westchester	National Grid	Central Hudson
NYISO Zone	H	A	G
MW DC	0.75	7.5	2.98
MW AC	0.577	5	2
ESS Connection	AC	DC	DC

### Fixed VDER Values (2018)

E - \$/kWh	0.02741	<b>0.02741</b>	0.02741
DRV - \$/kW	0	<b>0</b>	0.5
LSRV - \$/kW	0.034	<b>0</b>	0
MTC - \$/kWh	0.1435	<b>0.0229</b>	0



30-min simulation using NSRDB irradiance data

All projects using an DC/AC ratio of  $\sim 1.5$

- DC-tied systems can store excess power that would be curtailed
- DC connections save on system cost by sharing an AC-DC inverter
- AC-tied systems do not share an inverter

PV output was modeled using the data from the System Advisor Model (SAM) and PVLIB

## 7 2-6PM June-August Value Stream

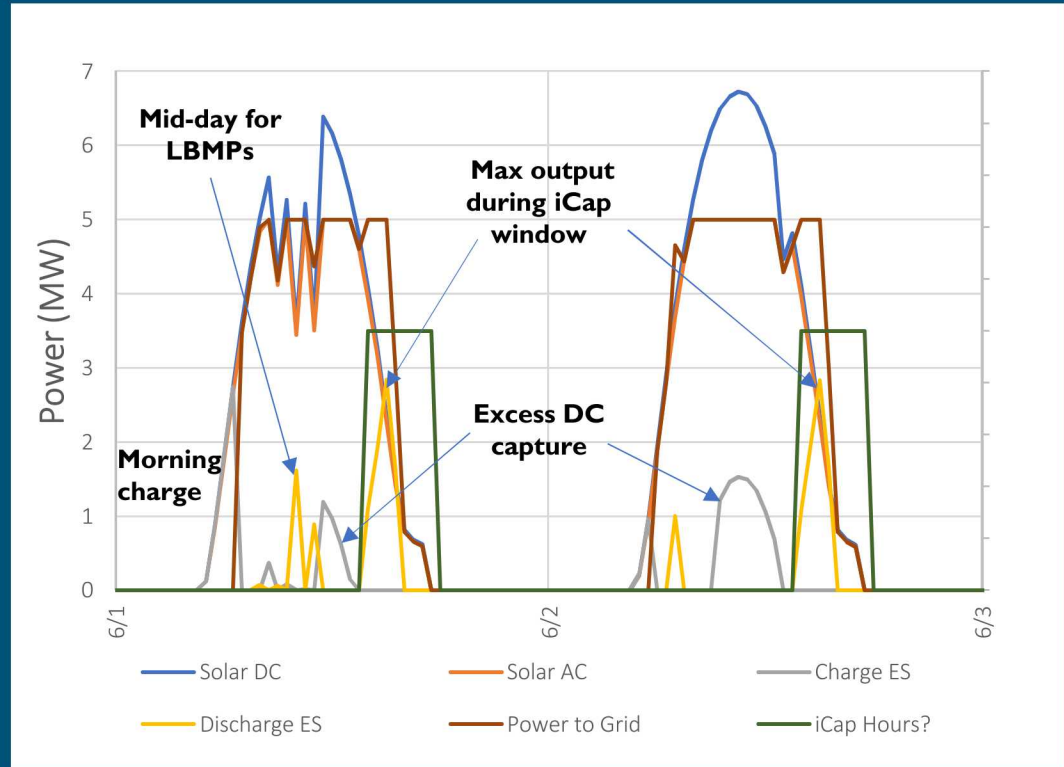
Charge early morning and from clipped power

Discharge mid-day to maximize LBMP

- Fully charge for start of iCap window

Discharge during iCap window to maintain peak power

- Until battery hits lower SOC limit



5 MW / 5 MWh

## 8 Coincident Peak Value Stream

Charge early morning and from clipped power

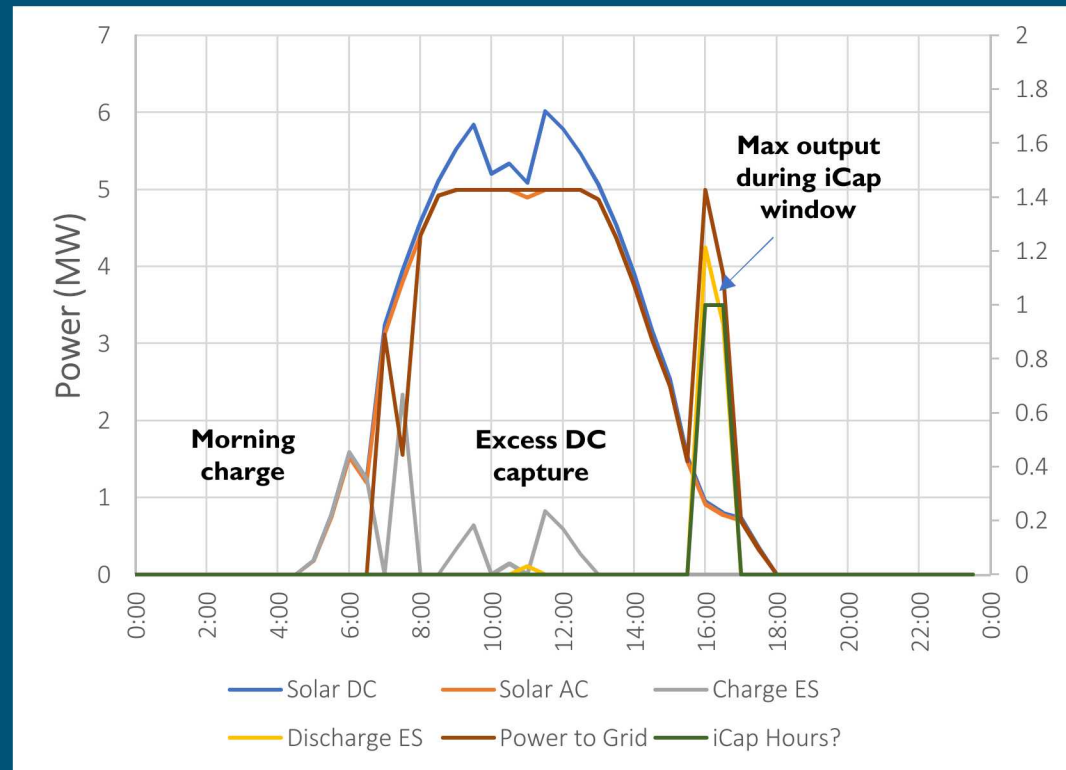
Discharge mid-day to maximize LBMP revenue

- Fully charge for start of iCap window

Discharge during monthly coincident peak

Major difference here is the iCap window

- 1 hour long
- Only once a month
- MUST be properly forecast or NO value

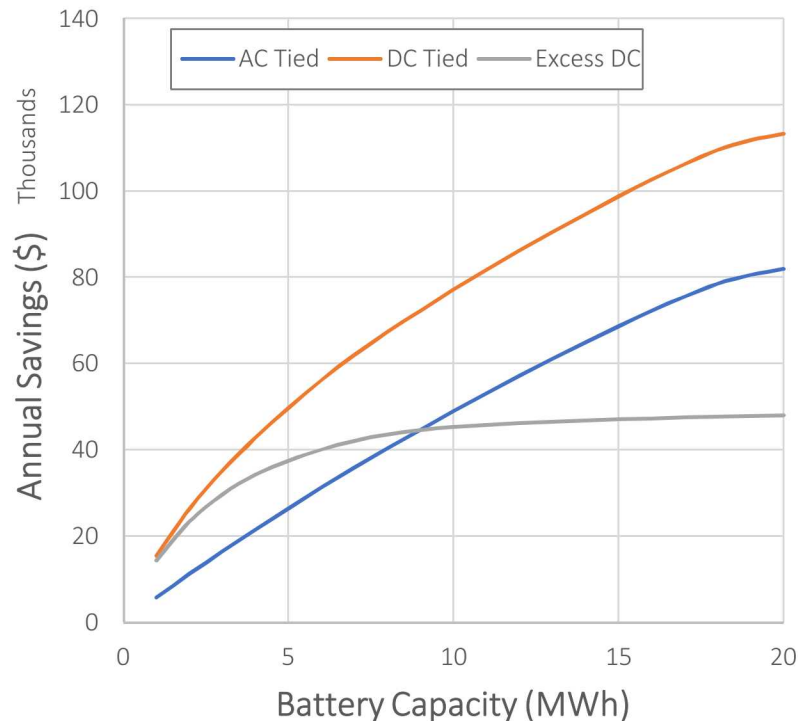


5 MW / 5 MWh

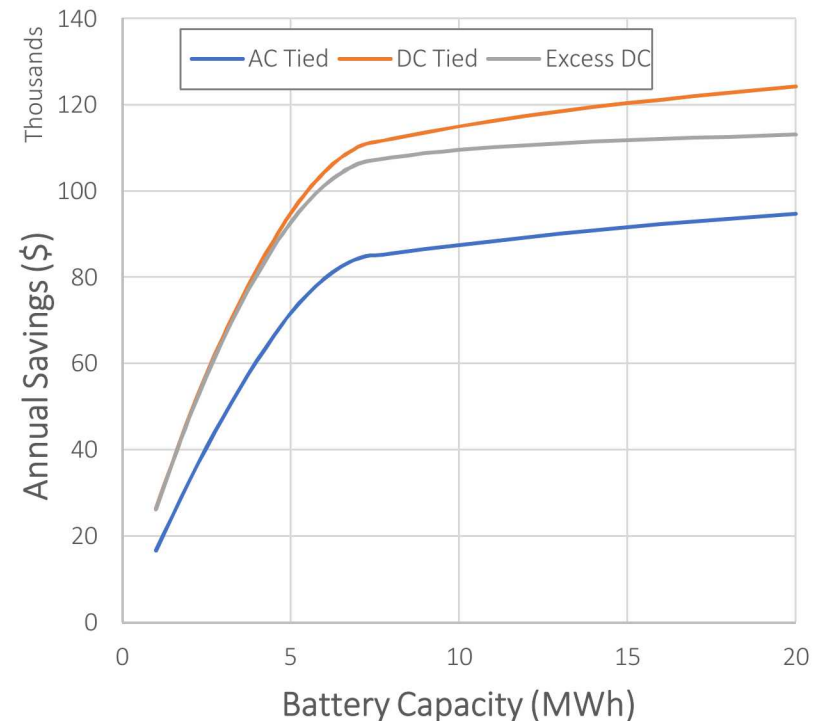


## Maximum Project Values

2-6PM  
June-August



Monthly  
Coincident Peak



Connecting PV and battery DC has advantages over AC connections

In higher energy applications, charging from all available energy is essential

Low energy applications yield the most value per MWh

- Depending on the pricing at the node

# Initial Battery Selection

For revenue, bigger is better

Maximizing net benefits comes down to system cost

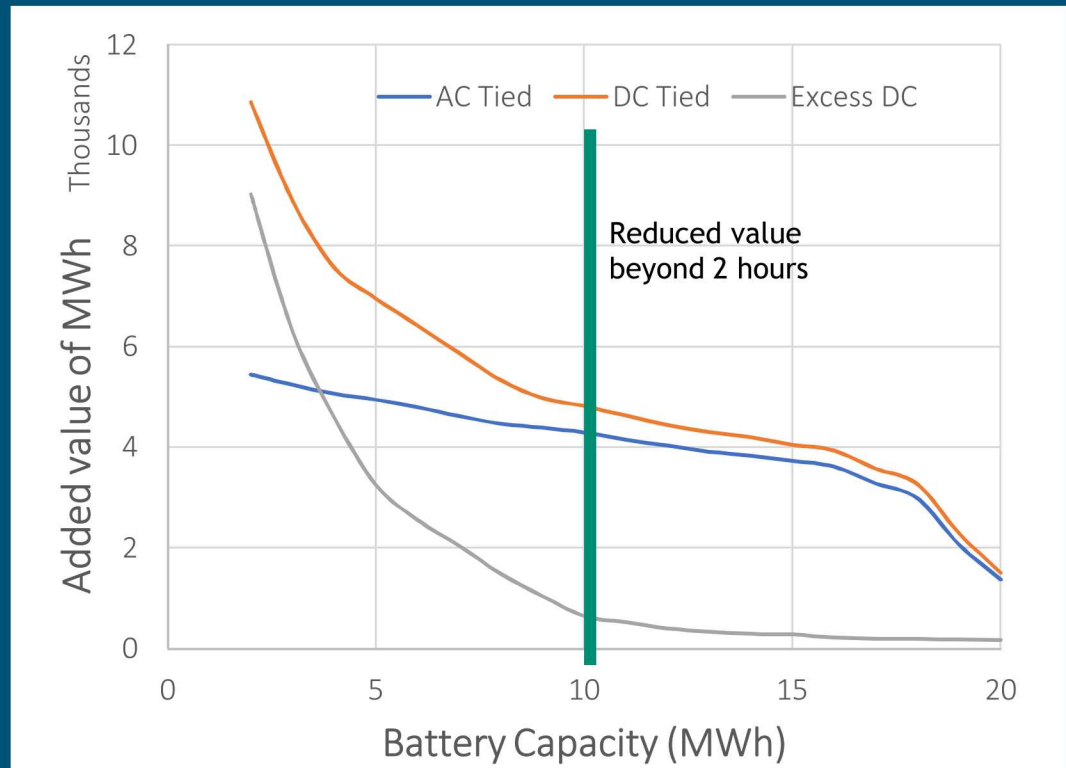
- How do you determine batteries sizes for RFPs?

Diminishing returns indicate upper limits

- Calculate additional savings from next smallest capacity
- Similar calculation is useful for varying power ratings

iCap 2 application, 10 MWh hour battery good center point for search

- 7.5 MWh for iCap 3



To give accurate estimates of energy storage value, scenario details need to be represented accurately

- Local pricing structures
- System configurations
- Generation if being paired with renewables

Low energy applications generally yield the most value per kWh

For PV/storage systems, DC-DC connections take advantage of energy that would be curtailed

- Depends on PV inverter size and transmission limits

Forecasting is important to capture coincident peak benefits

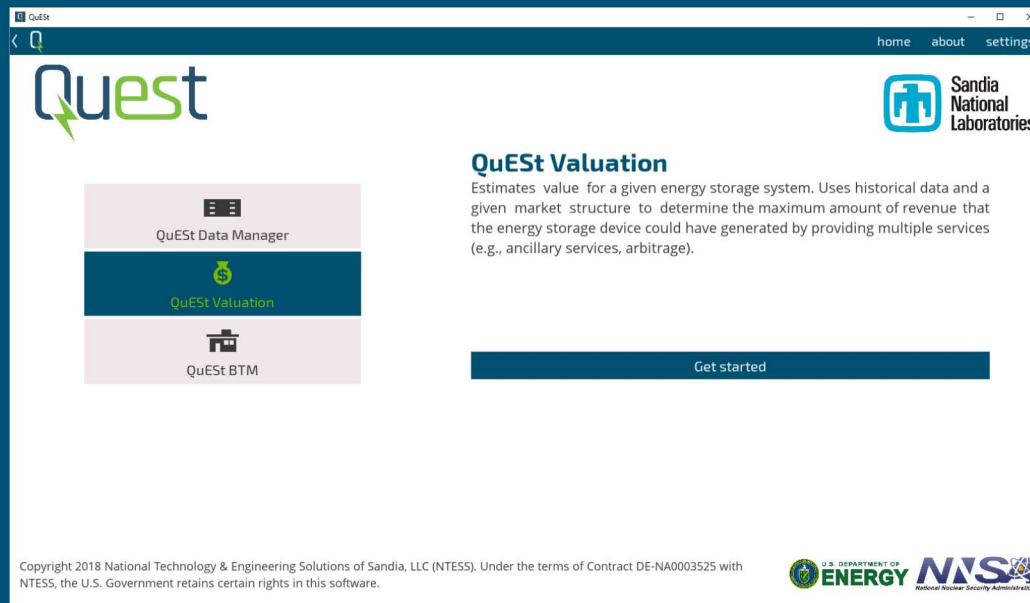
- This is often a high value application
- Peaks are often at the same hour in a month year-to-year

Changing pricing landscapes can make it difficult for developers

- NY made major changes to VDER policies shortly after this analysis

Net revenue comes down to system cost coming from RFPs

- Prior analysis helps to determine what to request and assessment of bids



- Open source, Python-based energy storage analysis software application suite
- Developed as a graphical user interface (GUI) for the optimization modeling capabilities of Sandia's energy storage analytics group
- Version 1.0 publicly released in September 2018
- Version 1.1 available on GitHub; Version 1.2 coming soon
  - [github.com/rconcep/snl-quest](https://github.com/rconcep/snl-quest) or [sandia.gov/ess](https://sandia.gov/ess)



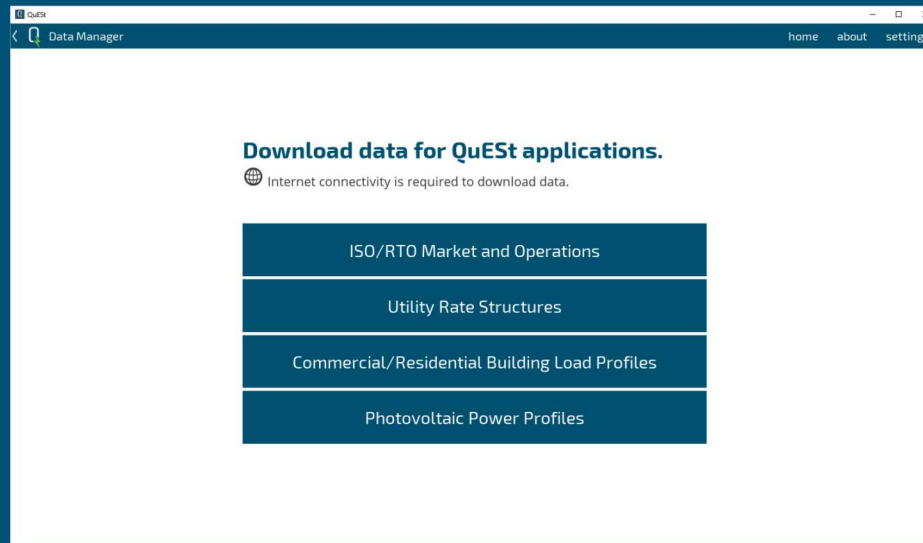


# Why QuEST?

- For energy storage project stakeholders
  - Accessible and easy-to-use software tool for energy storage valuation and related applications
- For engineers/developers
  - Open source software project
  - GUI design, application design, Pyomo optimization modeling
  - Pyomo models and other optimization code can be adjusted to fit specific needs
- It's free
  - Written in Python; no software licenses required
- Current application list
  - QuEST Data Manager - Manages acquisition of ISO market data, US utility rate data, commercial and residential load profiles, etc.
  - QuEST Valuation - Estimate potential revenue generated by energy storage systems providing multiple services in the electricity markets of ISOs/RTOs.
  - QuEST BTM\* - Estimate the cost savings for time-of-use/net energy metering customers using behind-the-meter energy storage systems.
  - Continuing to add functionality to cover more cases

\* For v1.2 release





We use publicly available APIs, posted market data, and crowd-sourced data.

- LMPs, frequency regulation performance/capacity clearing prices, etc. posted by ISOs/RTOs
- U.S. utility rate structures sourced and validated by OpenEI.org
- Commercial and residential hourly load profiles for all TMY3 (typical meteorological year) locations in the U.S. by OpenEI.org
- Hourly photovoltaic power profiles by PVWatts

The screenshot shows the QuEST Data Manager web application. The browser window title is "QuEST" and the page title is "Data Manager: ISO/RTO Market and Operations Data". The page has a navigation bar with "home", "about", and "settings" links. The main heading is "Download ISO/RTO market and operations data." Below this is a tabbed interface with tabs for SPP, PJM, NYISO, MISO, ISO-NE (selected), ERCOT, and CAISO. The ISO-NE section contains three main input areas: 1. "Enter ISO-NE ISO Express credentials." with fields for Username (rconcep@sandia.gov) and Password (masked with asterisks). 2. "Specify the range of months." with "Start" (January 2018) and "End" (December 2018) dropdowns. 3. "Pricing node ID and/or types of nodes" with a text field containing "4006" and checkboxes for "Internal Hub" and "Zones". At the bottom right of the ISO-NE section are "Download" and "Cancel" buttons. A "Settings" button is located at the bottom right of the entire page.



- LMPs, frequency regulation performance/capacity clearing prices, etc. posted by ISOs/RTOs
- Use operator-provided APIs, some requiring a short registration for an API key
  - ISONE, PJM
- Use web crawling libraries to parse marketplace data portals to find data files

The screenshot shows the QuEST Data Manager web application. The browser window title is "QuEST Data Manager: Utility Rate Structure Data". The page has a navigation bar with "home", "about", and "settings" links. The main heading is "Search for a utility rate structure.". Below this, there is a "Data.gov API key" field with a blue icon and a redacted value. A search input field contains the text "pacific" and a "Search" button. Below the search bar, there are three buttons: "by name" (highlighted in green), "by zip", and "by state (abbr.)". The page is divided into two columns. The left column is titled "Select a utility." and contains a "Filter by name" input field. Below it is a list of utilities: "PUD No 2 of Pacific County", "PacifiCorp", "PacifiCorp", "PacifiCorp", "PacifiCorp", "PacifiCorp", "PacifiCorp", "Pacific Gas & Electric Co." (highlighted in green), and "Sierra Pacific Power Co.". The right column is titled "Select a rate structure." and contains a "e-tou option b" input field. Below it is a list of rate structures: "E-TOU Option B - Residential Time of Use Service (All Baseline Regions) (Effective Date : 03/23/2016)", "E-TOU Option B - Residential Time of Use Service (All Baseline Regions) (Effective Date : 10/22/2017)" (highlighted in green), and "E-TOU Option B - Residential Time of Use Service (All Baseline Regions) (Effective Date : 12/30/2016)". At the bottom center of the page is a "Continue" button.

QuEST Data Manager: Utility Rate Structure Data

home about settings

**Search for a utility rate structure.**

Data.gov API key  

pacific **Search**

by name by zip by state (abbr.)

**Select a utility.**

Filter by name

PUD No 2 of Pacific County  
PacifiCorp  
PacifiCorp  
PacifiCorp  
PacifiCorp  
PacifiCorp  
PacifiCorp  
**Pacific Gas & Electric Co.**  
Sierra Pacific Power Co.

**Select a rate structure.**

e-tou option b

E-TOU Option B - Residential Time of Use Service (All Baseline Regions) (Effective Date : 03/23/2016)  
**E-TOU Option B - Residential Time of Use Service (All Baseline Regions) (Effective Date : 10/22/2017)**  
E-TOU Option B - Residential Time of Use Service (All Baseline Regions) (Effective Date : 12/30/2016)

**Continue**

- OpenEI.org, maintained by NREL, hosts a database for U.S. utility rates
- Time-of-use energy rate schedules
- Peak demand and flat demand rate schedules



QuEST Data Manager: Utility Rate Structure Data

home about settings

### Verify the energy rate structure.

Period	Rate [\$/kWh]
0	0.26029
1	0.36335
2	0.20708
3	0.22588

**Weekday**

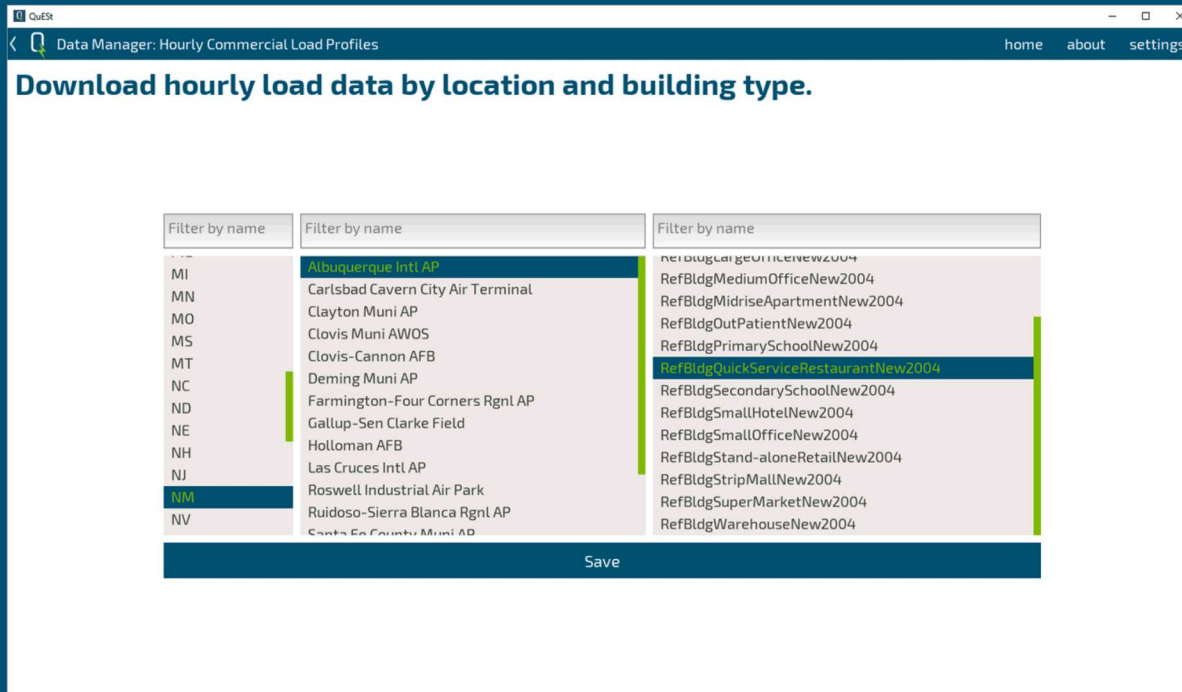
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	2	2	2	2	2	2	2	2	2	2	2	2
1	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2
3	2	2	2	2	2	2	2	2	2	2	2	2

**Weekend**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	2	2	2	2	2	2	2	2	2	2	2	2
1	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2
3	2	2	2	2	2	2	2	2	2	2	2	2

Previous Continue

- OpenEI.org, maintained by NREL, hosts a database for U.S. utility rates
- Time-of-use energy rate schedules
- Peak demand and flat demand rate schedules



- OpenEI.org also hosts simulated hourly load profiles for TMY3 (typical meteorological year)
  - Residential (base, low, high)
  - Commercial (16 reference building types by DOE)

<https://openei.org/datasets/dataset/commercial-and-residential-hourly-load-profiles-for-all-tmy3-locations-in-the-united-states>

The screenshot shows a web browser window titled "QuEST" with a sub-header "Data Manager: Photovoltaic Power Profiles". The page has navigation links for "home", "about", and "settings". The main heading is "Search for a photovoltaic power profile." Below this is a "Data.gov API key" field with a blue information icon. The form contains several input fields with labels and descriptions:

- latitude**: The latitude of the site in the range (-90, 90). Input: 37.78 deg
- longitude**: The longitude of the site in the range (-180, 180). Input: -122.42 deg
- system capacity**: The nameplate capacity of the photovoltaic system. Input: 5 kW
- losses**: The total system losses, including all sources, in the range (-5, 99). Input: 14 %
- tilt angle**: The tilt angle of the PV surface. Input: 0 deg
- azimuth angle**: The azimuth angle of the PV surface. Input: 0 deg

At the bottom, there are two radio buttons: "Standard" (selected) and "Fixed (roof mounted)". Below these is a text input field containing "san\_fran\_5kW" and a "Save" button.

## ■ PVWatts by NREL


- Uses data from the National Solar Radiation Database and a solar panel system model to simulate hourly power output

[https://pvwatts.nrel.gov/version\\_6.php](https://pvwatts.nrel.gov/version_6.php)

QuEST Wizard home about settings

**Select a market area to place the energy storage device in.**

Different market areas can have different market structures, resulting in various opportunities for generating revenue.



ERCOT	PJM	MISO
NYISO	ISONE	<b>SPP</b>
CAISO		

Previous Next

IRC

- Market area
- Arbitrage and Frequency Regulation streams
- Historical dataset to study
- Energy storage model parameters



The screenshot shows a web application window titled "QuEST Wizard". The interface is for configuring an energy storage device. It features a header with navigation links: "home", "about", and "settings". The main heading is "Describe the type of energy storage device to be used." Below this, a paragraph explains that energy storage devices are modeled by power and energy ratings and instructs the user to select a template or customize one. There are five device templates: "Li-ion Battery" (highlighted in dark blue), "Advanced Lead-acid Battery", "Flywheel", "Vanadium Redox Flow Battery", and "Li-Iron Phosphate Battery". Below the templates, four parameters are adjustable with sliders and numeric input boxes: "self-discharge efficiency (%/h)" set to 100.0, "round trip efficiency (%)" set to 90.0, "energy capacity (MWh)" set to 24.0, and "power rating (MW)" set to 36.0. A "Li-ion Battery" section provides a note: "Modeled after the Notrees Battery Storage Project in western TX." At the bottom, there are "Previous" and "Next" buttons.

QuEST Wizard

home about settings

### Describe the type of energy storage device to be used.

Energy storage devices come in many forms and technologies. In this application, they are mainly modeled according to their power and energy ratings. Select an energy storage device template and/or customize your own.

Li-ion Battery

Advanced Lead-acid Battery

Flywheel

Vanadium Redox Flow Battery

Li-Iron Phosphate Battery

self-discharge efficiency (%/h) 100.0

round trip efficiency (%) 90.0

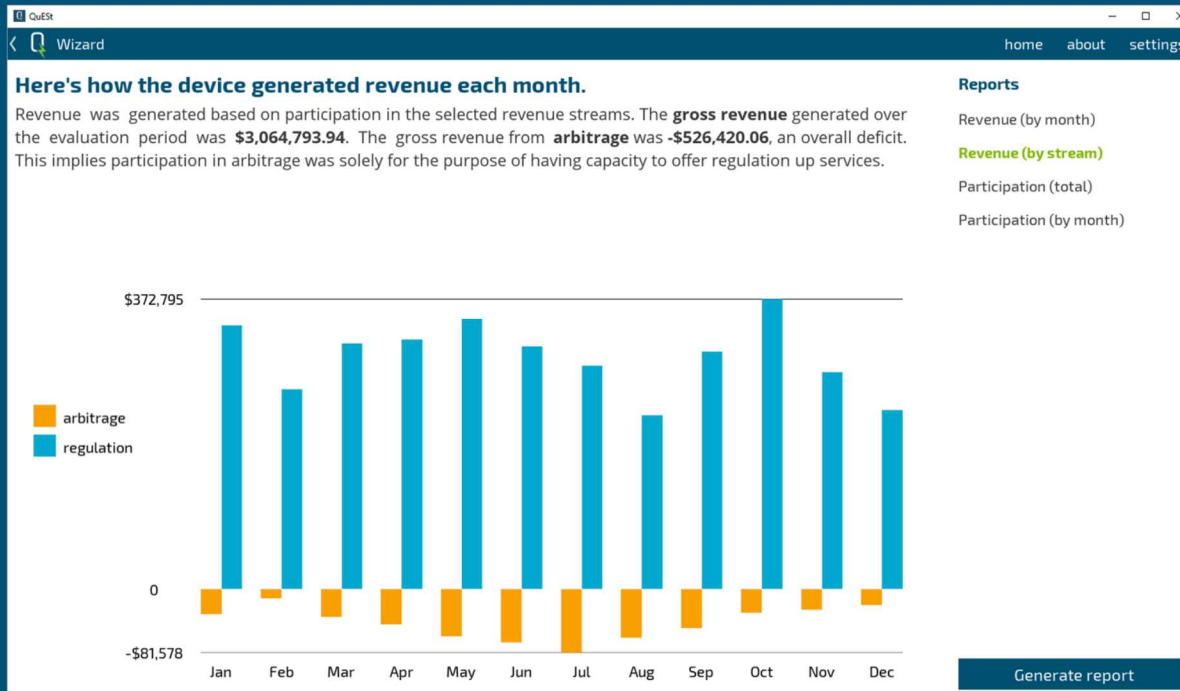
energy capacity (MWh) 24.0

power rating (MW) 36.0

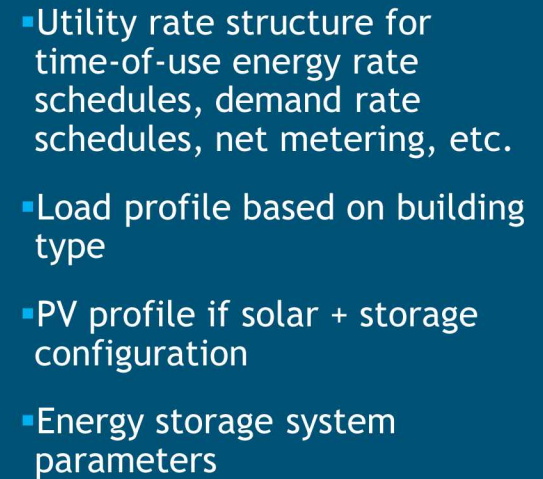
**Li-ion Battery**  
Modeled after the Notrees Battery Storage Project in western TX.

Previous Next

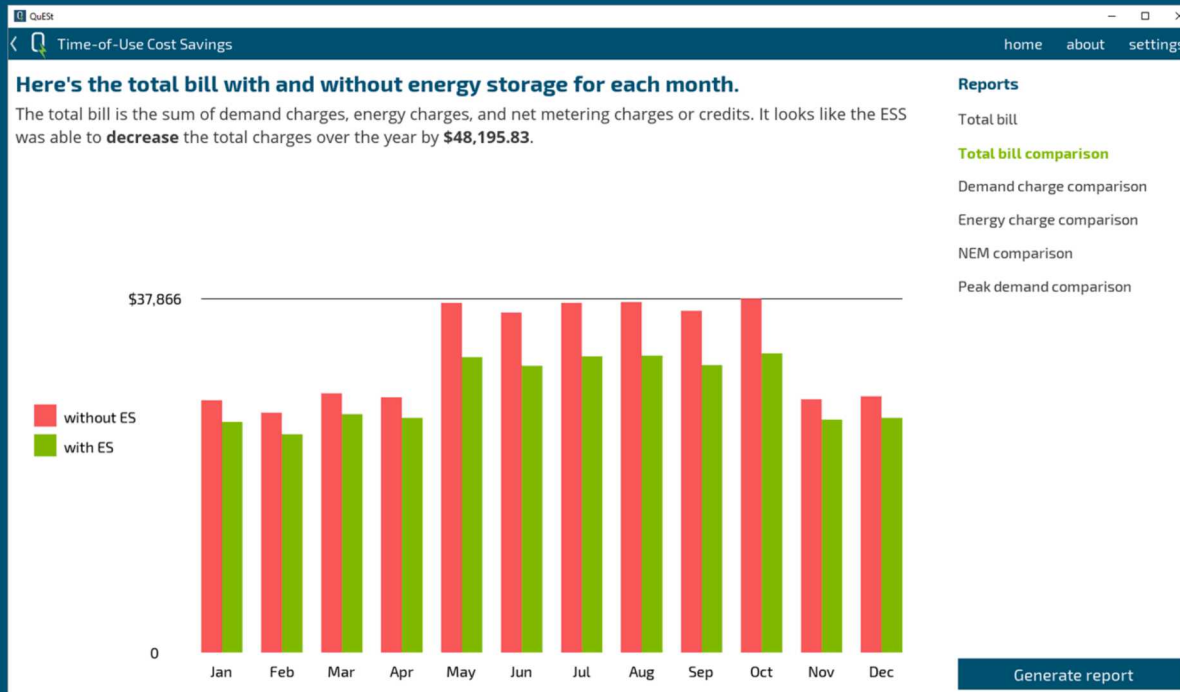
- Market area
- Revenue streams
- Historical dataset to study
- Energy storage model parameters



- Revenue by month
- Revenue by revenue stream
- Frequency of participation in each available revenue stream



\*For v1.2 release; content is under development and subject to change.



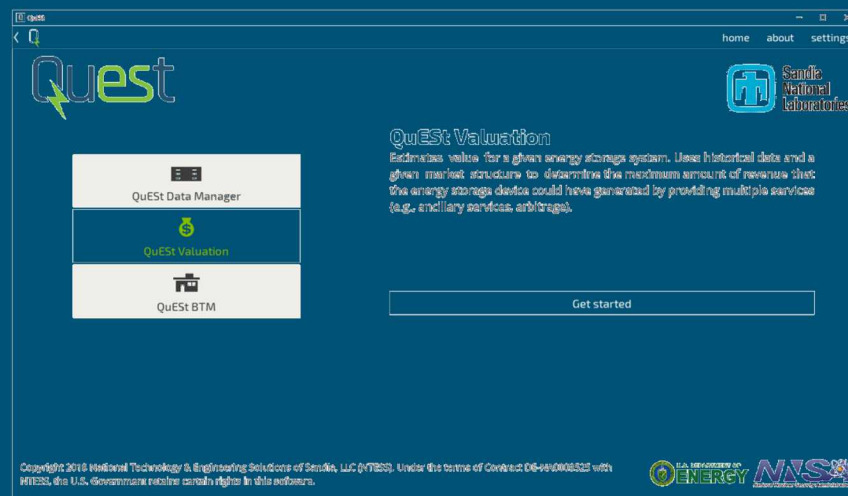
- Compare monthly bill with and without energy storage
- Peak demand reduction to decrease demand charges
- Time-shifting to reduce time-of-use energy charges
- Net metering credits

\*For v1.2 release; content is under development and subject to change.



Mission: Continue adding applications and new capabilities to the suite, building upon the software architecture and GUI foundation that we have established.

- Consider more complex valuation models, such as modeling degradation
- New applications
  - Technology selection assistant
  - Explorer for energy storage project cost data
  - Optimal sizing of energy storage for solar + storage
  - ?



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## Follow us on GitHub:

[github.com/rconcep/snl-quest](https://github.com/rconcep/snl-quest)



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# Optimal Battery Dispatch for Peak Revenue

The objective of the optimization is to maximize revenue subject to:

- Battery state-of-charge model – 25% minimum SOC
- PV generation
- Time-variant pricing structure

Battery charging options

- Only clipped DC power
- Full generation range
- AC-tied battery/PV

Optimized battery dispatch schedule using Python/PYOMO

- Open source tools

$$\begin{aligned}
 & \max_{P_C, P_D, P_{curtail}} \sum_{t=1}^T P_{toGrid,t} \cdot (iCap_t \cdot \textcolor{red}{iCap}_{hour,t} + E + MTC + LBMP_t) \\
 & \text{subject to } \delta E_{sys} \leq SOC_{t-1} \eta_s + \Delta t (P_{C,t-1} \eta_C - P_{D,t-1}) \leq (1 - \delta) E_{sys} \\
 & P_D \leq P_{sys} \\
 & \textcolor{red}{P}_{C,t} \leq \textcolor{red}{P}_{DC,t} - \textcolor{red}{P}_{AC,t} \\
 & P_{toGrid} \leq P_{sys} \\
 & P_{toGrid,t} = \eta_{inv} (P_{DC,t} + P_{D,t} - P_{C,t} - P_{curtail,t})
 \end{aligned}$$