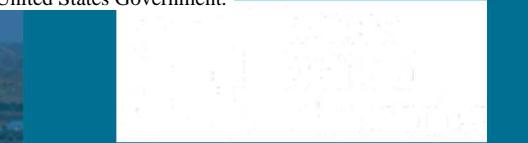
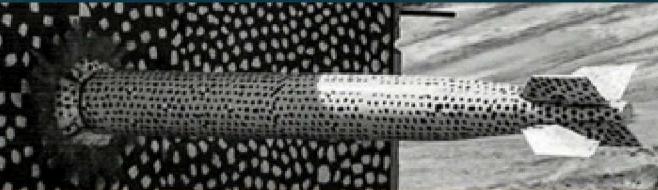




An Energy Storage Application Suite

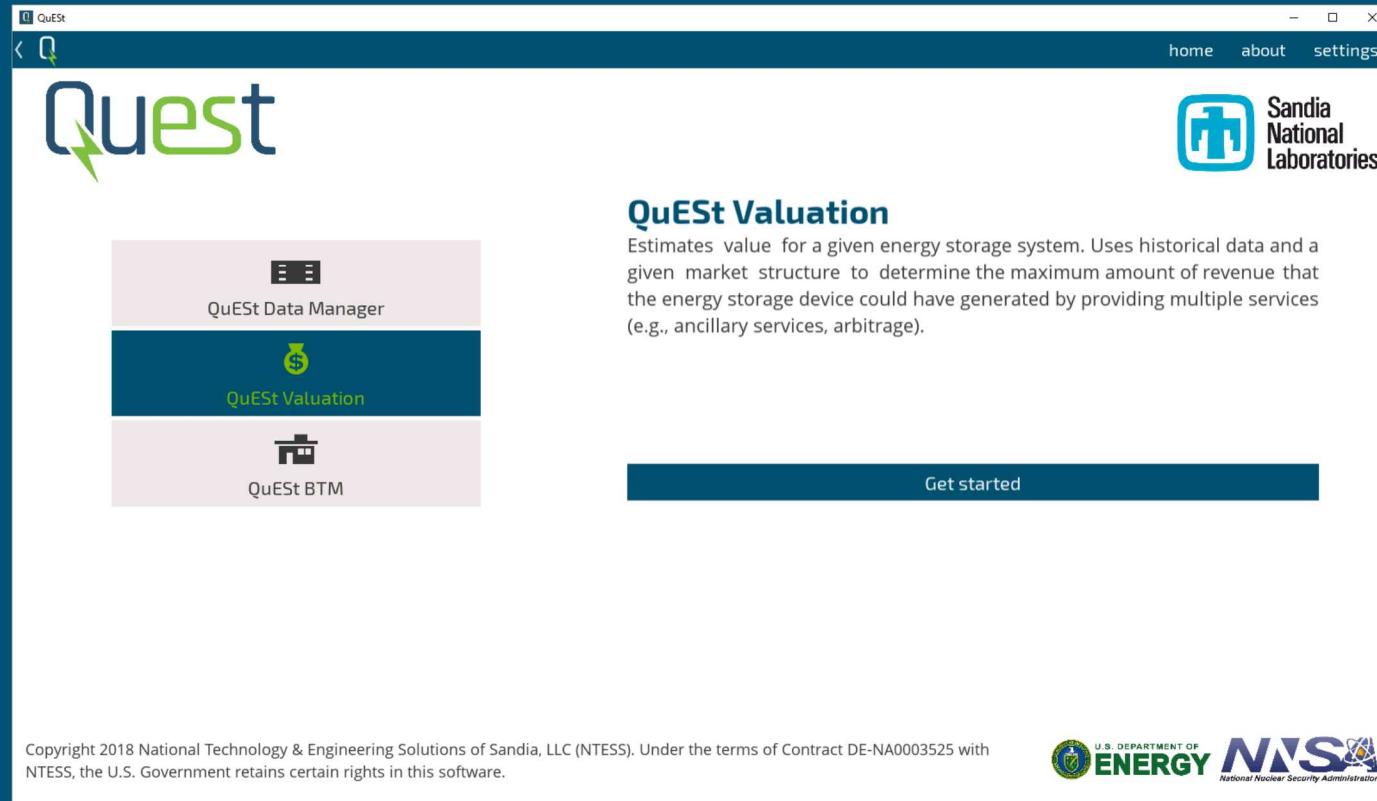


PRESENTED BY

Ricky Concepcion



What is it?



- 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 or sandia.gov/ess



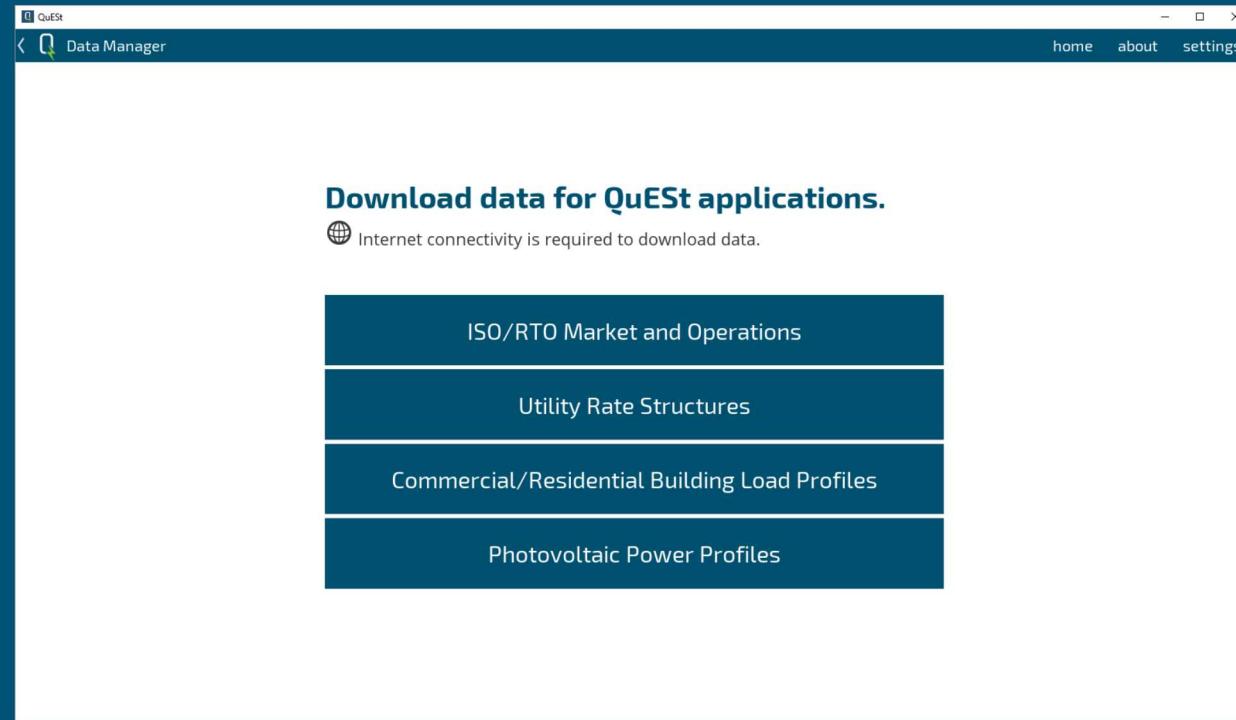
3 Why QuEST?

- 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



QuEST Data Manager



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

QuEST Data Manager

QuEST Data Manager: ISO/RTO Market and Operations Data

home about settings

Download ISO/RTO market and operations data.

SPP PJM NYISO MISO ISO-NE ERCOT CAISO

ISO-NE

Enter ISO-NE ISO Express credentials. ?

Username: rconcep@sandia.gov

Password: *****

Specify the range of months.

Start: January 2018

End: December 2018

Pricing node ID and/or types of nodes

4006

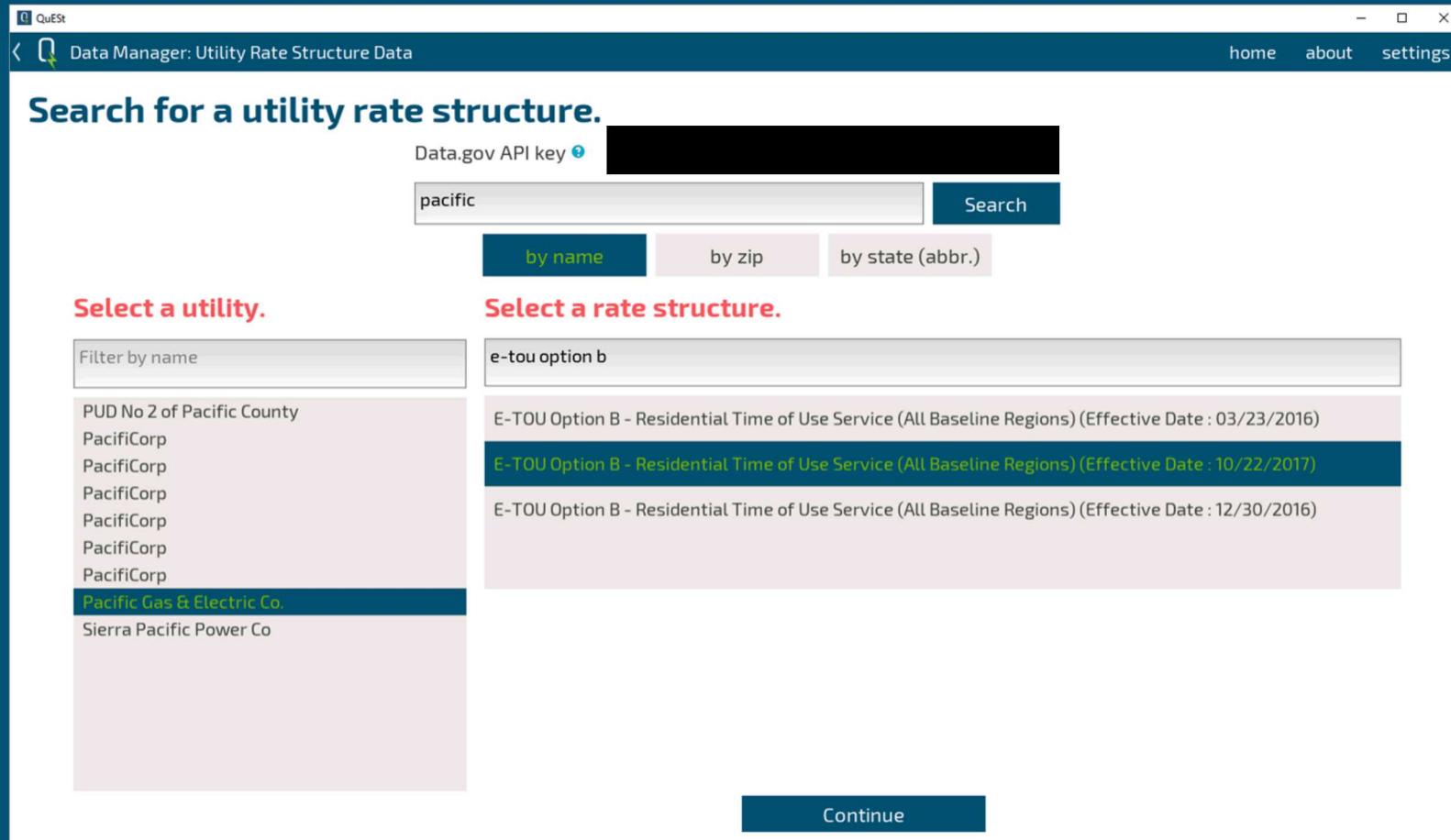
Internal Hub Zones

Download Cancel

Settings

- 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

6 QuEST Data Manager



The screenshot shows the QuEST Data Manager interface for searching utility rate structures. The search term 'pacific' has been entered into the search bar. The search results are categorized into two main sections: 'Select a utility.' and 'Select a rate structure.'.

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

7 QuEST Data Manager

Verify the energy rate structure.

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

Weekday

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
Jan	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2
Feb	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	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	3	3	3	3	3	3	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	3	3	3	3	3	3	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	3	3	3	3	3	3	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	1	1	1	1	1	1	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	1	1	1	1	1	1	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	1	1	1	1	1	1	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	1	1	1	1	1	1	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	3	3	3	3	3	3	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	3	3	3	3	3	3	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	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2
Jan	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	2	2	2	2	2	2	2	2	2	2
Feb	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	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	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	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	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	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	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	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	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	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	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	2	2	2	2	2	2	2	2	2	2	2	2

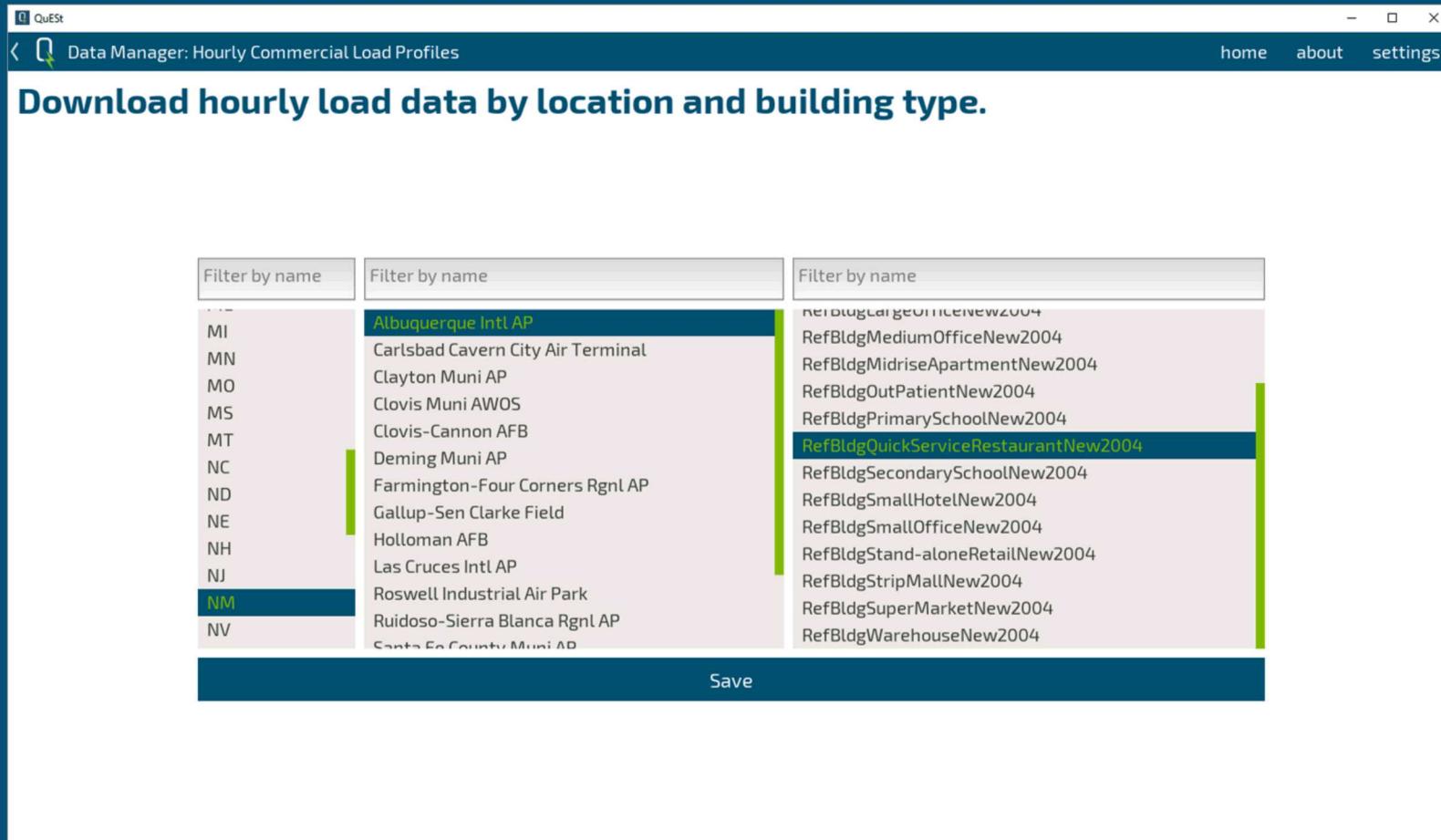
Weekend

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
Jan	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	2	2	2	2	2	2	2	2	2	2
Feb	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	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	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	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	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	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	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	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	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	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	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	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

8 QuEST Data Manager

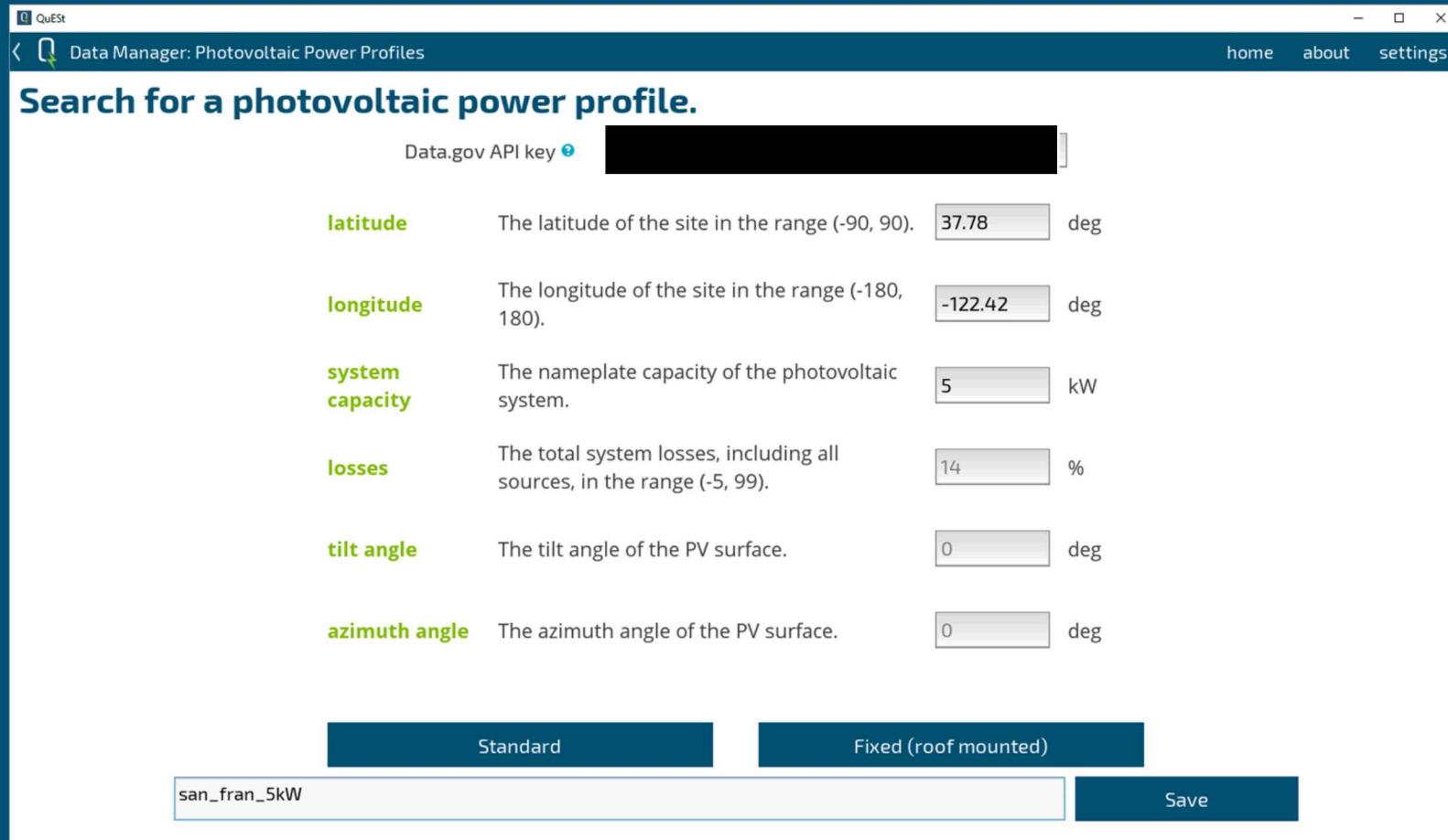


The screenshot shows the QuEST Data Manager interface. At the top, there are three filter boxes: 'Filter by name' for location, 'Filter by name' for building type, and 'Filter by name' for building sub-type. The location filter shows states (MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV) with NM selected. The building type filter shows various building types (RefBldgLargeOfficeNew2004, RefBldgMediumOfficeNew2004, RefBldgMidriseApartmentNew2004, RefBldgOutPatientNew2004, RefBldgPrimarySchoolNew2004, RefBldgQuickServiceRestaurantNew2004, RefBldgSecondarySchoolNew2004, RefBldgSmallHotelNew2004, RefBldgSmallOfficeNew2004, RefBldgStand-aloneRetailNew2004, RefBldgStripMallNew2004, RefBldgSuperMarketNew2004, RefBldgWarehouseNew2004) with RefBldgQuickServiceRestaurantNew2004 selected. The building sub-type filter shows sub-types (RefBldgLargeOfficeNew2004, RefBldgMediumOfficeNew2004, RefBldgMidriseApartmentNew2004, RefBldgOutPatientNew2004, RefBldgPrimarySchoolNew2004, RefBldgQuickServiceRestaurantNew2004, RefBldgSecondarySchoolNew2004, RefBldgSmallHotelNew2004, RefBldgSmallOfficeNew2004, RefBldgStand-aloneRetailNew2004, RefBldgStripMallNew2004, RefBldgSuperMarketNew2004, RefBldgWarehouseNew2004) with RefBldgQuickServiceRestaurantNew2004 selected. A 'Save' button is at the bottom.

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

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

9 QuEST Data Manager



The screenshot shows a web application window titled "Data Manager: Photovoltaic Power Profiles". The window has a header with "QuEST" logo, a back arrow, and a search icon. The top right has "home", "about", and "settings" links. The main content area has a title "Search for a photovoltaic power profile." and a "Data.gov API key" input field with a redacted value. Below are six input fields with labels in green:

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

At the bottom, there are two buttons: "Standard" and "Fixed (roof mounted)". A text input field contains "san_fran_5kW" and a "Save" button is on the right.

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

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?

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

subject to:

$$\begin{aligned} s_{i+1} &= \eta_s s_i + \eta_c q_i^r - q_i^d + \eta_c \delta_i^{rd} q_i^{rd} - \delta_i^{ru} q_i^{ru} && \text{state of charge definition} \\ 0 \leq s_i &\leq \bar{S} && \text{state of charge limits} \\ q_i^d + q_i^r + q_i^{ru} + q_i^{rd} &\leq \bar{Q} && \text{power/energy charged limits} \end{aligned}$$

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 Valuation

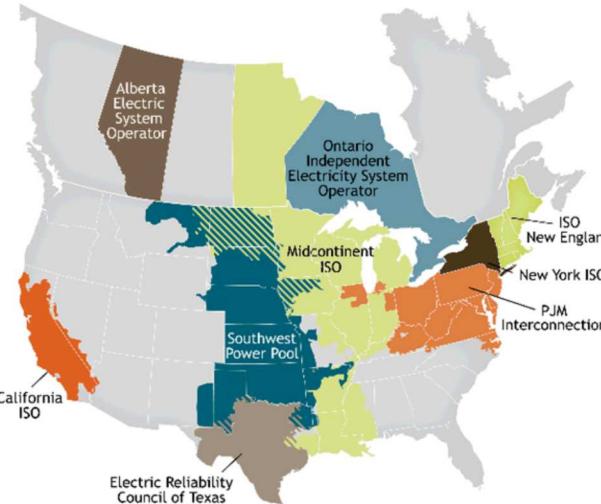
QuEST

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.



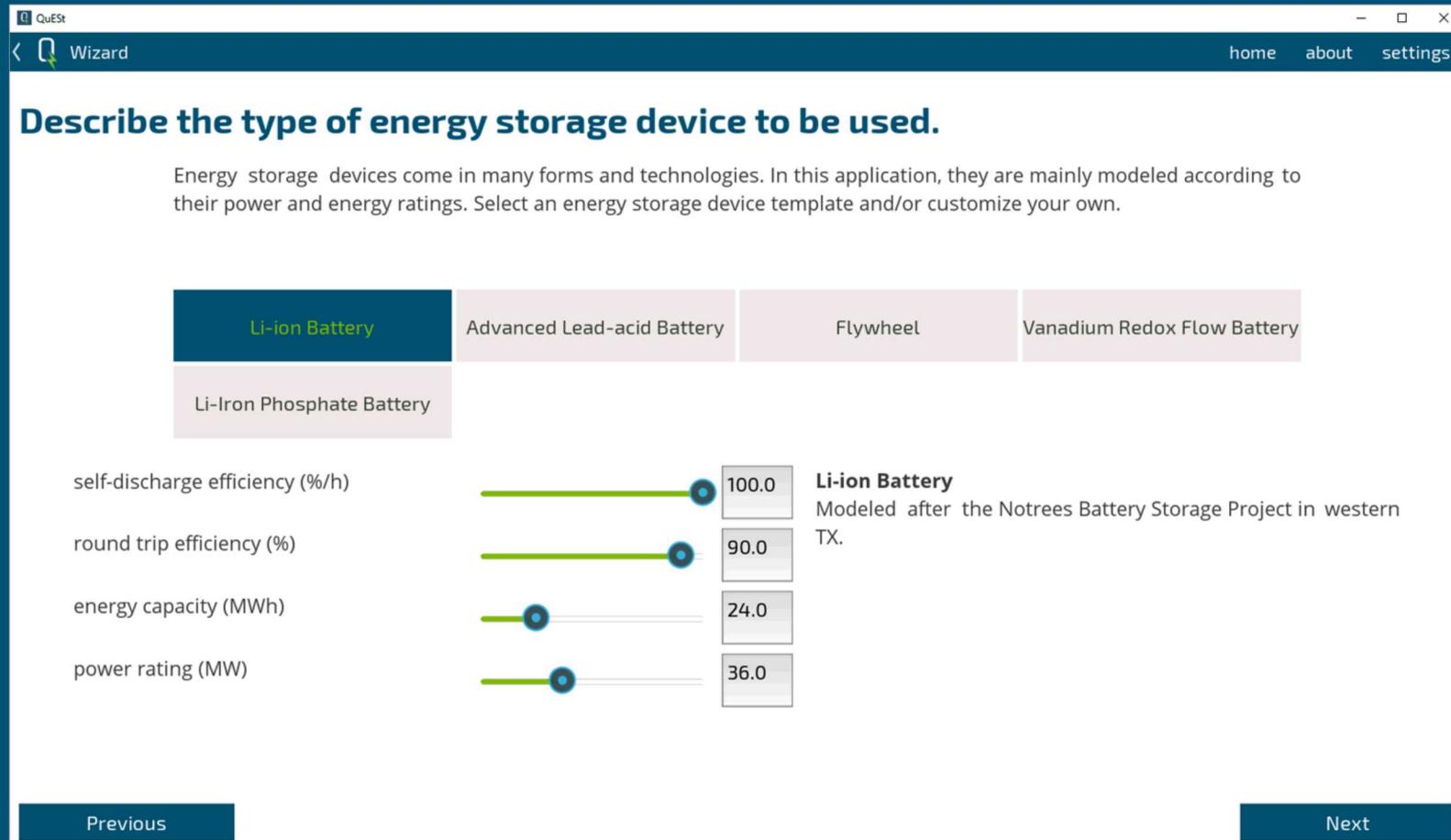
IRC
INTERSTATE COUNCIL

Previous

Next

ERCOT	PJM	MISO
NYISO	ISONE	SPP
CAISO		

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



The screenshot shows the QuEST Wizard application interface. The title bar reads "QuEST Wizard". The main content area has a heading "Describe the type of energy storage device to be used." followed by a sub-instruction: "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." Below this, a navigation bar includes "home", "about", and "settings". A tab bar at the top has "Li-ion Battery" (selected), "Advanced Lead-acid Battery", "Flywheel", and "Vanadium Redox Flow Battery". A sub-menu "Li-Iron Phosphate Battery" is visible under "Li-ion Battery". On the left, there are four sliders with numerical inputs: "self-discharge efficiency (%/h)" (100.0), "round trip efficiency (%)" (90.0), "energy capacity (MWh)" (24.0), and "power rating (MW)" (36.0). To the right of the sliders, the "Li-ion Battery" template is selected, with the note: "Modeled after the Notrees Battery Storage Project in western TX." Navigation buttons "Previous" and "Next" are at the bottom.

Li-ion Battery

Advanced Lead-acid Battery

Flywheel

Vanadium Redox Flow Battery

Li-Iron Phosphate Battery

self-discharge efficiency (%/h)

round trip efficiency (%)

energy capacity (MWh)

power rating (MW)

Li-ion Battery

Modeled after the Notrees Battery Storage Project in western TX.

Previous

Next

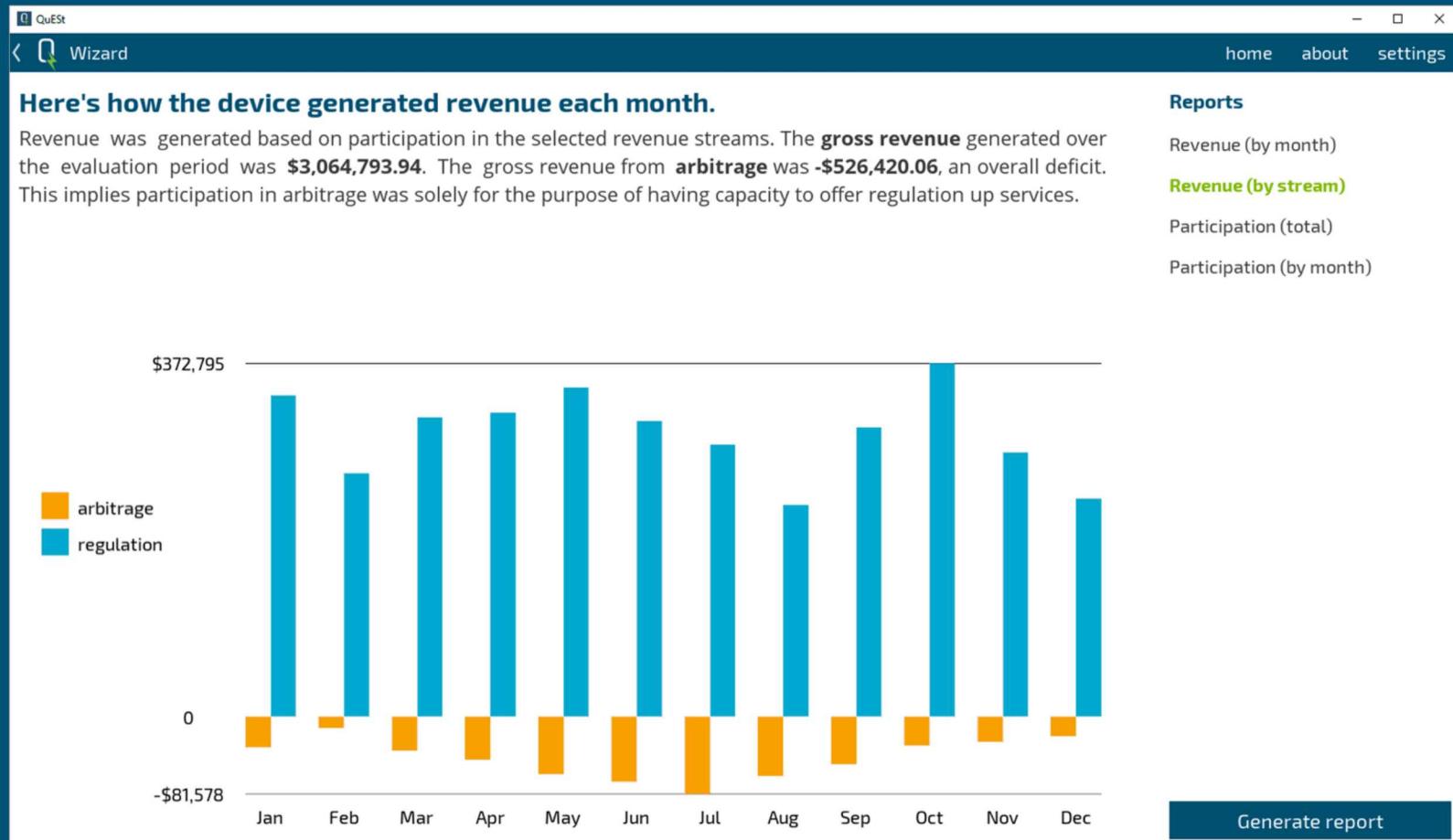
- Market area

- Revenue streams

- Historical dataset to study

- Energy storage model parameters

QuEST Valuation



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

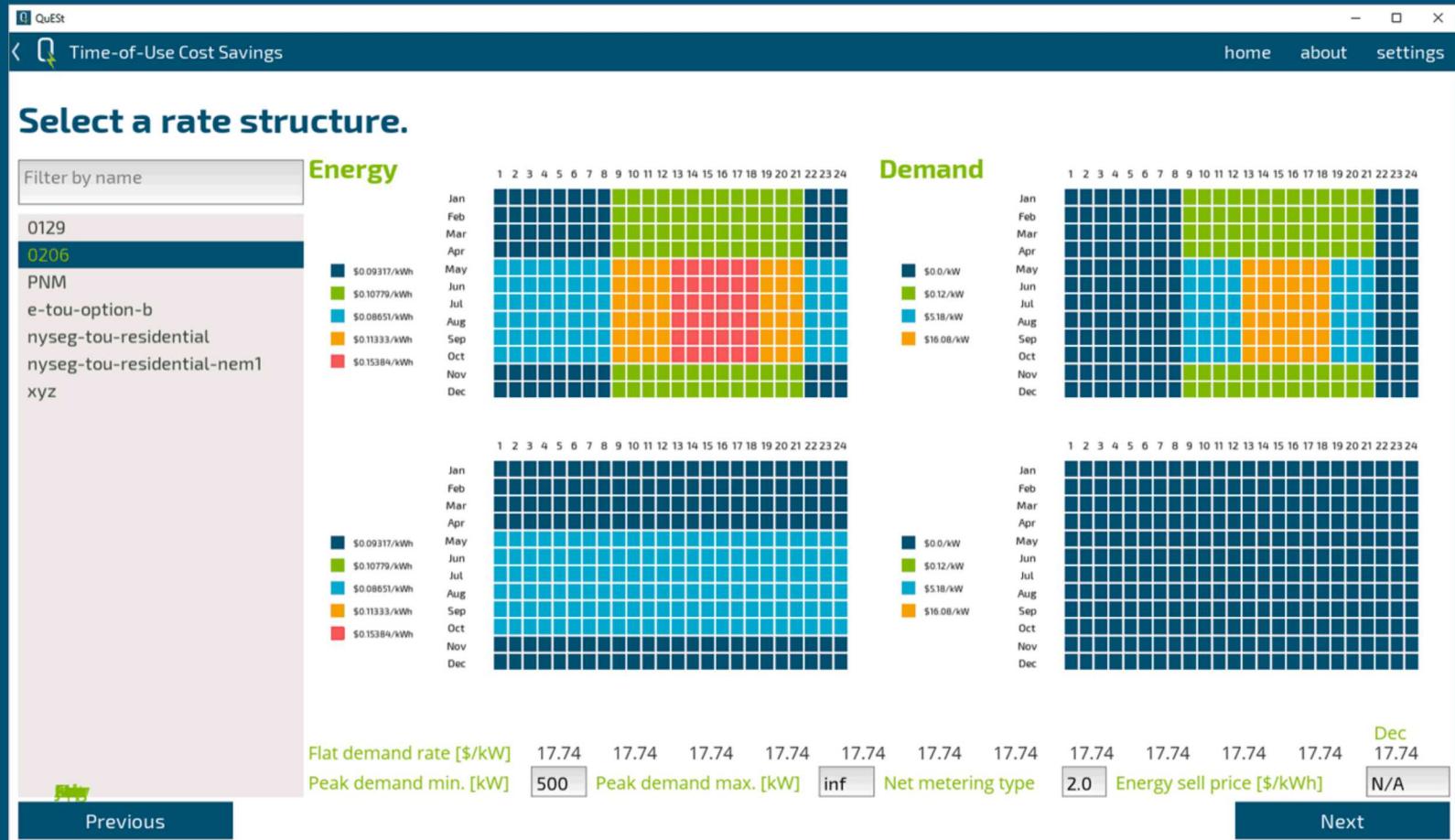
QuEST BTM*

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.





- 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

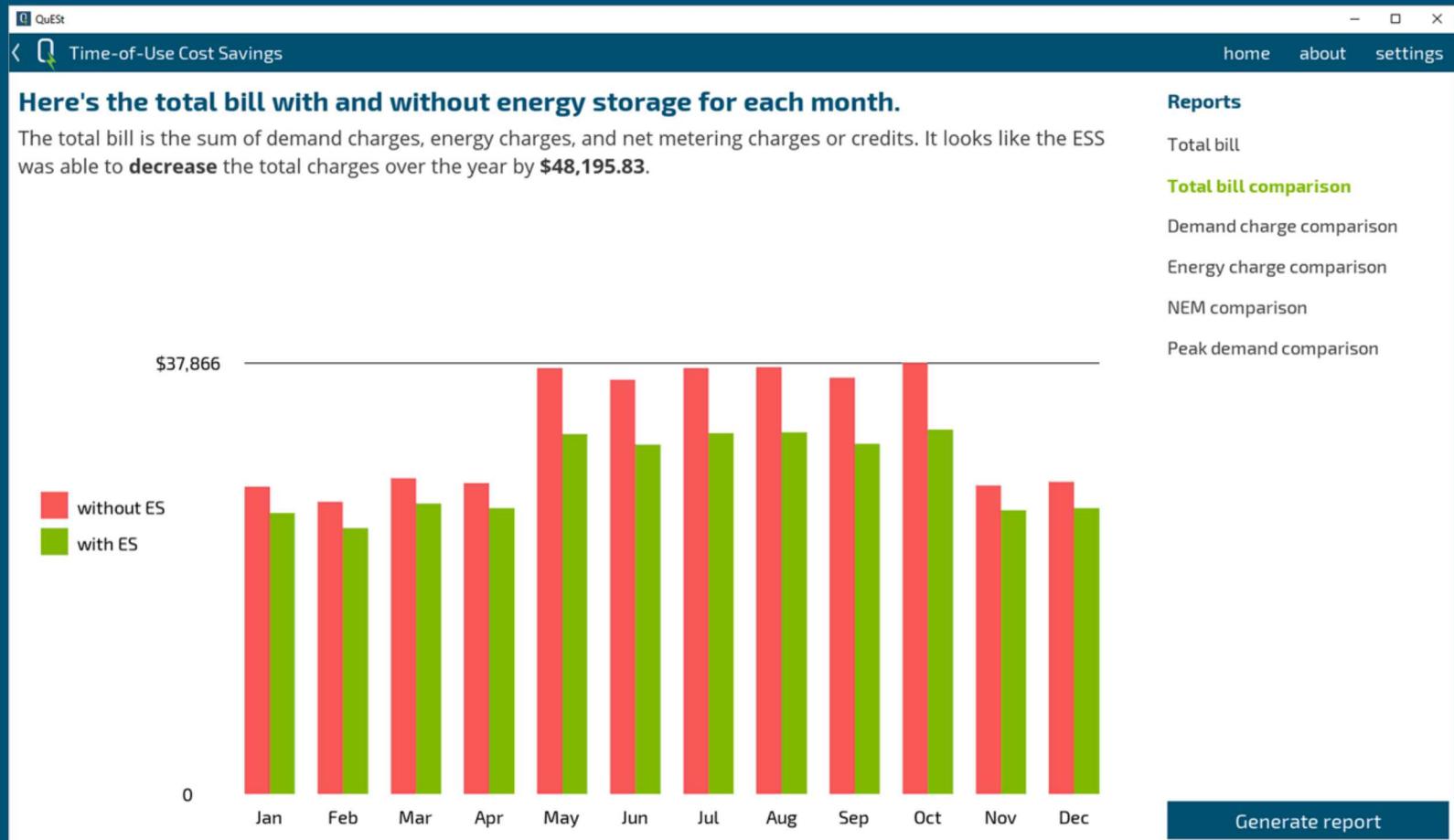
Specify the energy storage system parameters.

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

Previous

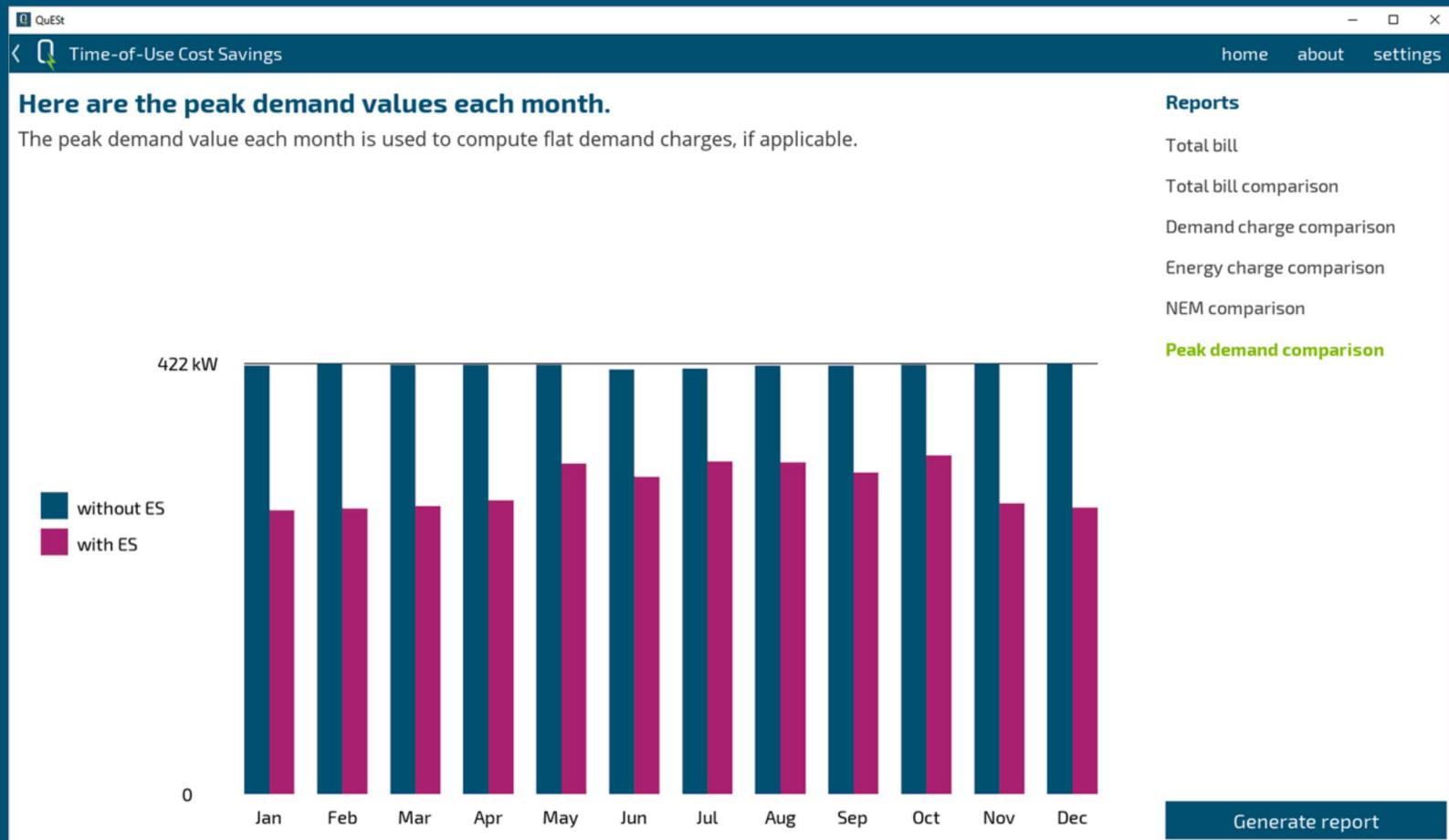
Next

- 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



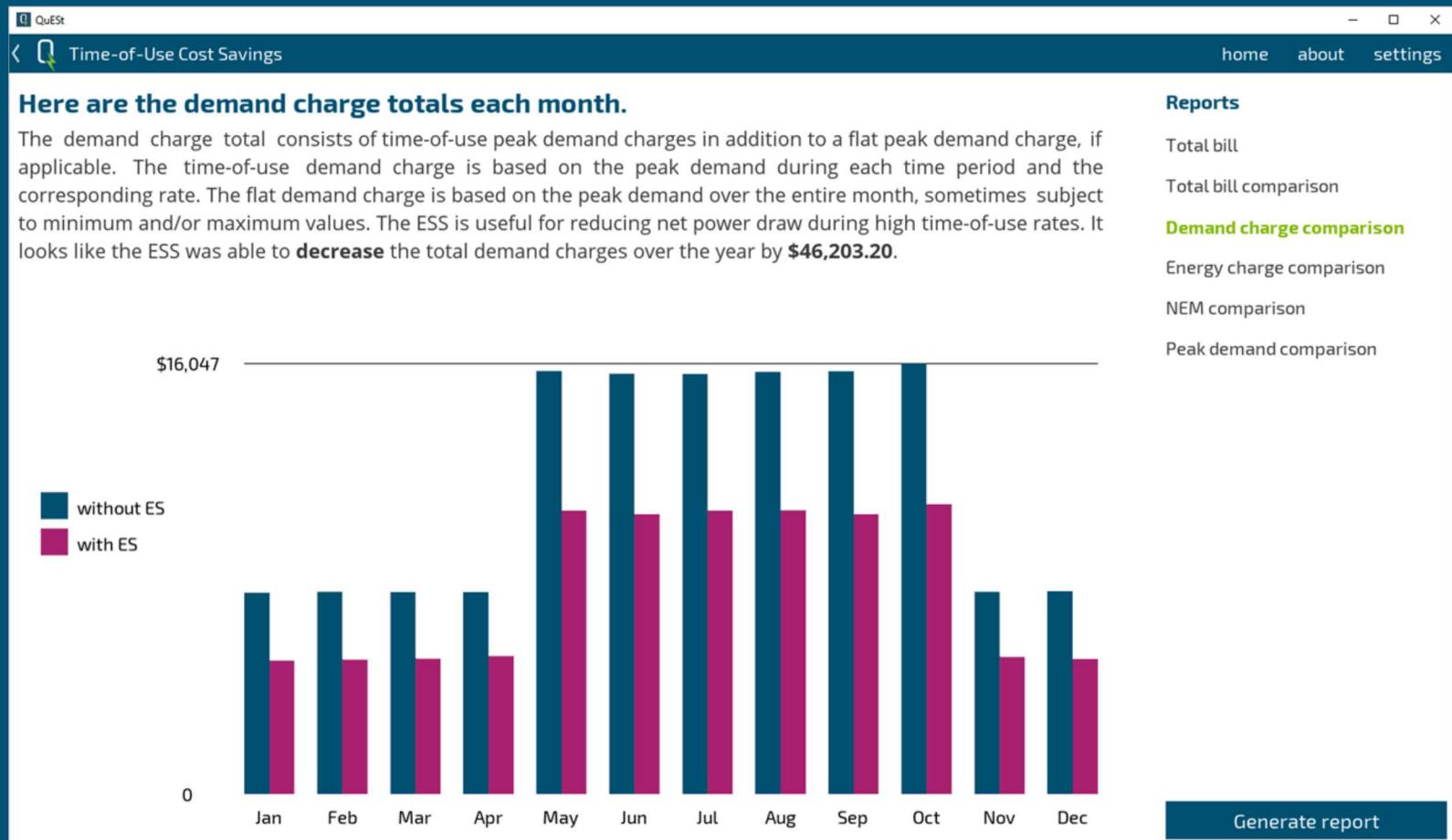
- Compare monthly bill with and without energy storage
- Peak demand reduction to decrease demand charges
- Time-shifting to reduce time-of-use energy charges
- Net metering credits

QuEST BTM*



- 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

QuEST BTM*

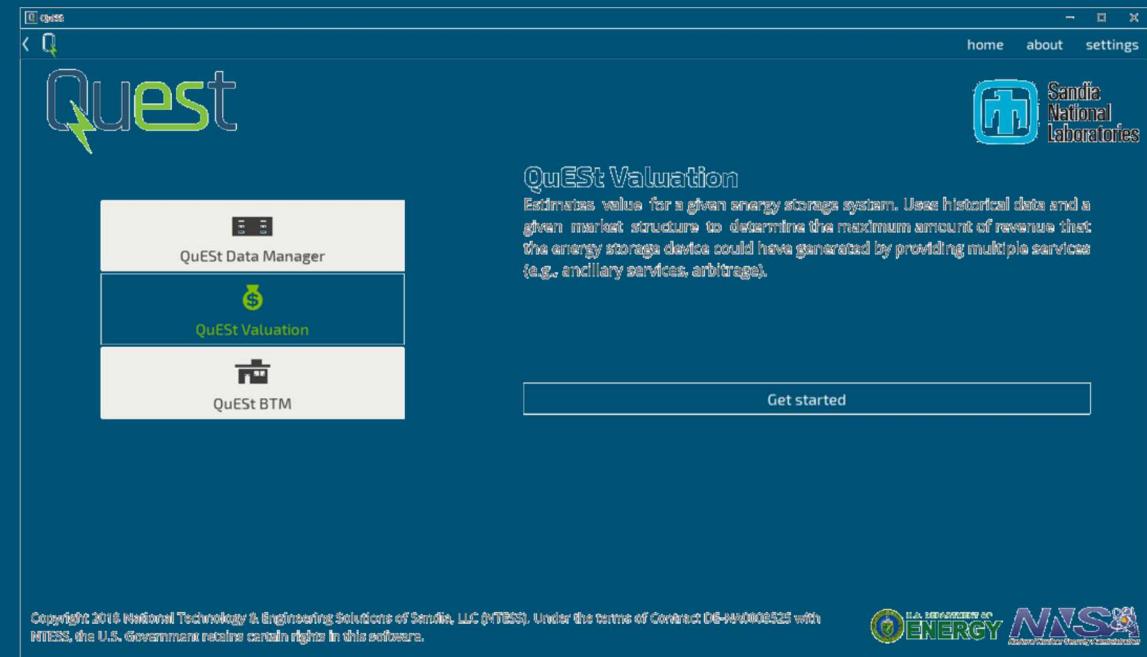


- Compare monthly bill with and without energy storage
- Peak demand reduction to decrease demand charges
- Time-shifting to reduce time-of-use energy charges
- Net metering credits

The Future

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
 - ?



Acknowledgements

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.

Authors

Ricky Concepcion

David Copp

Tu Nguyen

Felipe Wilches-Bernal



Inquiries to:

Ricky Concepcion

rconcep@sandia.gov

Follow us on GitHub:

github.com/rconcep/snl-quest