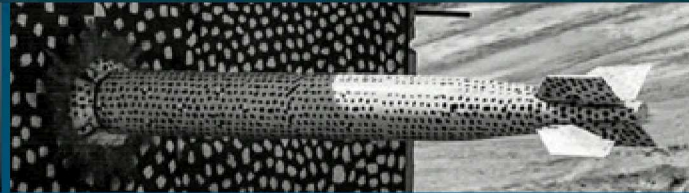
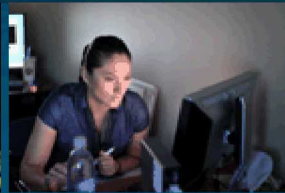


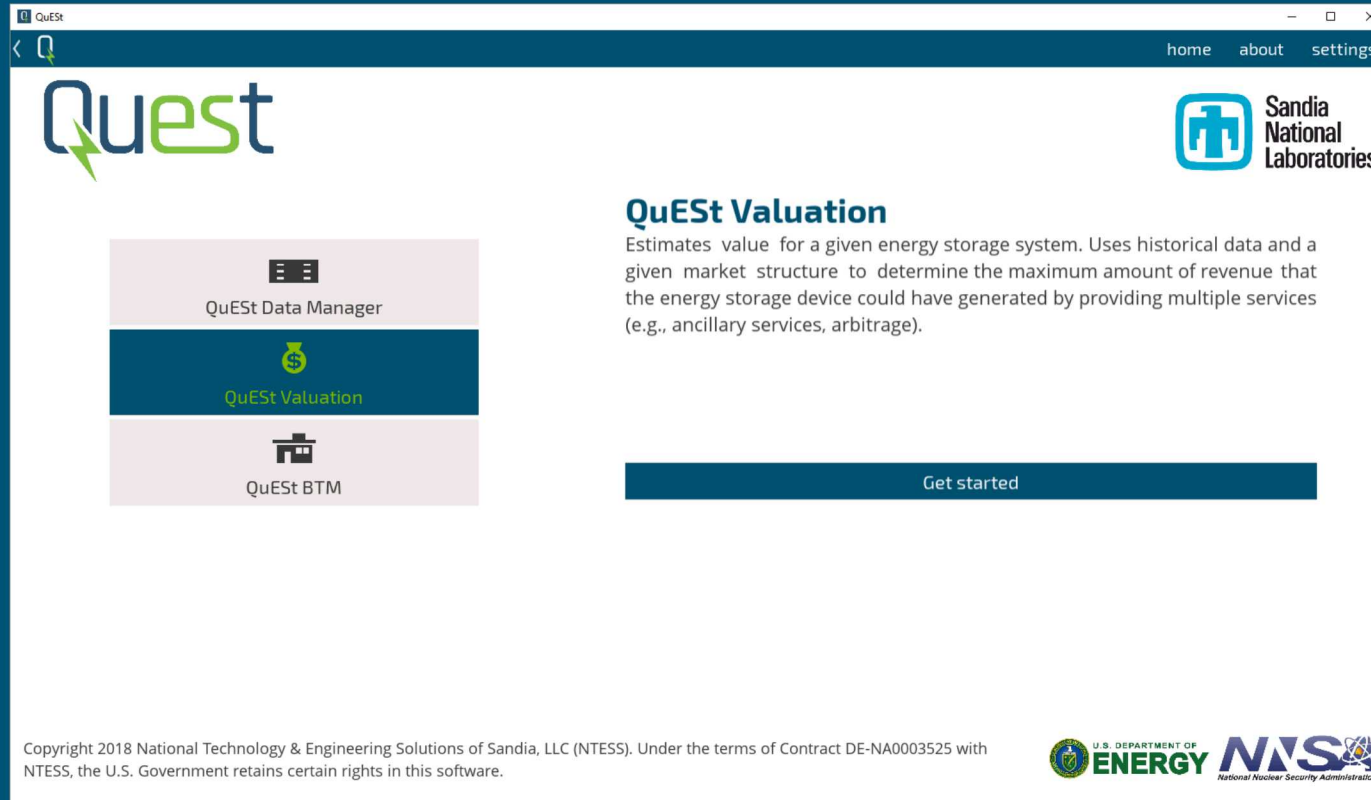


# An Energy Storage Application Suite



PRESENTED BY

Ricky Concepcion



- 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)



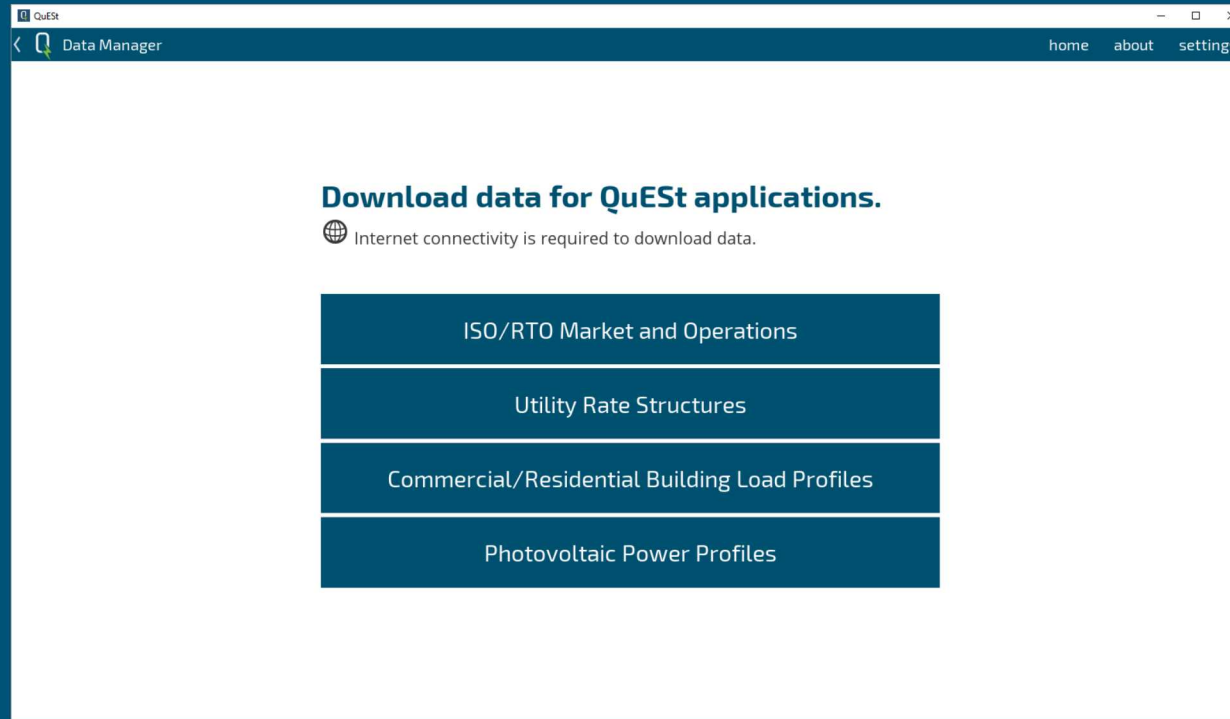
## Why QuEST?

- 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.

\* 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". The page header is "Data Manager: ISO/RTO Market and Operations Data" with navigation links for "home", "about", and "settings". 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 form are "Download" and "Cancel" buttons. A "Settings" button is located at the bottom right of the 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 like BeautifulSoup to parse marketplace data portals to find data files

QuEst

Data Manager: Utility Rate Structure Data

homeaboutsettings

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

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

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

Weekend

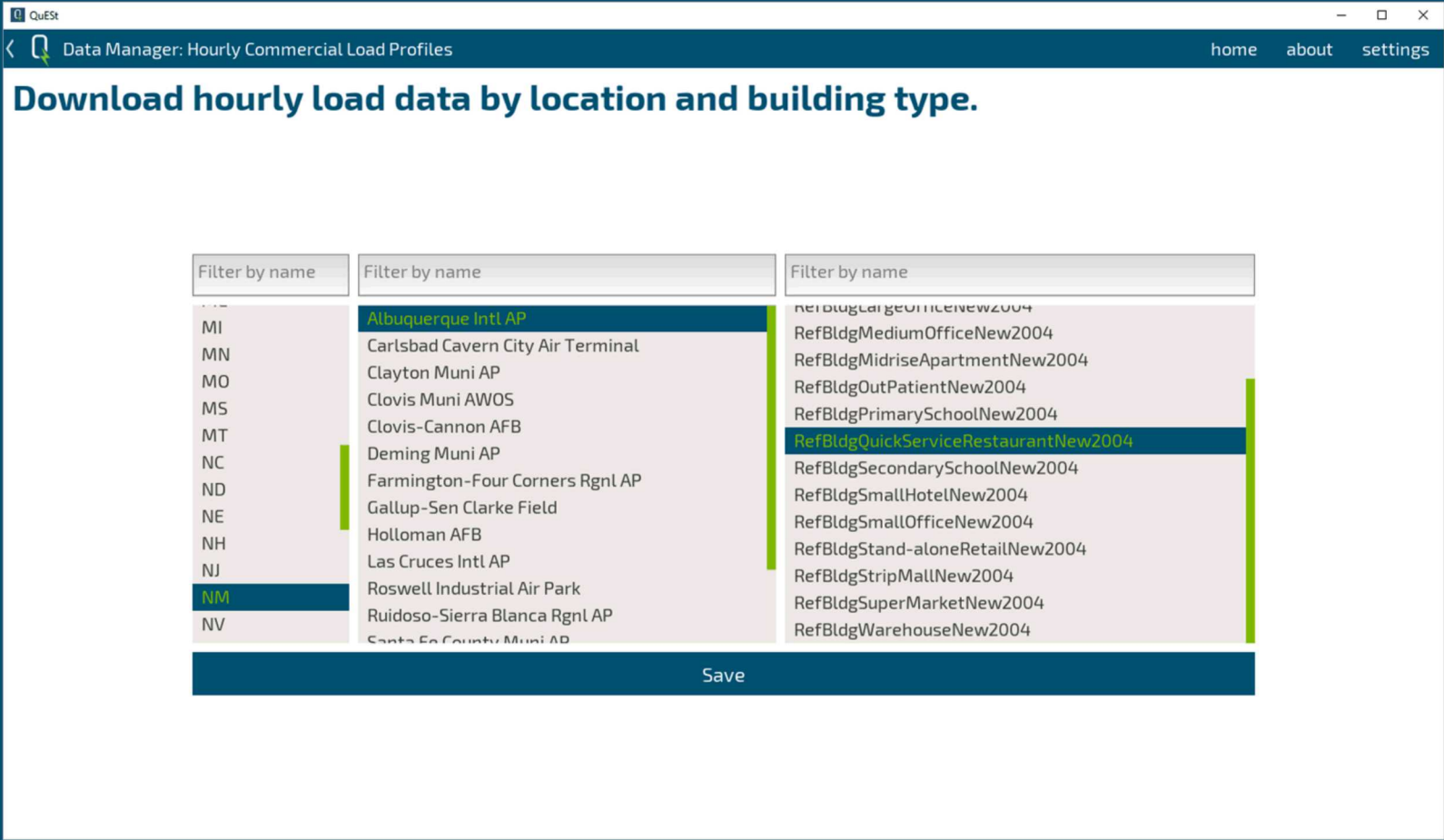
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Feb	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mar	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Apr	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
May	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Nov	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Dec	2	2	2	2	2	2	2	2	2	2	2	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>




QuEst

Data Manager: Photovoltaic Power Profiles

home about settings

### Search for a photovoltaic power profile.

Data.gov API key 

latitude	The latitude of the site in the range (-90, 90).	<input type="text" value="37.78"/>	deg
longitude	The longitude of the site in the range (-180, 180).	<input type="text" value="-122.42"/>	deg
system capacity	The nameplate capacity of the photovoltaic system.	<input type="text" value="5"/>	kW
losses	The total system losses, including all sources, in the range (-5, 99).	<input type="text" value="14"/>	%
tilt angle	The tilt angle of the PV surface.	<input type="text" value="0"/>	deg
azimuth angle	The azimuth angle of the PV surface.	<input type="text" value="0"/>	deg

Standard

Fixed (roof mounted)

## ■ PVWatts by NREL

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

# QuESt Valuation

Given an energy storage device, an electricity market with a certain payment structure, and market data, how would the device maximize the revenue generated and provide value?

$$\max \sum_i \left( \underbrace{\lambda_i (q_i^d - \eta_c q_i^r)}_{\text{arbitrage}} + \underbrace{q_i^{ru} (\lambda_i^{ru} + \delta_i^{ru} \lambda_i)}_{\text{regulation up}} + \underbrace{q_i^{rd} (\lambda_i^{rd} - \delta_i^{rd} \lambda_i)}_{\text{regulation down}} \right) e^{-Ri}$$

subject to:

$$s_{i+1} = \eta_s s_i + \eta_c q_i^r - q_i^d + \eta_c \delta_i^{rd} q_i^{rd} - \delta_i^{ru} q_i^{ru}$$

state of charge definition

$$0 \leq s_i \leq \bar{S}$$

state of charge limits

$$q_i^d + q_i^r + q_i^{ru} + q_i^{rd} \leq \bar{Q}$$

power/energy charged limits

Other constraints, such as requiring the final SoC to equal the initial SoC or reserving energy capacity for resiliency applications can be set.


Byrne, Raymond H., et al. "Energy management and optimization methods for grid energy storage systems." *IEEE Access* 6 (2018): 13231-13260.

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	SPP
CAISO		

Previous Next

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

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

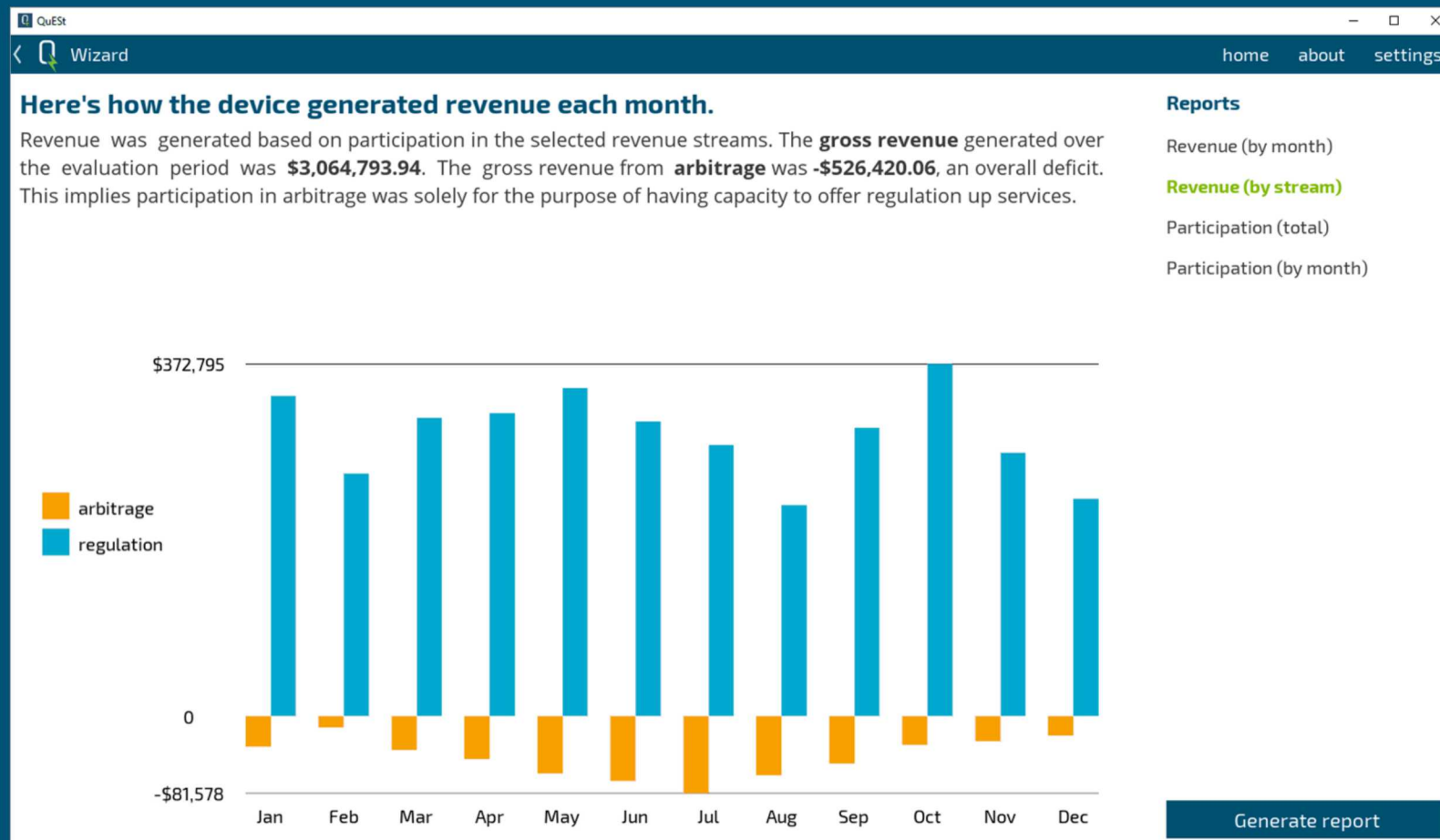
Modeled after the Notrees Battery Storage Project in western TX.

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

A collection of applications for behind-the-meter energy storage. The first application will be estimating cost savings for time-of-use and net energy metering customers.

- Incorporate specific utility rate structures (energy TOU schedule and rates, etc.)
- Use location-specific simulated load and photovoltaic power data

Nguyen, T., and R. Byrne. "Maximizing the cost-savings for time-of-use and net-metering customers using behind-the-meter energy storage systems." *Proceedings of the 2017 North American Power Symposium (NAPS)*. 2017.





QuEST

Time-of-Use Cost Savings

home about settings

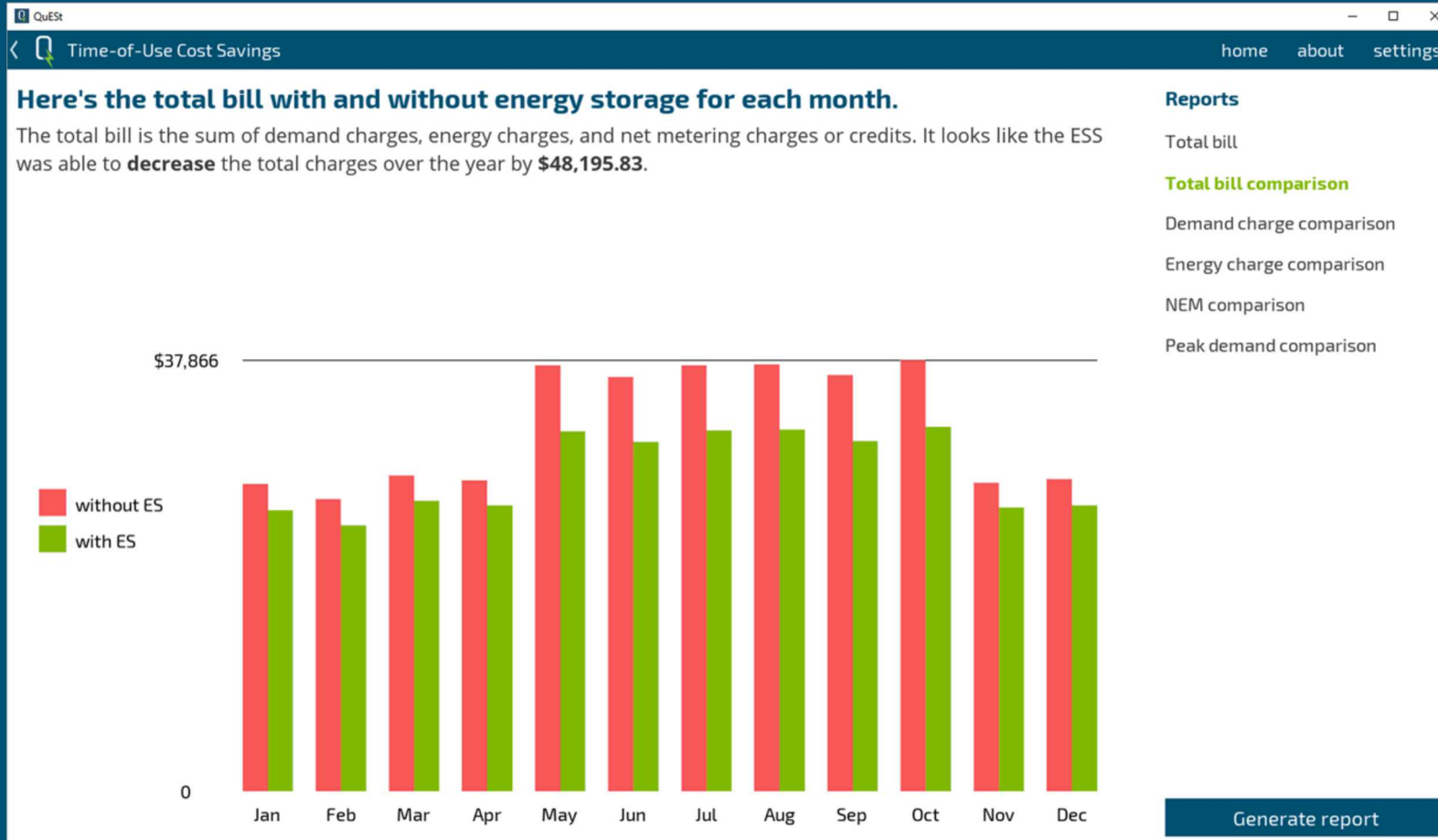
### Specify the energy storage system parameters.

<b>energy capacity</b>	The maximum amount of energy that the ESS can store.	<input type="text" value="800"/>	kWh
<b>power rating</b>	The maximum rate that at which the ESS can charge or discharge energy.	<input type="text" value="200"/>	kW
<b>transformer rating</b>	The maximum amount of power that can be exchanged.	<input type="text" value="1000000"/>	kW
<b>self-discharge efficiency</b>	The percentage of stored energy that the ESS retains on an hourly basis.	<input type="text" value="100"/>	%/h
<b>round trip efficiency</b>	The percentage of energy charged that the ESS actually retains.	<input type="text" value="85"/>	%
<b>capacity reserved for discharging capacity</b>	The percentage of energy capacity that the ESS reserves for discharging.	<input type="text" value="0"/>	%
<b>capacity reserved for charging</b>	The percentage of energy capacity that the ESS reserves for charging.	<input type="text" value="0"/>	%
<b>initial state of charge</b>	The percentage of energy capacity that the ESS starts at.	<input type="text" value="0"/>	%

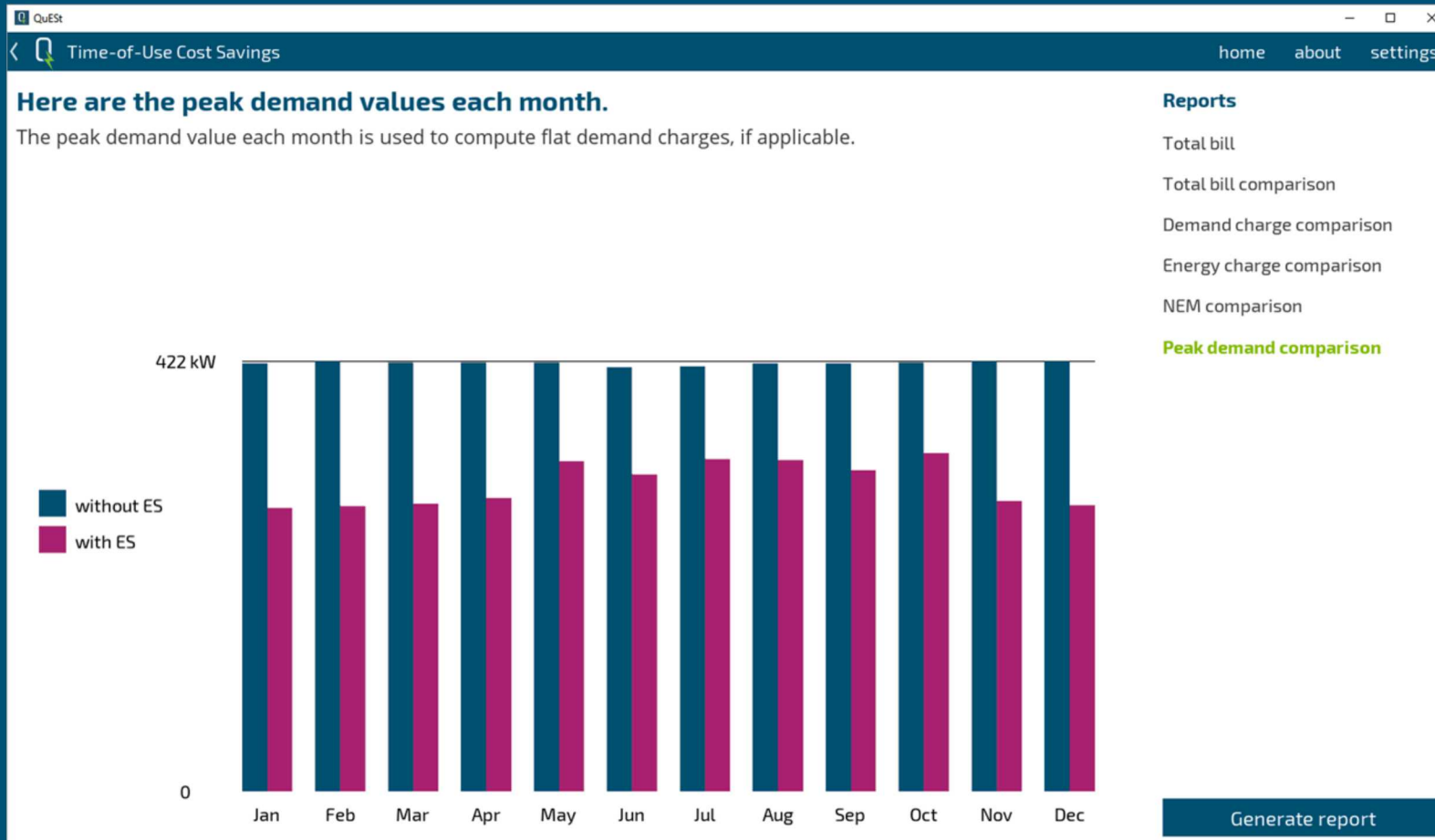
Previous Next

- Utility rate structure for time-of-use energy rate schedules, demand rate schedules, net metering, etc.
- Load profile based on building type
- PV profile if solar + storage configuration
- Energy storage system parameters

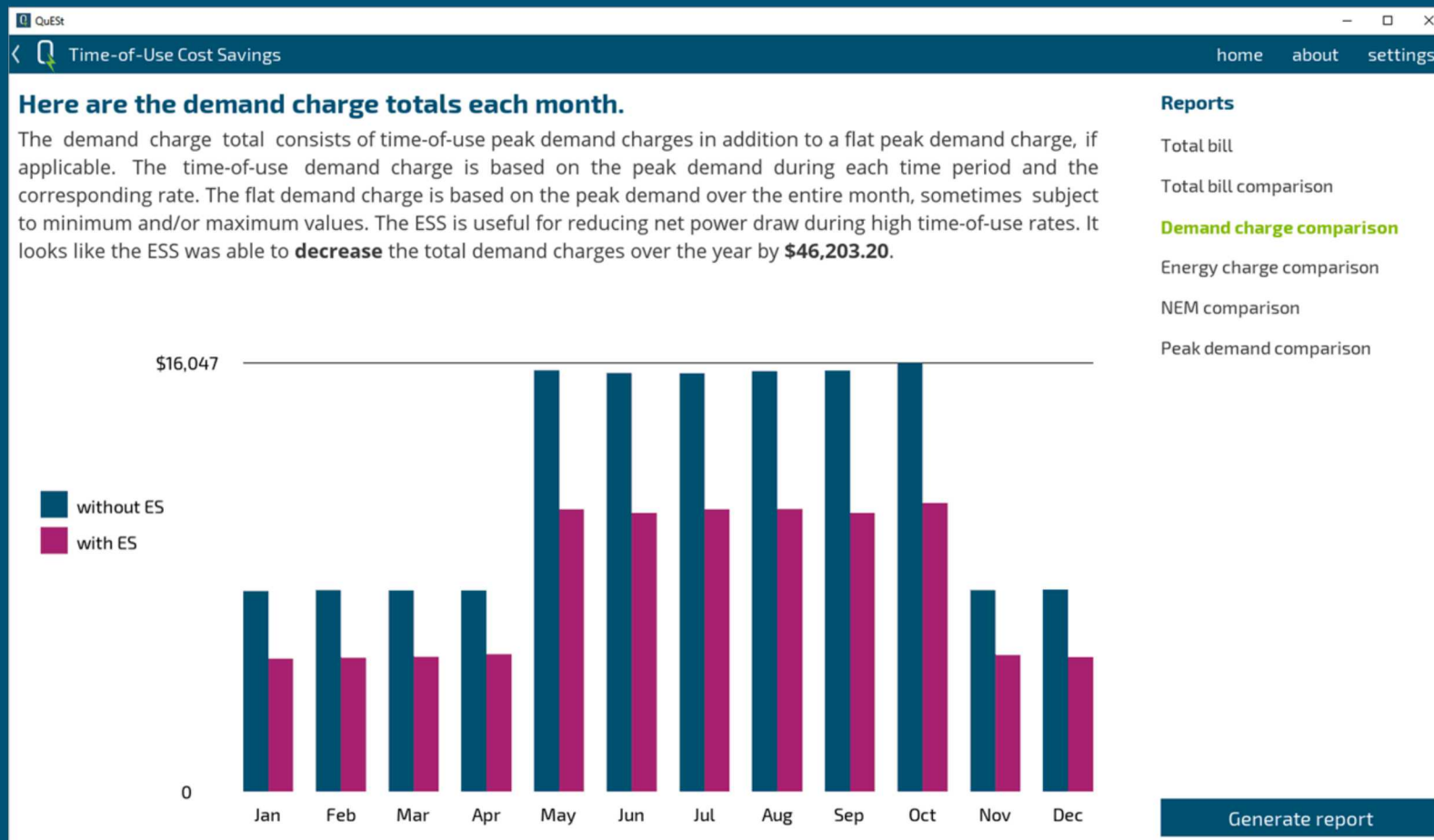




- Compare monthly bill with and without energy storage
- Peak demand reduction to decrease demand charges
- Time-shifting to reduce time-of-use energy charges
- Net metering credits



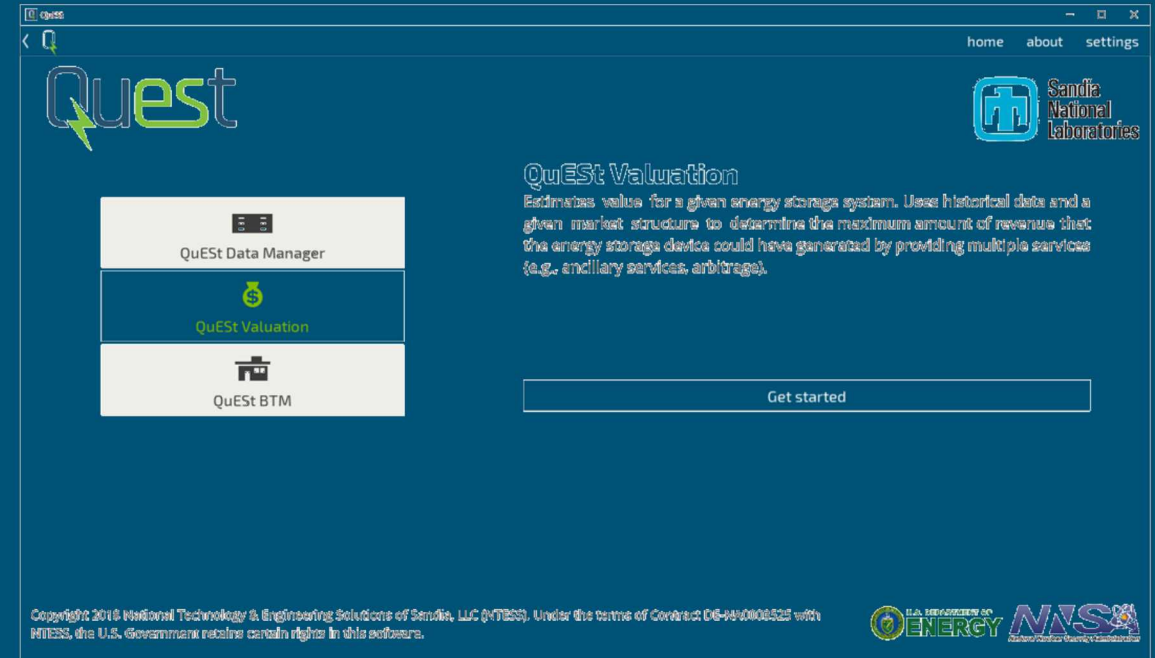
- Compare monthly bill with and without energy storage
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- Time-shifting to reduce time-of-use energy charges
- Net metering credits



- 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

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
  - ?





The authors would like to acknowledge the support and guidance from Dr. Imre Gyuk, the program manager for the U.S. Department of Energy Office of Electricity Energy Storage program.

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