U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Pumped Storage Hydro Valuation Program

Presented by: Patrick Balducci (Argonne National Laboratory)

2023 U.S. DOE Energy Storage Finance Summit

January 26, 2023

Pumped Storage Hydro (PSH) Valuation Team

Valuation Guidance & Techno-Economic Studies and Tool for Pumped Storage Hydropower

Argonne National Laboratory (Argonne)

Idaho National Laboratory (INL)

National Renewable Energy Laboratory (NREL)

Oak Ridge National Laboratory (ORNL)

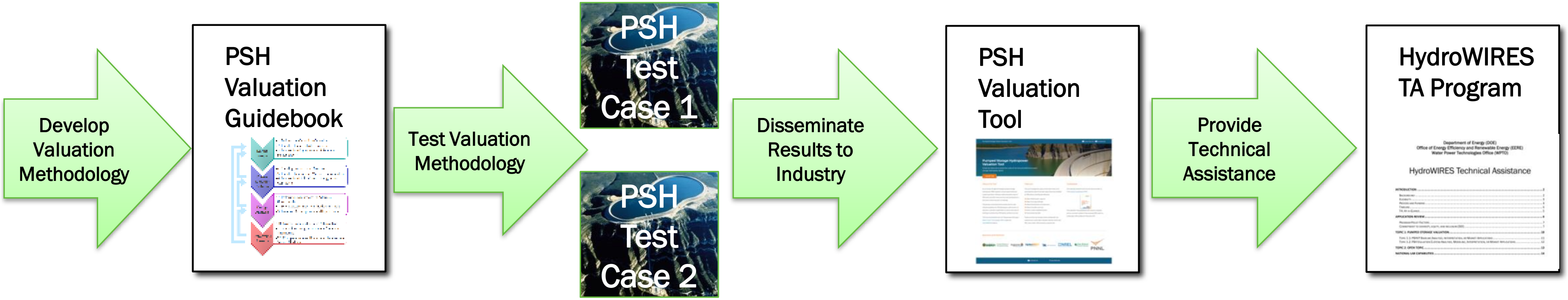
Pacific Northwest National Laboratory (PNNL)

Program Goals and Objectives

Objective: Advance the state of the art in the assessment of value of PSH plants and their role and contributions to the power system

Specific goals:

1. Develop and test a comprehensive and transparent valuation guidance that will allow for consistent valuation assessments and comparisons of PSH projects
2. Transfer and disseminate the PSH valuation guidance to the hydropower industry, PSH developers, and other stakeholders
3. Provide technical assistance (TA) to the hydropower industry ($4 million TA program)



Techno-Economic Studies

A variety of analyses were carried out to assess the costs and benefits of various PSH services and contributions to the grid

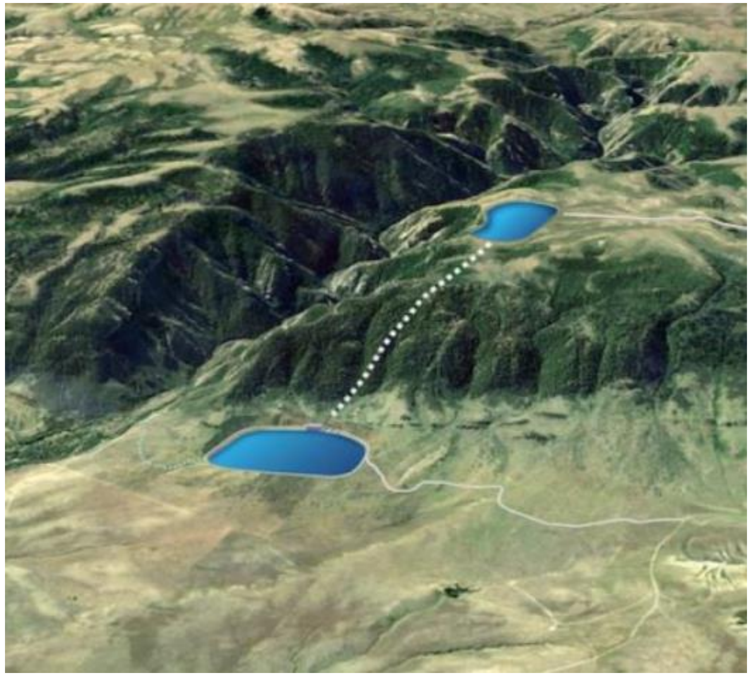
- Bulk power capacity and energy value over PSH lifetime
- Value of PSH ancillary services (regulation service, contingency reserves, etc.)
- Power system stability services (inertial response, governor response, transient and small signal stability, voltage support)
- PSH impacts on reducing system cycling and ramping costs
- Other indirect (system-wide or portfolio) effects of PSH operations (e.g., PSH impacts on decreasing overall power system production costs, benefits for integration of variable energy resources, and impacts on power system emissions)
- PSH transmission benefits (transmission congestion relief, transmission investments deferral)
- PSH non-energy services (water management services, socioeconomic benefits, and environmental impacts)

The Project Team Collaborated with Two Industry Partners

Absaroka Energy

Banner Mountain PSH

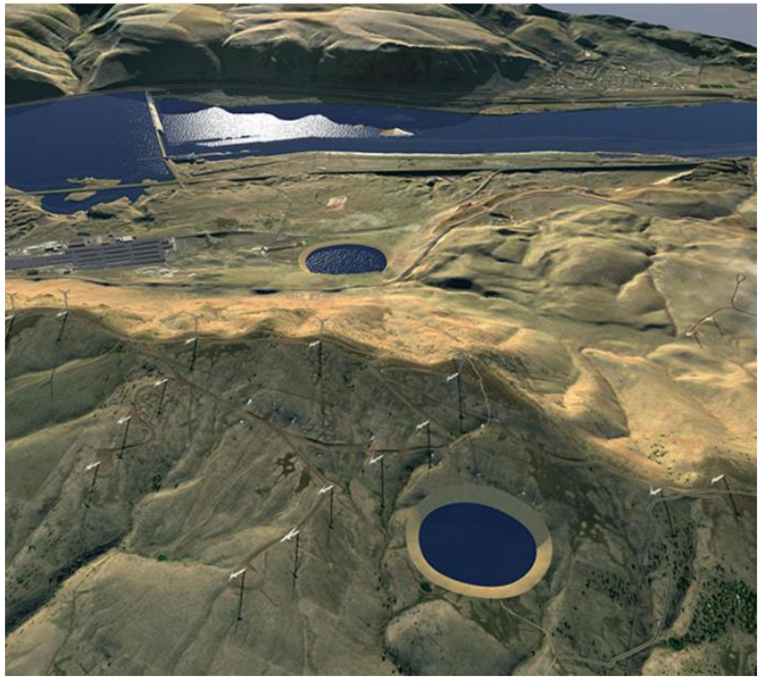
- 400 MW, quaternary technology
- Closed loop
- Site near Casper, WY



CIP & Rye Development*

Goldendale Energy Storage Project

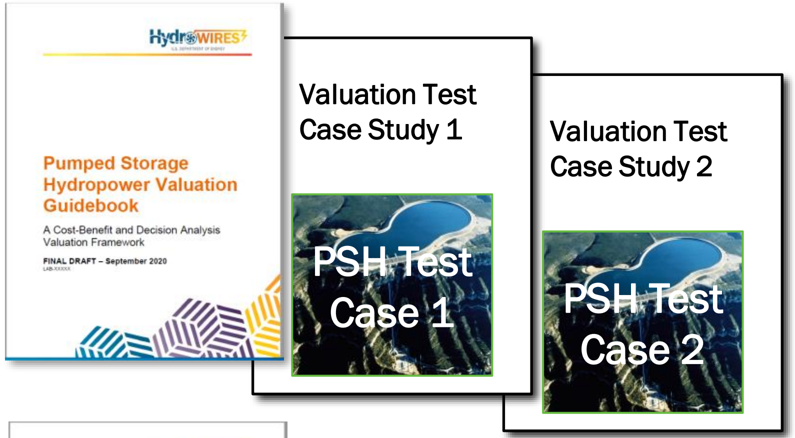
- 1,200 MW, adjustable speed technology
- Closed loop
- Site just north of OR/WA border



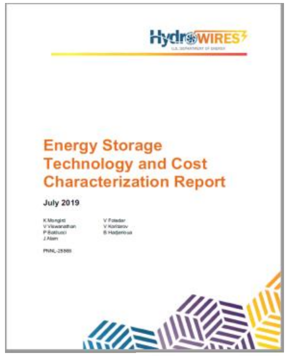
*CIP = Copenhagen Infrastructure Partners

Key Products of the PSH Valuation Project

- PSH Valuation Guidebook (published)
- Two technical reports illustrating test case studies for actual PSH projects (complete)



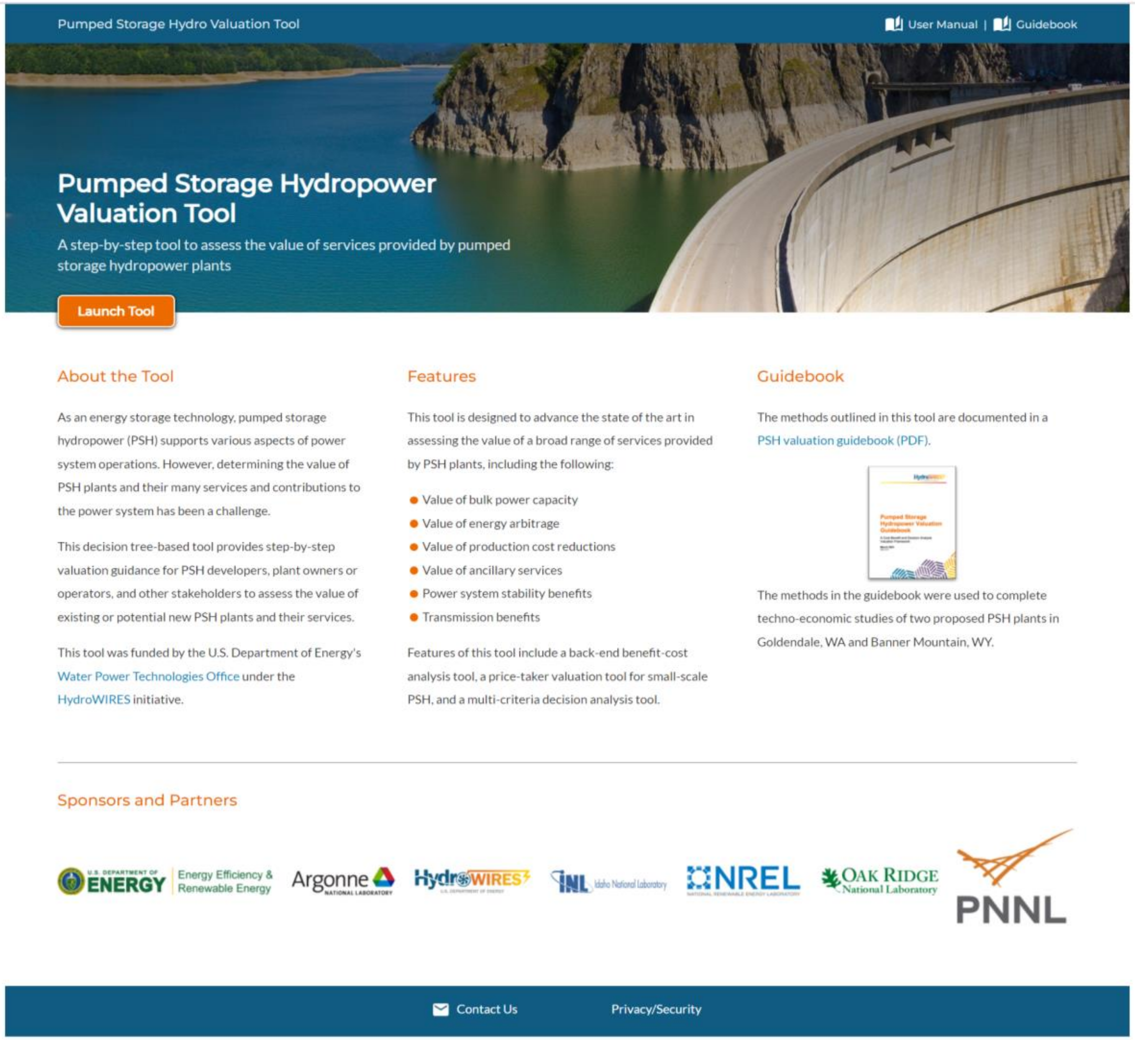
- Energy storage cost and performance study (published)



- PSH valuation tool to help the users navigate the PSH valuation process (https://pshvt.egs.anl.gov/)

PSH Valuation Tool

- PSH valuation tool provides step-by-step valuation guidance for PSH developers, plant owners or operators, and other stakeholders
- PSH tool advances the state of the art in evaluating a broad set of use cases from three perspectives: owner/operator, system, and society
- PSH tool has several advanced features:
  - Embedded price-taker model
  - Multi-criteria decision analysis (MCDA) tool
  - Embedded financial worksheets and benefit-cost analysis (BCA) model
  - Embedded price-influencer model



PSH Valuation Tool Home Page

Price-taker Model

- **PNNL adapted its Battery Storage Evaluation Tool (BSET) to PSH**
- **Embed BSET within the tool**
- **Tool provides:**
  - Optimization across single or multiple services customized by users
  - Optimization without perfect foreknowledge of prices; operations based on historical prices or price predictions
  - Power and energy limit specifications
  - Model can be used to determine optimal power capacity and energy ratings

Category	Use Case
Bulk Energy	Energy Arbitrage
	Capacity
Ancillary Services	Frequency Regulation
	Spin / Non-Spin
Transmission	Upgrade Deferral
	Congestion Relief
Distribution	Upgrade Deferral
	Volt-VAR
Customer Energy Management	Power Reliability
	TOU Charge Management
	Demand Charge Management

Price-taker Model Use Cases

MCDA Tool

- Choosing among different alternatives with multiple attributes
- Many PSH impacts are not easily monetized and must be expressed in physical units or qualitatively
- How to compare different alternatives that are described by both monetized and non-monetized impacts?
- A decision-support system can help decision-makers choose among different alternatives defined by multiple attributes

Entered Optimization Goal and Bounds of Measurement Scale
Computed Performance Index Scores

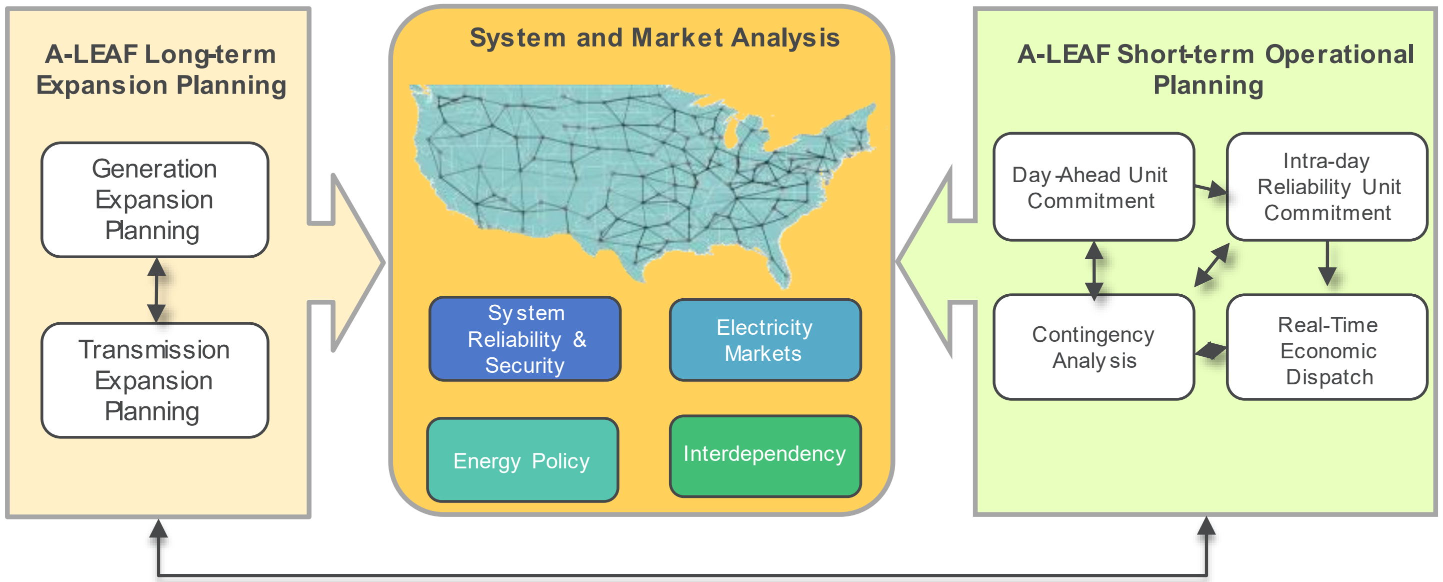
		Lower Bound	Upper Bound	Goal	Alternative 1		Alternative 2		Alternative 3	
Metric 1	NPV	-40.0	60.0	Maximize	45	85	30	70	40	80
Metric 2	VER Curtailments	0.0	50.0	Minimize	30	40	40	20	45	10
Metric 3	Interruption Cost	0.0	30.0	Minimize	15	50	22	27	19	37
Metric 4	Environmental Score	0.0	5.0	Maximize	4	80	2	40	3	60

	Value	Average Weight	Weighted Scores	Value	Weight	Weighted Scores	Value	Weight	Weighted Scores
NPV	85	0.222	18.88	70	0.222	15.55	80	0.222	17.77
VER Curtailments	40	0.188	7.50	20	0.188	3.75	10	0.188	1.88
Interruption Cost	50	0.289	14.47	27	0.289	7.72	37	0.289	10.61
Environmental Score	80	0.301	24.08	40	0.301	12.04	60	0.301	18.06
Performance Index			64.93			39.06			48.31

PSHVT MCDA Tool

Argonne Low-carbon Electricity Analysis Framework (A-LEAF)

- Integrated national-scale power system simulation framework developed at the Argonne National Laboratory, used to analyze various issues related to the evolution of the nation's power system.
- Suite of least-cost generation & transmission expansion, unit commitment, and economic dispatch models
- Determine system optimal generation portfolio and hourly or sub-hourly unit dispatch under a range of user-defined input assumptions for technology characteristics and system/market requirements



Embedded A-LEAF Tool

How A-LEAF Works in the PSH Valuation Tool

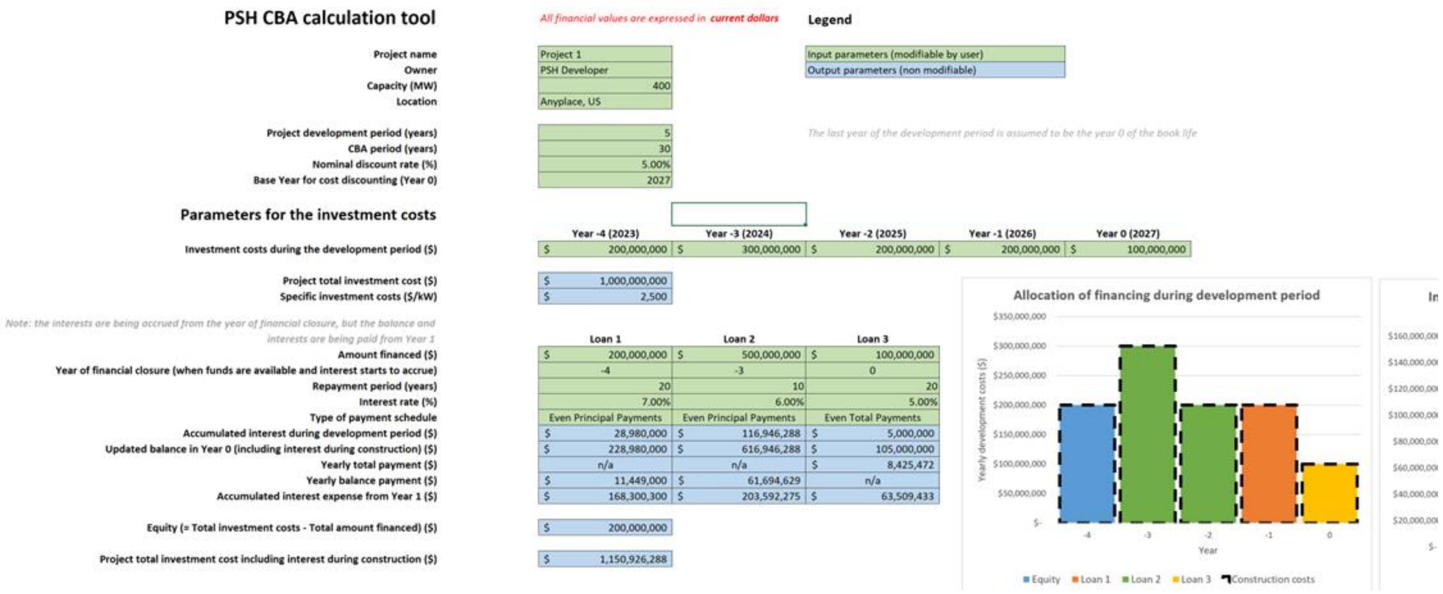
- **A-LEAF is embedded as an option**
  – Users can choose the current approach for estimating PSH values using multiple external tools or select the A-LEAF option
- **Data**
  – Users can use the default national scale dataset provided in A-LEAF
  – The tool supports users as they define input data for their own analysis
- **Alternative Scenarios**
  – Natural gas prices and technology costs
  – Environmental policies and tax credits
  – 134 balancing areas around US
- **Use Cases**
  – A-LEAF is customized to support several use cases in the PSH valuation tool

Category	Service
Bulk Energy Services	Electricity price arbitrage
	Bulk power capacity
Ancillary Services	Frequency regulation
	Contingency reserve
	Flexibility reserve
	Black start service
Reliability and Resilience	Reduced power outages
Power System Indirect Benefits	Reduced electricity generation cost
	Reduced ramping of thermal units
	Reduced curtailments of variable generation
Transmission Infrastructure Benefits	Transmission upgrade deferral
	Transmission congestion relief
Energy Security Benefits	Fuel savings and diversification
	Major blackouts avoided

A-LEAF Use Cases

BCA Calculator, Financial Worksheets, and Reporting

- BCA calculator runs the user through a series of data requests
- Model enables the user to define alternative scenarios, evaluate many use cases, and consider alternative debt structures, alternative depreciation methods, tax implications, salvage value, all capital and operations and maintenance costs, and refurbishment costs



PSHVT BCA Calculator

- BCA calculator defines a benefit-cost ratio, discounted payback period, and an internal rate of return for each case
- The tool produces a report providing a technology overview, stakeholder engagement plan, use case and metrics, and results of the BCA and MCDA

Thank you! Questions?

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Energy Storage, DER, and Microgrid Project Valuation

EPRI DER-VET™ Analysis in Action

Eva Gardow
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Technical Executive | EPRI

January 26, 2023

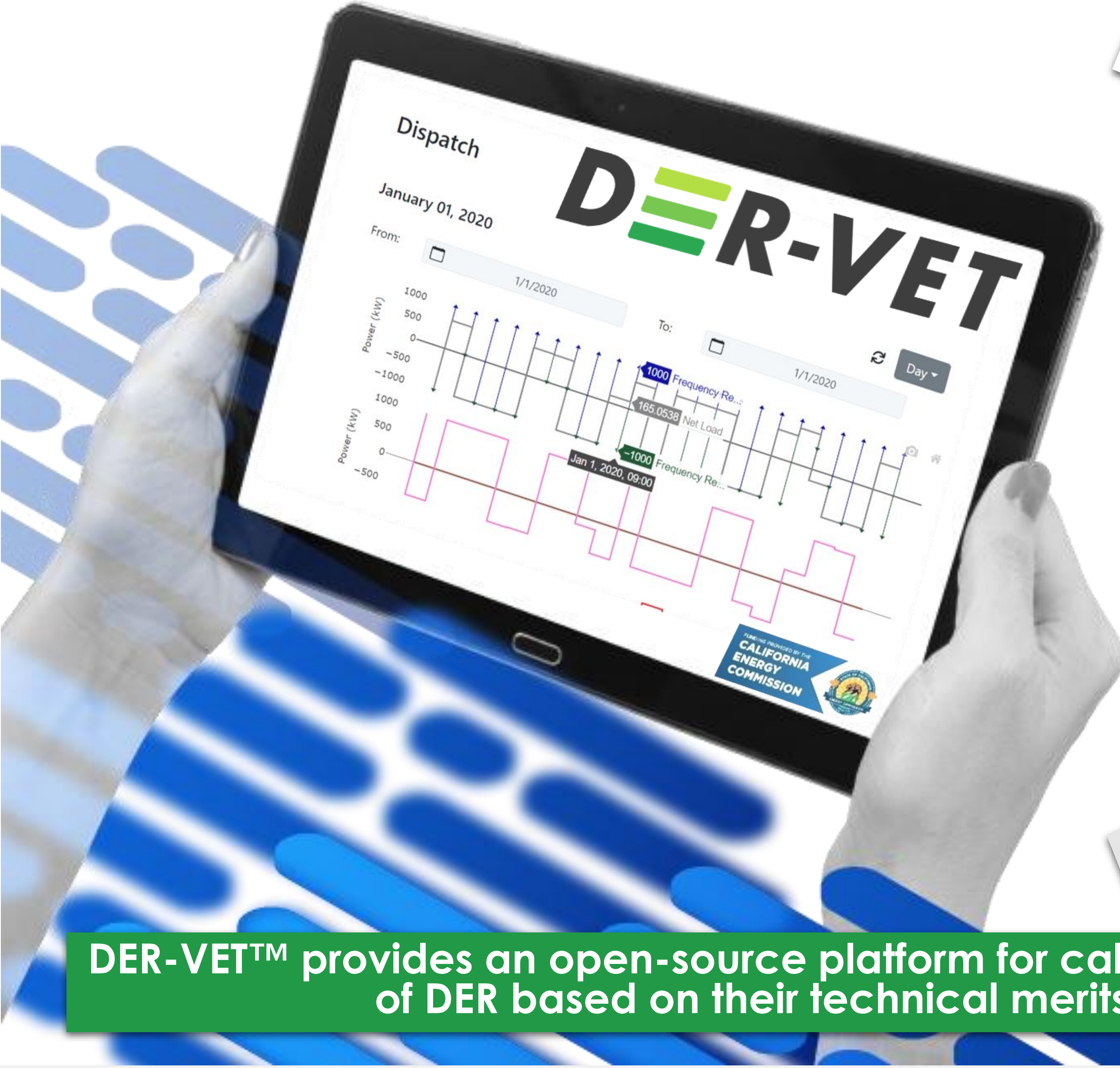
The Challenges of Storage, DER*, & Microgrid Modeling

- Today's energy storage, DER, and microgrid deployments demand robust analysis for strategic planning
- Valuation of energy storage requires project-level analyses for specific applications and locations
- This is a complex co-optimization, decision-making process

*DER: Distributed Energy Resources

EPRI's Distributed Energy Resources Value Estimation Tool, DER-VET™ addresses these challenges

The Solution: EPRI's DER-VET™



Bridges industry gaps in project-level energy storage, DER, and microgrid analysis with a publicly available tool and methodology

Creates a common and consistent communication tool among stakeholders

Evaluates various perspectives from customers values to grid values in any market; estimates benefits and costs of energy storage and other DER

DER-VET™ provides an open-source platform for calculating, understanding, and optimizing the value of DER based on their technical merits and constraints: www.der-vet.com

EPRI

DER-VET's Past, Present, and Future

2013
EPRI ESVT

Cost-Effectiveness of Energy Storage in California
https://www.epri.com/research/products/000000003002001164

2016
EPRI StorageVET®

www.storagevet.com

DER-VET

2020
EPRI DER-VET Beta

2022
EPRI DER-VET™ V1.2
1,000+ Users

www.der-vet.com

202X
DER-VET User Group and Open-Source Developer Community

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Distributed Energy Resource Value Estimation Tool (DER-VET™)

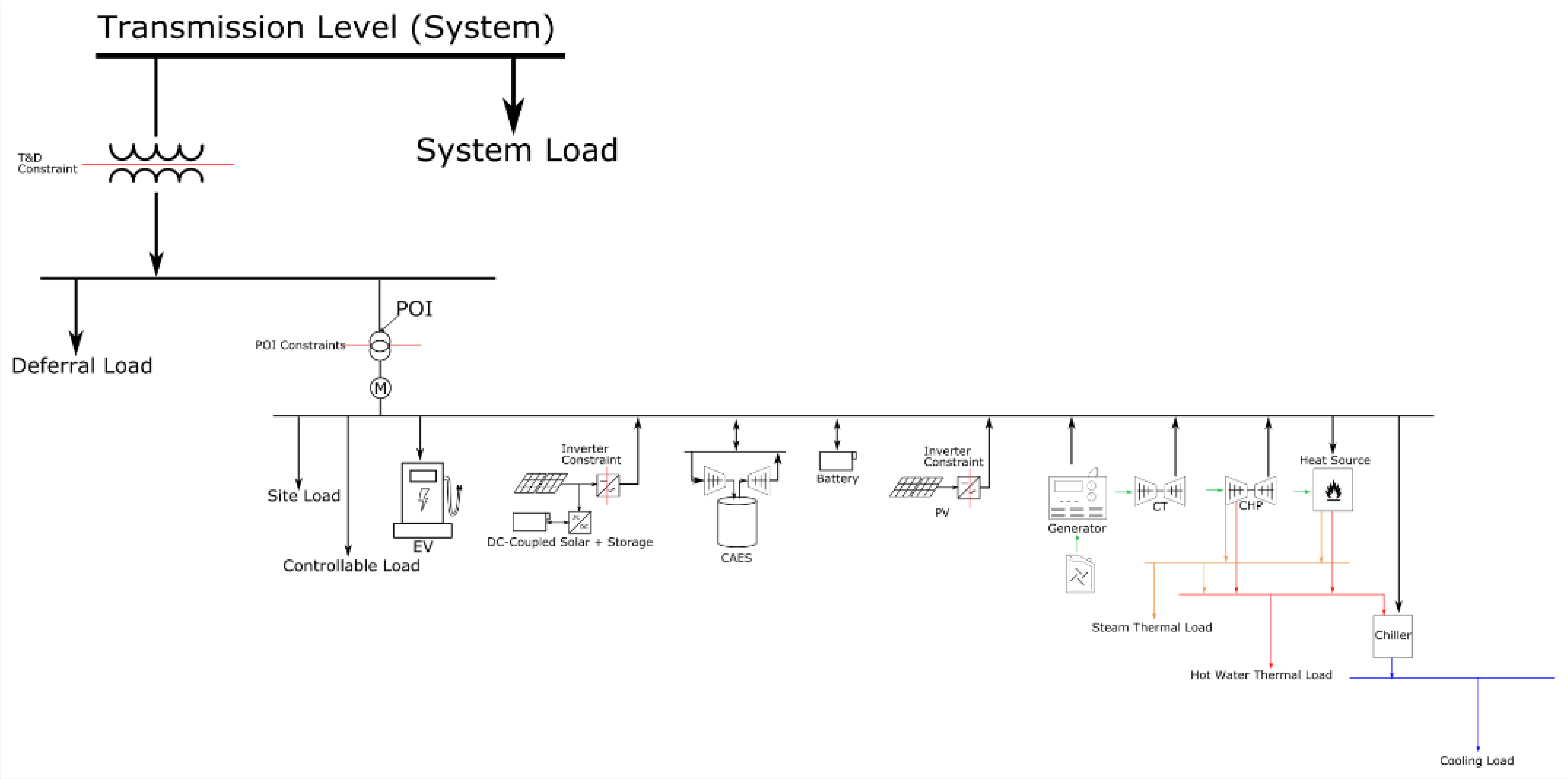
DER-VET™	Software	Reference Cases	ESIC Task Force	Help	Forums

To download DER-VET, go to https://www.der-vet.com/

- Download the tool for free as it was developed with California Energy Commission funding
- **Software Release: DER-VET™ Version 1.2 (Updated July 11, 2022)**
- **DER-VET™ Overview Presentation (September 2022)**
- **DER VET User Guide**

- **Get Involved**
  - Engage with monthly Public ESIC Task Force Web Meetings. The Energy Storage Integration Council (ESIC), an open technical forum. More info can be found at **www.epri.com/esic**.
  - ESIC Working Group 1 DER-VET™ Task Force Meeting Recordings can be found at **www.der-vet.com/esictf**
  - The ESIC collaboration site contains live draft user documentation from the ESIC DER-VET™ Subgroup at **collab.epri.com/esic**.

Technologies in DER-VET



Services in DER-VET

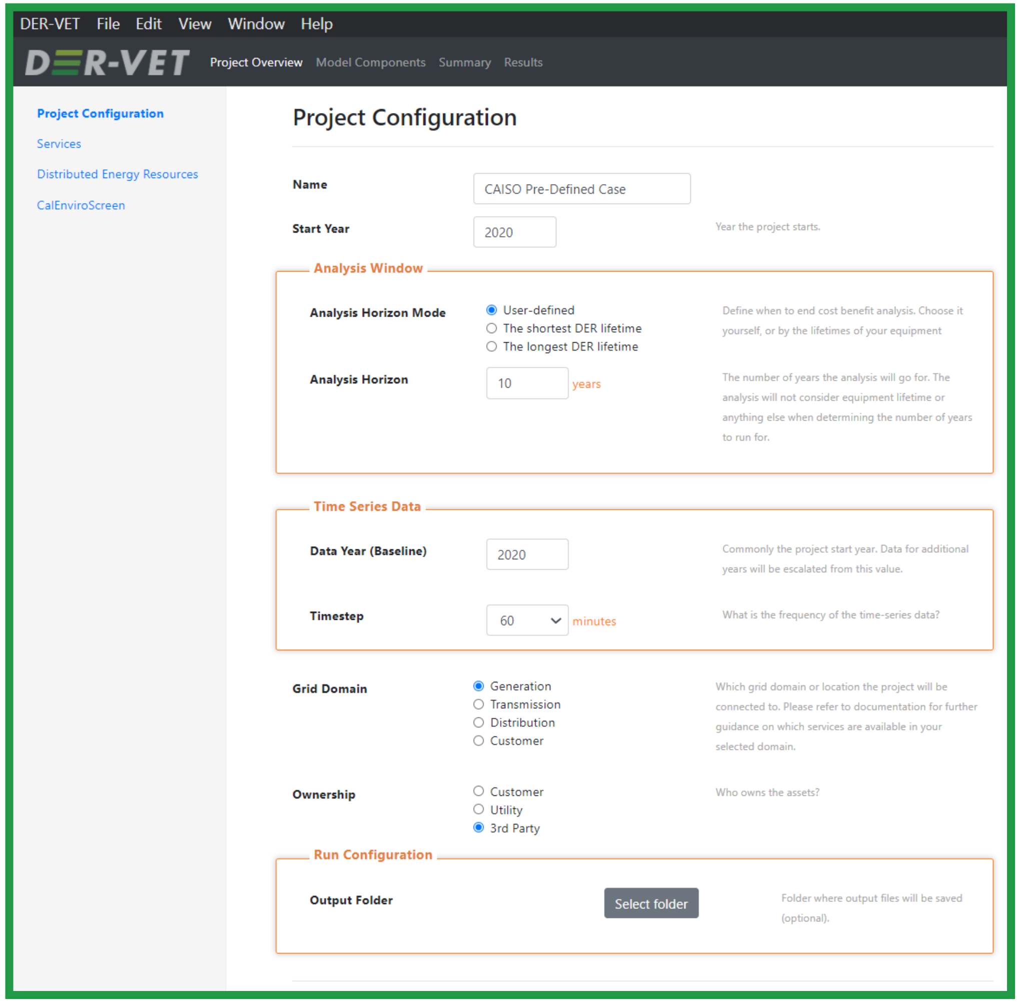
- Energy Time Shift
- Load Following
- Frequency Regulation
- Spinning Reserves
- Non-spinning Reserves
- Resource Adequacy Capacity

- Upgrade Deferral
- Reliability/Resilience

- Retail Energy Time Shift
- Demand Charge Reduction
- Demand Response
- Reliability/Resilience

Input and Output Examples in DER-VET

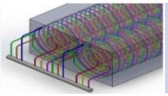
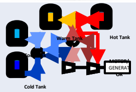
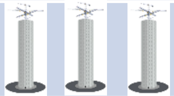
DER-VET Project Configuration Example



DER-VET Dispatch Results Example

Long Duration Energy Storage Case Study

Long Duration Energy Storage (LDES) DER-VET Analysis

Type	Technology	Acronym	TRL
	Concrete Thermal Energy Storage	CTES	4
	Electro-Thermal Energy Storage	ETES	3
	Gravitational Energy Storage	GES	6
	Liquid Air Energy Storage	LAES	6
	Lithium-Ion Battery Storage	Li-Ion	9

Base

- All technologies were run using the original pricing curves in each region for 4h for Li-Ion Benchmark as well as 6, 8, and 10h

Sensitivities

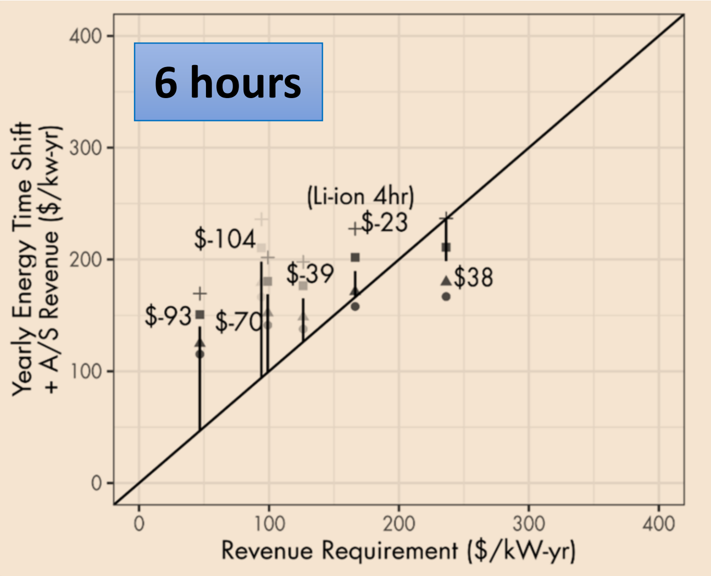
- Capital costs were adjusted +10% / -30%
- Energy prices were modified (mod) from their original (orig)
- RTE was adjusted +/- 5% points

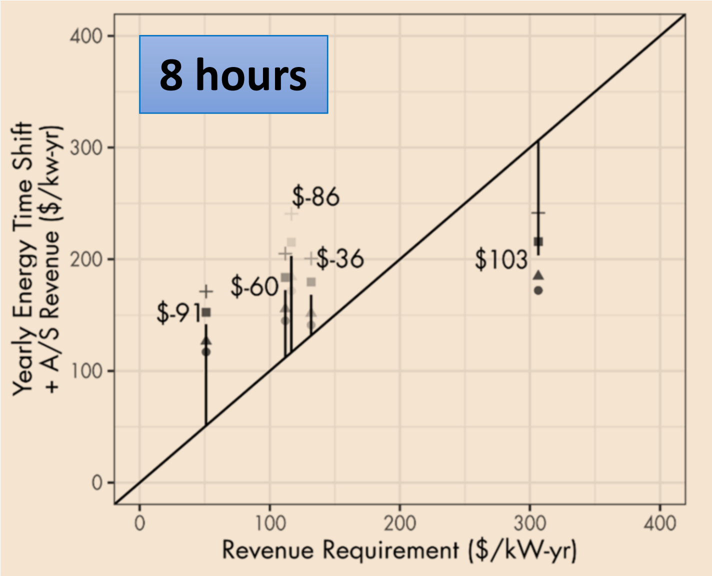
Pricing	Orig	Orig	Orig	Orig	Orig	Orig	Orig	Orig	Orig
RTE	Base	Base	Base	High	High	High	Low	Low	Low
Costs	Base	High	Low	Base	High	Low	Base	High	Low

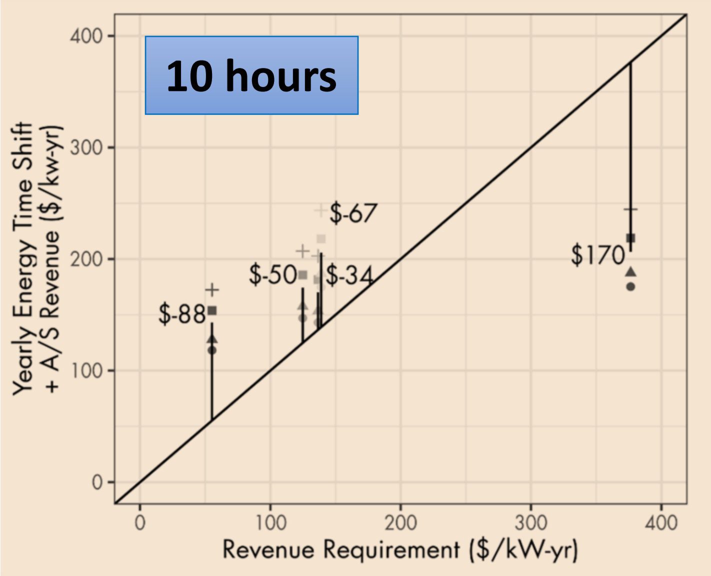
Pricing	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod
RTE	Base	Base	Base	High	High	High	Low	Low	Base
Costs	Base	High	Low	Base	High	Low	Base	High	Base

Significant number of DER-VET cases: 1728 total

DER-VET Results: Tech Duration vs. Revenue Requirements







Duration, hours	LDES A	LDES B	LDES C	LDES D	Li-ion
4	---	---	---	---	-23
6	-93	-39	-104	-70	38
8	-91	-36	-86	-60	103
10	-88	-34	-67	-50	170

Technology cost forecast is a key driver for LDES analysis

Transmission Solar + Energy Storage Case Study

LADWP Energy Storage + Solar Project

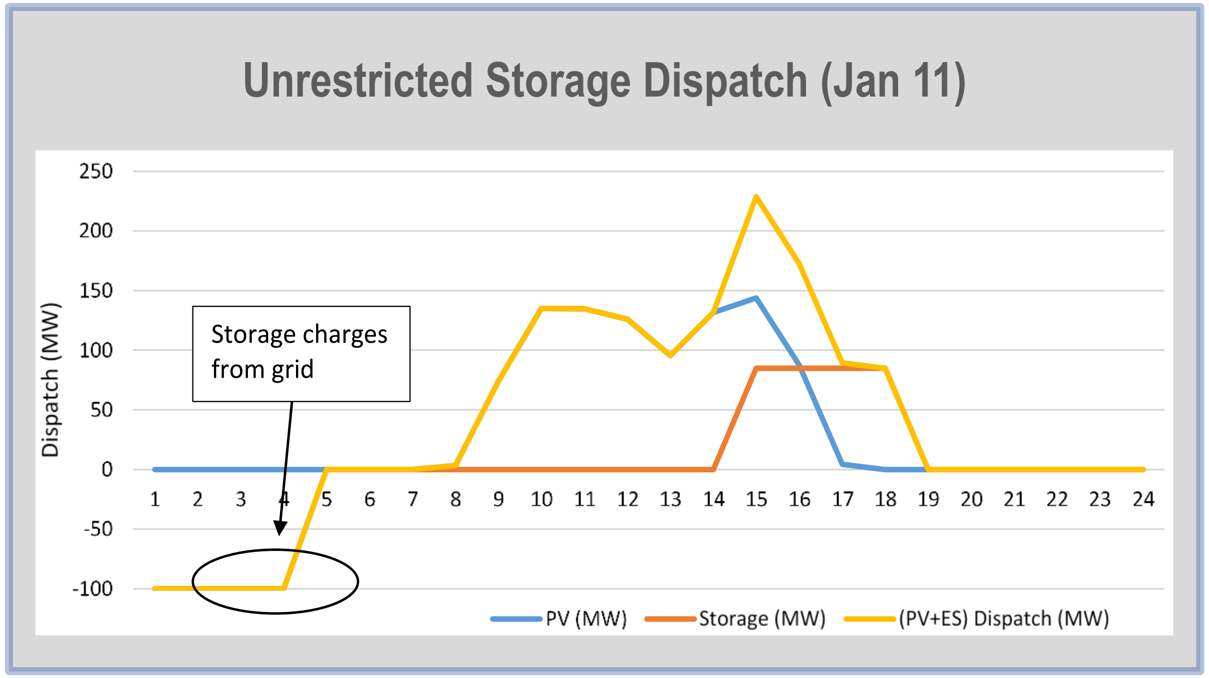
- Los Angeles Department of Water and Power (LADWP) required to study and procure energy storage
- 100 MW, 4-hour battery energy storage system
- 200 MW solar PV
- Power Purchase Agreement (PPA) able to claim Federal Investment Tax Credit (FITC) incentive

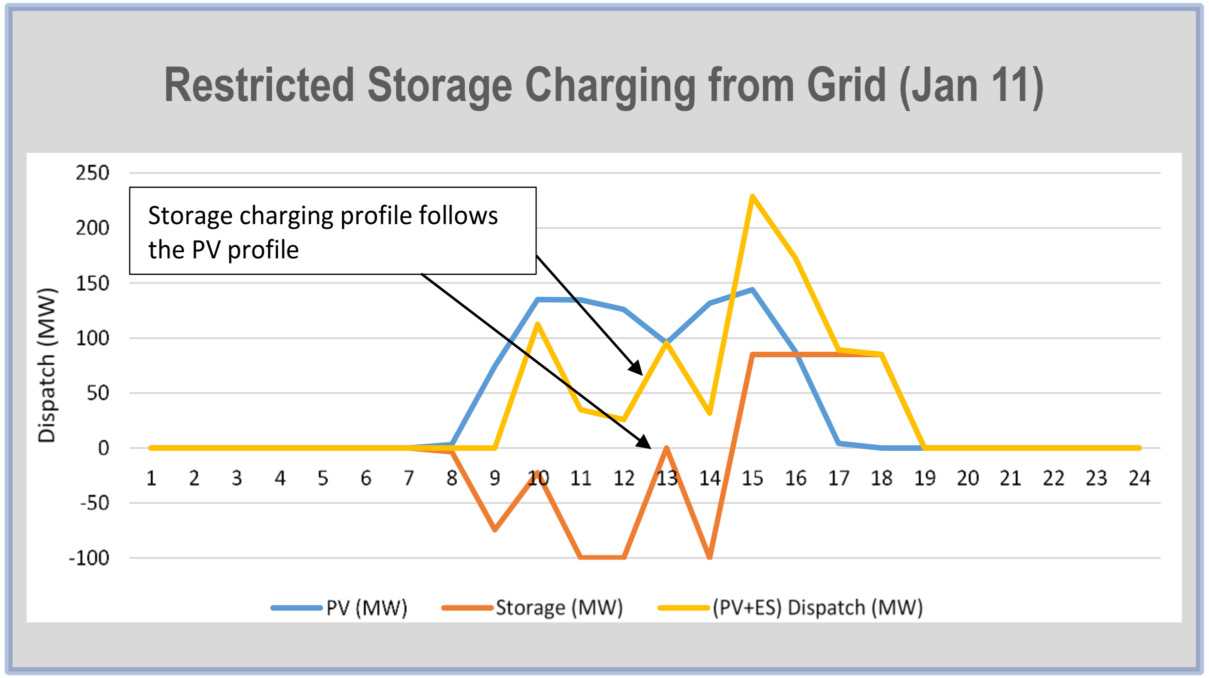
	Provide Energy Time Shift and Spinning Reserve	Restrict Charging from Grid	Restrict Charging from Grid and Discharge Min	Provide Frequency Response
Case #1	✓		✓	
Case #2	✓		✓	✓
Case #3	✓	✓		
Case #4	✓	✓		✓

LADWP Full Report: ***Integrating Energy Storage System with Photovoltaic Generation: Analysis within Los Angeles Department of Water and Power (LADWP) Service Territory to Meet SB801 Requirements*** **at http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002013007**

LADWP Case Results - Dispatch

- Impact of grid charging constraints:

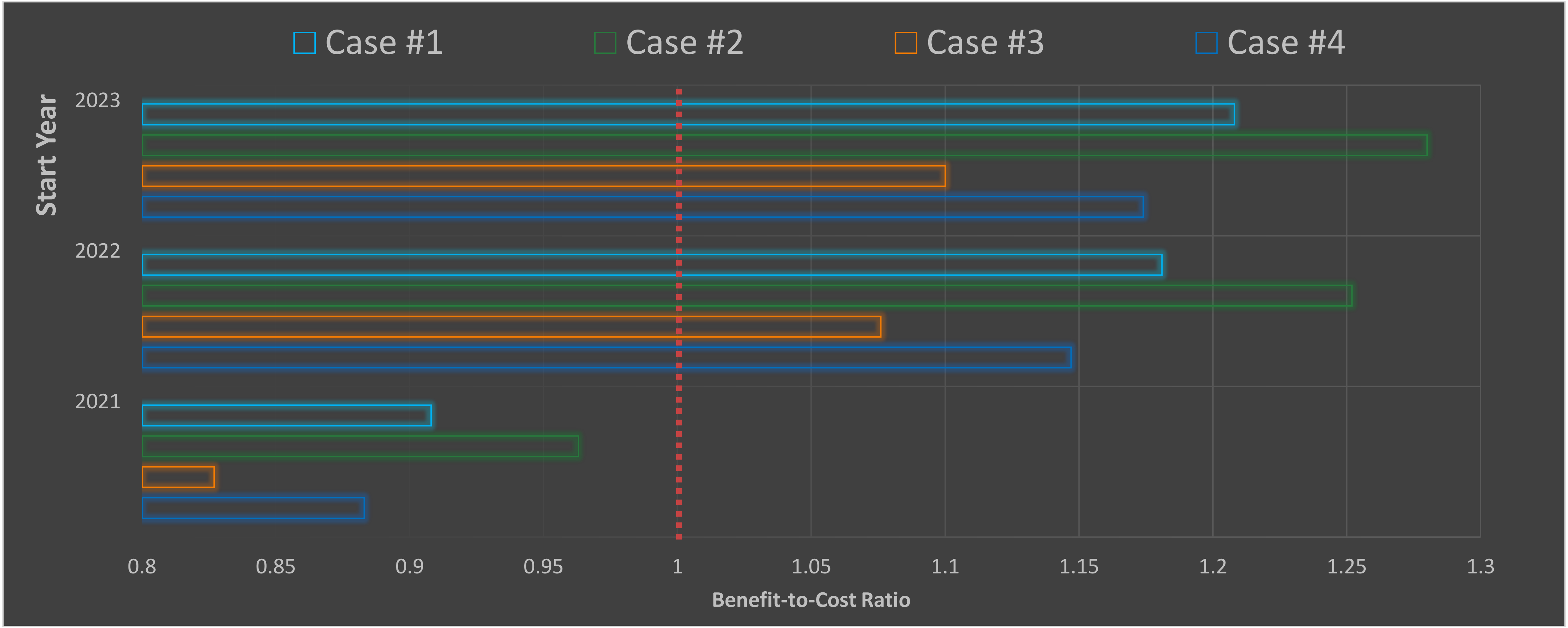




DER-VET Optimized Dispatch Outputs

LADWP Case Results - CBA

- Several cases resulted in benefit-cost ratios greater than one for project start years after 2022 as illustrated in the graph below



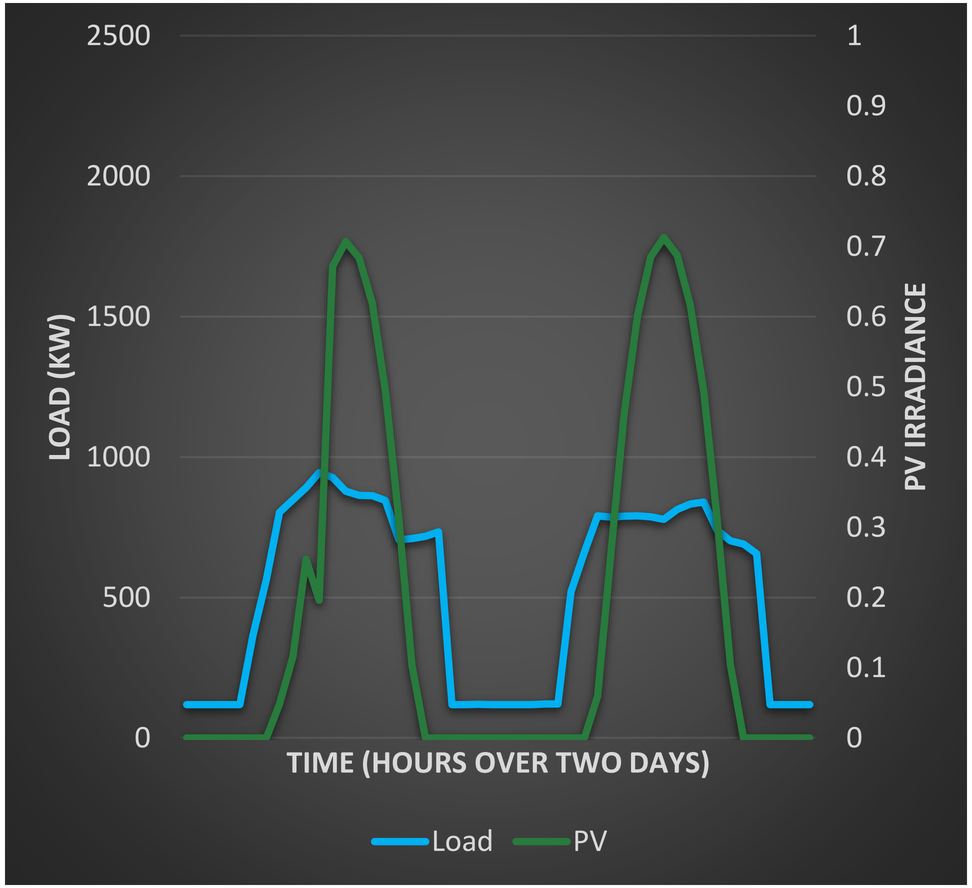
Microgrid Design for
California Public Service Power Shutoffs (PSPS) Events

Microgrid Design - DER-VET Modeling Assumptions

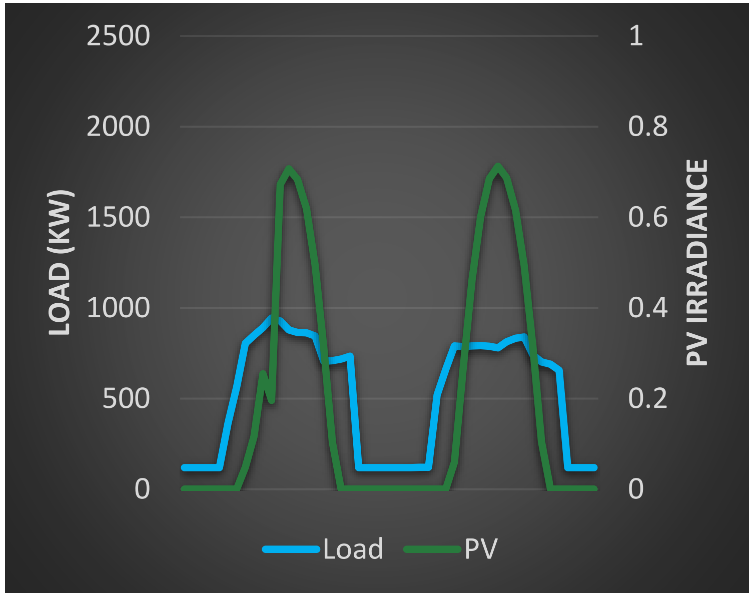
- Identify potential Public Safety Power Shutoff (PSPS) planned events and duration in California

- Solar PV plus battery energy storage microgrid technologies

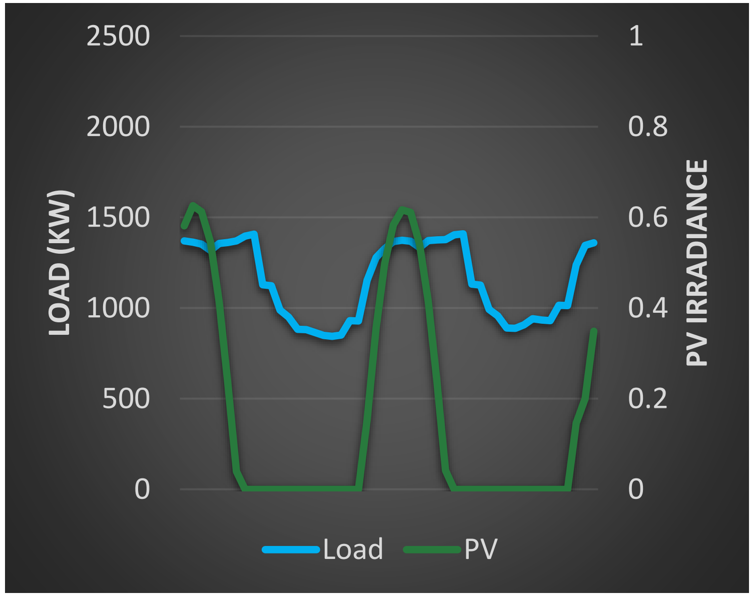
- Initial storage state of charge at the start of outage event is 100% with advanced PSPS notifications



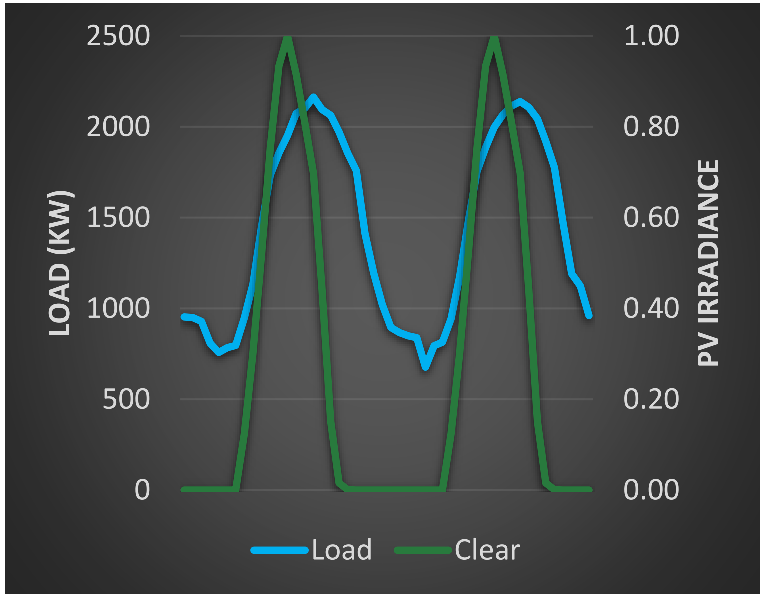
Load and PV Profile



Peak load – 0.9 MW
24hr load requirement – 13MWh
36hr load requirement – 18MWh
48hr load requirement – 25MWh



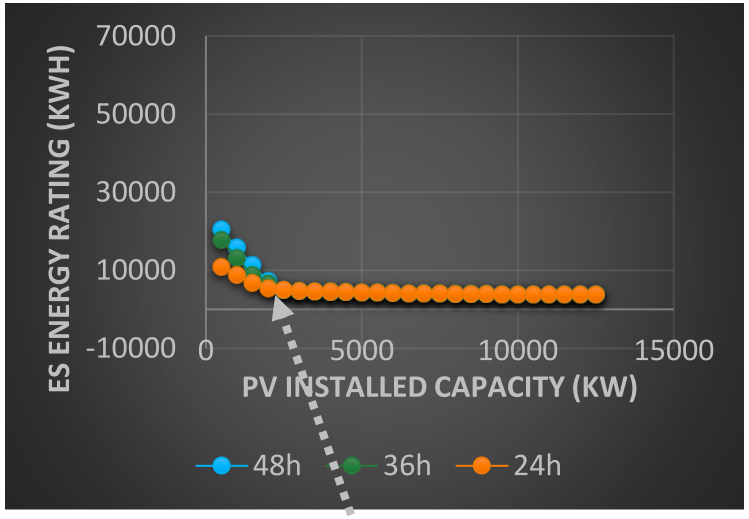
Peak load – 1.4 MW
24hr load requirement – 28MWh
36hr load requirement – 43MWh
48hr load requirement – 55MWh



Peak load – 2.16 MW
24hr load requirement – 35MWh
36hr load requirement – 48MWh
48hr load requirement – 76MWh

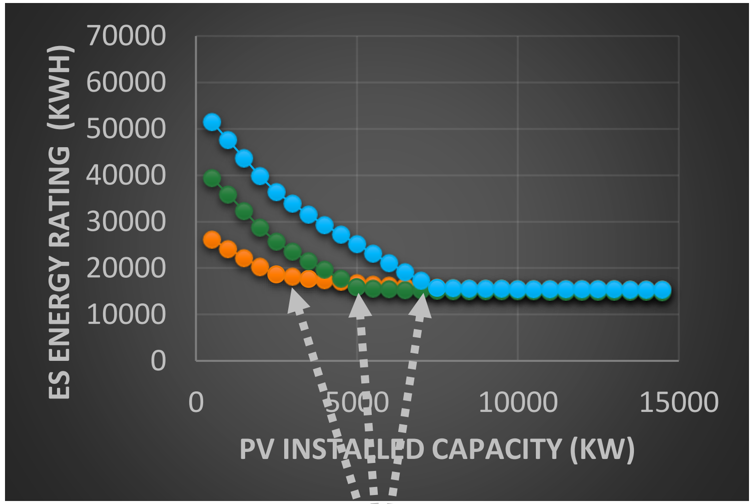
Microgrid Sizing Results

LA – Sec School



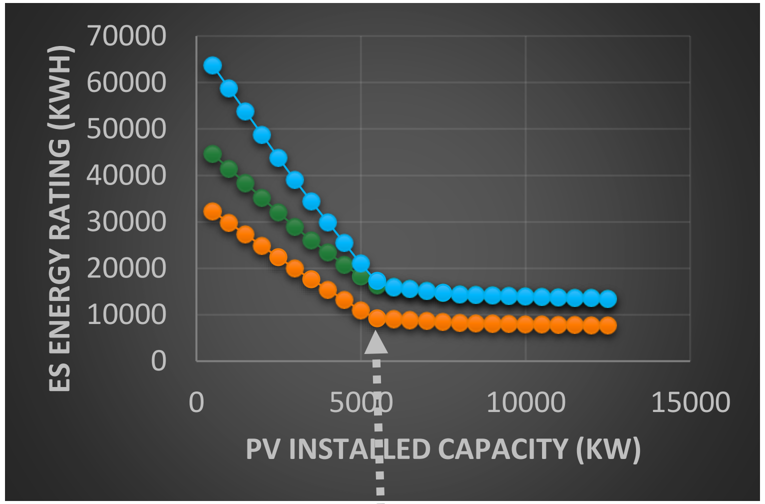
2.5MW PV +
0.735MW/4.9MWh ES

LA - Hospital



24h – 3.5MW PV+1.4MW/17MWh ES
36h – 5MW PV+1.6MW/15MWh ES
48h – 7.5MW PV+3MW/15MWh ES

SCE Feeder

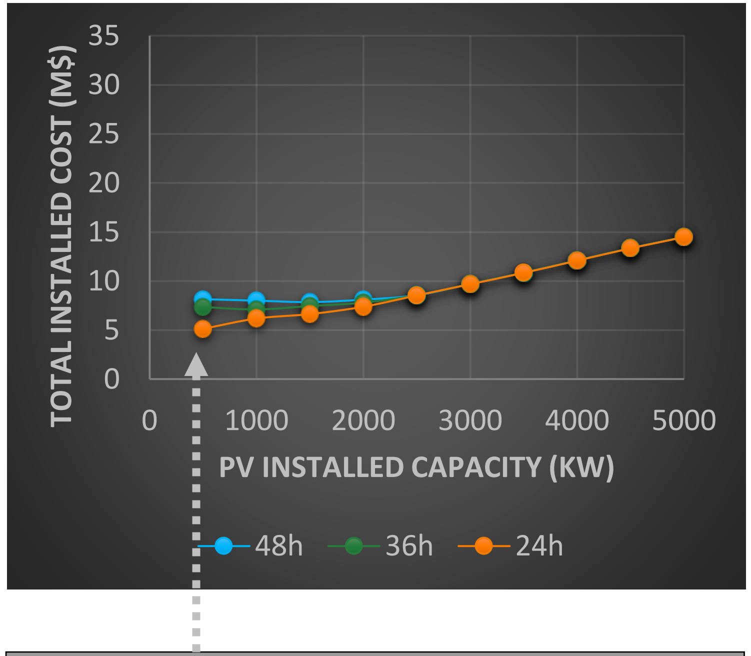


24h – 5.5MW PV+1.9MW/9.2MWh ES
36h– 5.5MW PV+1.9MW/17.2MWh ES
48h – 5.5MWPV +2 MW/17.2MWh ES

The energy storage and PV size corresponding to the knee point. Knee-point is a point where adding more PV does not affect the size of energy storage significantly.

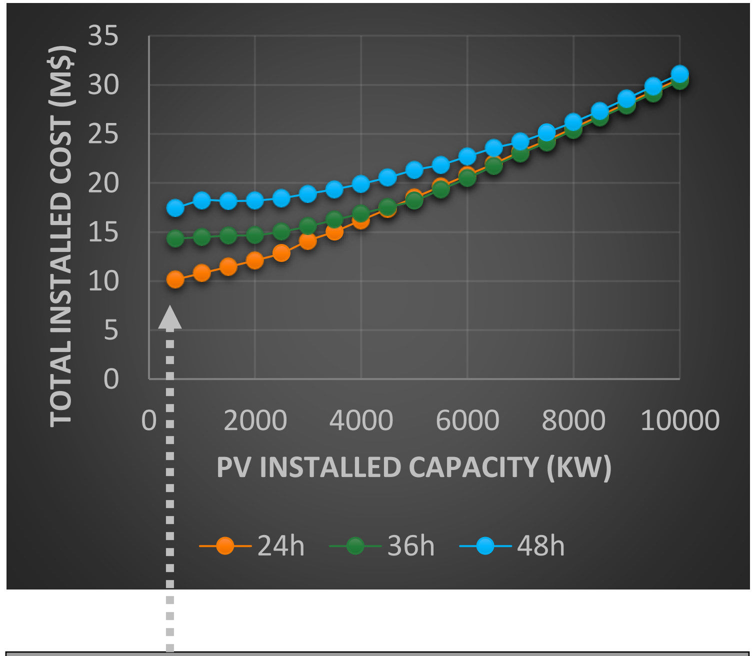
Microgrid Cost Summary

LA – Sec School



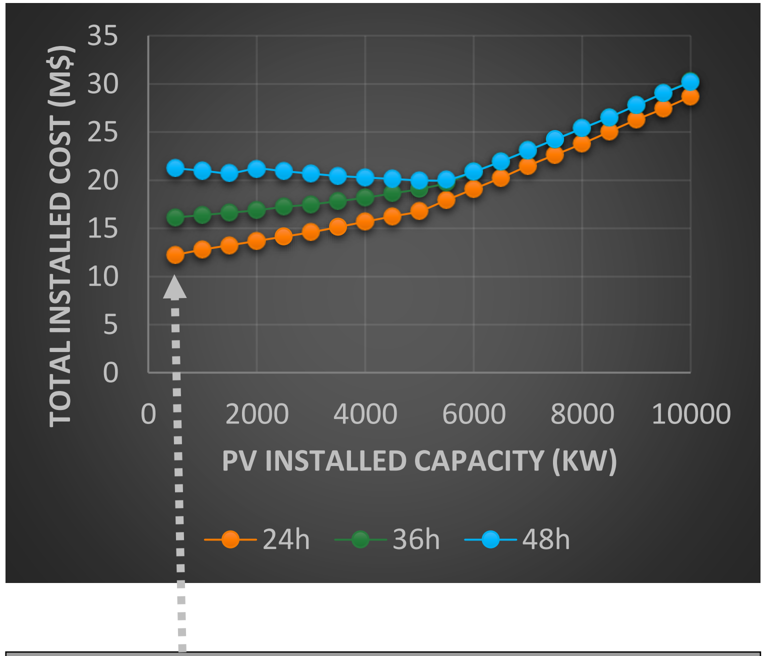
Min Cost of covering 24, 36, and 48hr outage – **$5M, $7M, and $8M**

LA - Hospital



Min Cost of covering 24, 36, and 48hr outage – $**10M, $14M, and $18M**

SCE Feeder

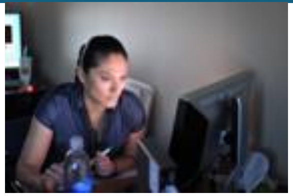
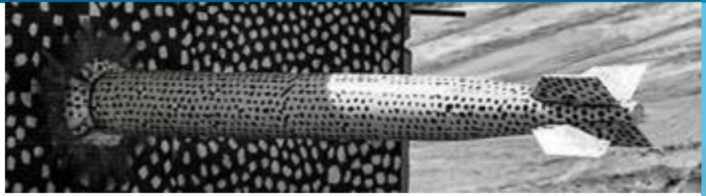


Min Cost of covering 24, 36, and 48hr outage – $**12M, $16M, and $22M**

Together…Shaping the Future of Energy®

Sandia National Laboratories

QuESt: Evaluation of Energy Storage

PRESENTED BY

Walker Olis

2023 DOE ENERGY STORAGE FINANCING SUMMIT

U.S. DEPARTMENT OF ENERGY NNSA

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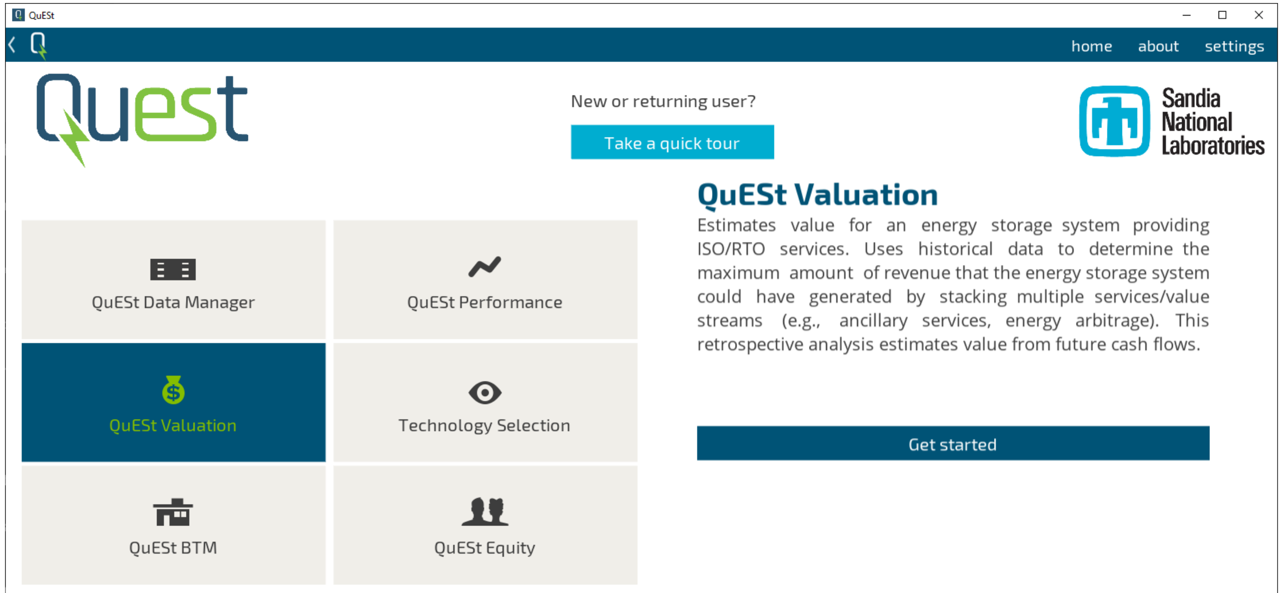
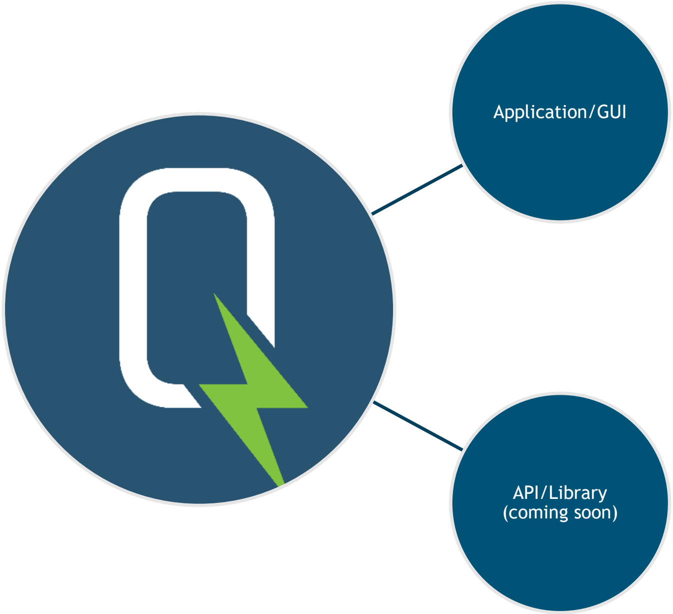
Techno-economic Analysis of Energy Storage

- Identify revenue streams: what are the possible services/applications that an ESS can provide?
- Select the right ES technology to provide those services.
- Evaluate the overall economic gain given the limits in performance of the selected storage technology.
- Optimally size ESS.

QuESt - Overview



Version 1.6 available on GitHub: https://github.com/snl-quest/snl-quest



- Developed for user experience
- No hassle installation

- For power users
- Use for Python scripting
- More capabilities

Decide what type of analysis to do.

- ISO/RTO value stacking => QuESt Valuation
- Behind-the-meter applications => QuESt BTM

Grab the appropriate data from QuESt Data Manager.

- ISO/RTO market data
- Utility rate structure
- PV profile
- Load profile

Select the appropriate application from the first step.

- Set up the analysis and run it
- View and process results

Current (v1.6):

- QuESt Data Manager
- QuESt Valuation
- QuESt BTM
- QuESt Tech Selection
- QuESt Performance

Alpha Release:

- QuESt Equity

Energy Storage Technology Selection

Goal: given a set of user selections, perform an initial screening to identify and rank feasible energy storage technologies for a given project.

ES technologies currently in the database:

- Pumped hydro storage (PHS)
- Compressed air energy storage (CAES)
- Sodium (Na)
- Zinc (Zn)
- Flywheel – Long duration (FWLD)
- Flywheel – Short duration (FWSD)
- Flow battery – Vanadium (FBV)
- Flow battery – Iron (FBFe)
- Flow battery – Zinc bromide (FBZnBr)
- Nickel (Ni)
- Lithium-ion – Energy (LiE)
- Lithium-ion – Power (LiP)
- Lead (Pb)
- Lead carbon (PbC)

User inputs:
- Grid location
- Application(s)
- System size (power)
- Discharge duration

ES technologies database
- discharge duration
- round-trip efficiency
- cycle life
- depth of discharge
- response time to full power
- cost
- maturity level
- …

Applications database
- minimum discharge duration
- minimum response time
- power vs. energy application
- deployment location restrictions
- …

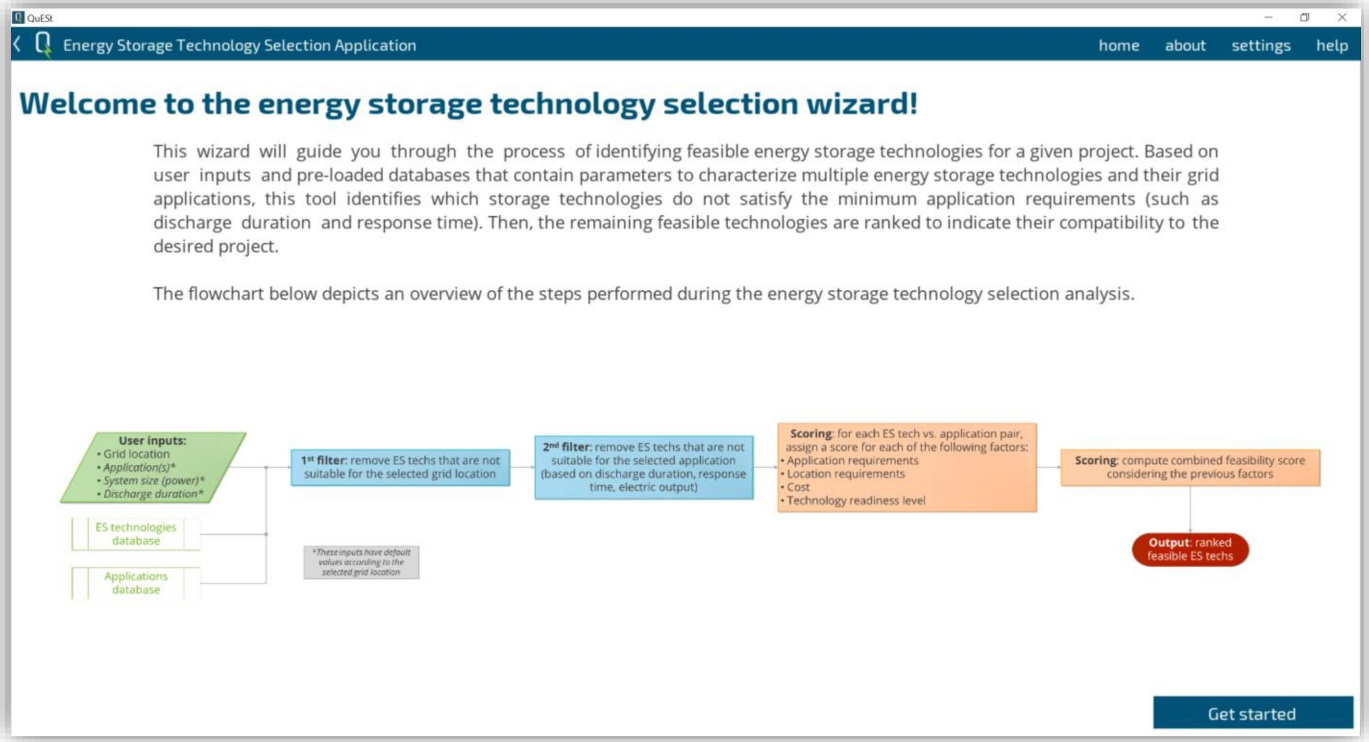
Filter out ES techs that are not suitable for the selected grid location and/or do not meet the minimum application requirements (discharge duration, response time, electric output)

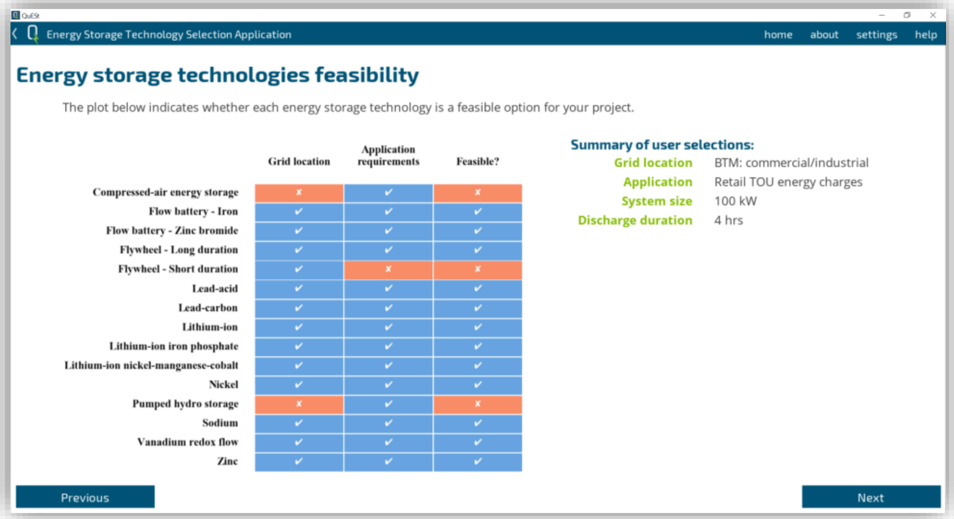
Score each feasible ES tech based on the following factors:
- Application requirements
- Location requirements
- Cost
- Technology readiness level

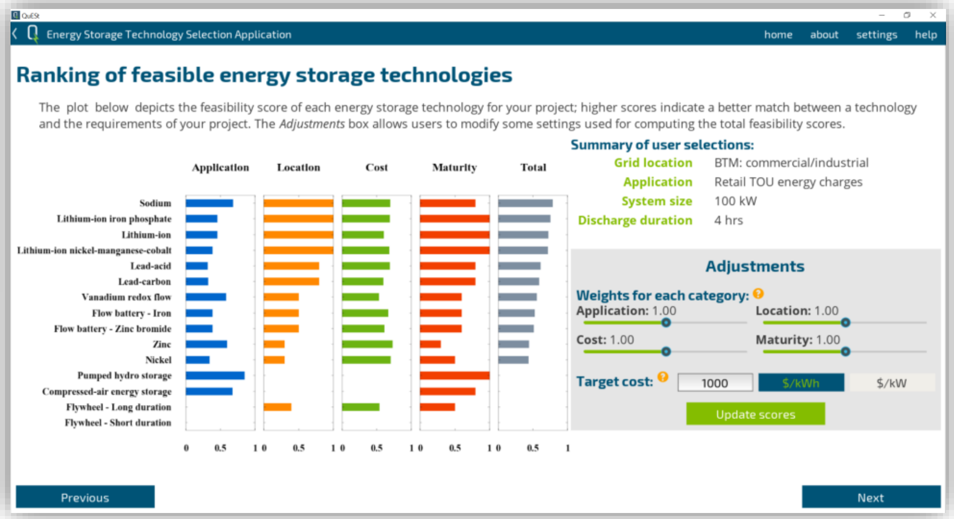
Output: ranked feasible ES techs

The final score for each ES tech is given as the weighted geometric mean of the four individual scores, so that the user can assign higher weights to the factors that they consider more relevant to the intended applications.

QuESt – Technology Selection







Energy Storage Valuation – Market Problem

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?

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

subject to:

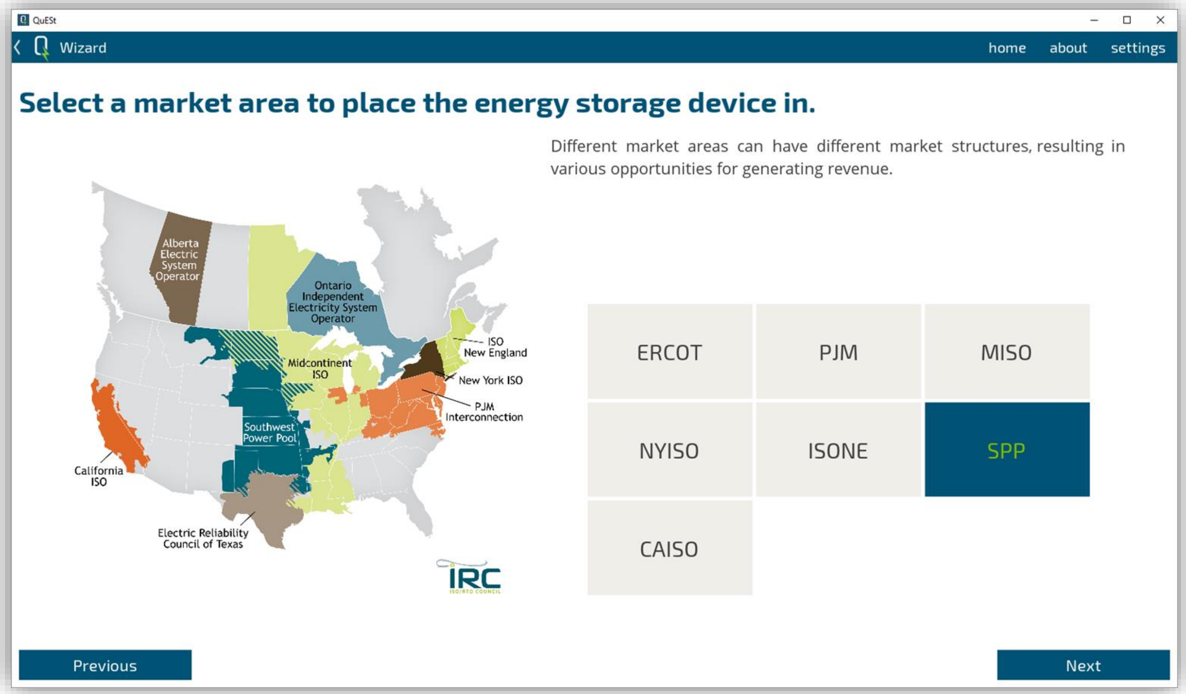
$$s_{i+1} = \eta_s s_i + \eta_c q_i^r - q_i^d + \eta_c \delta_i^{rd} q_i^{rd} - \delta_i^{ru} q_i^{ru}$$ state of charge definition

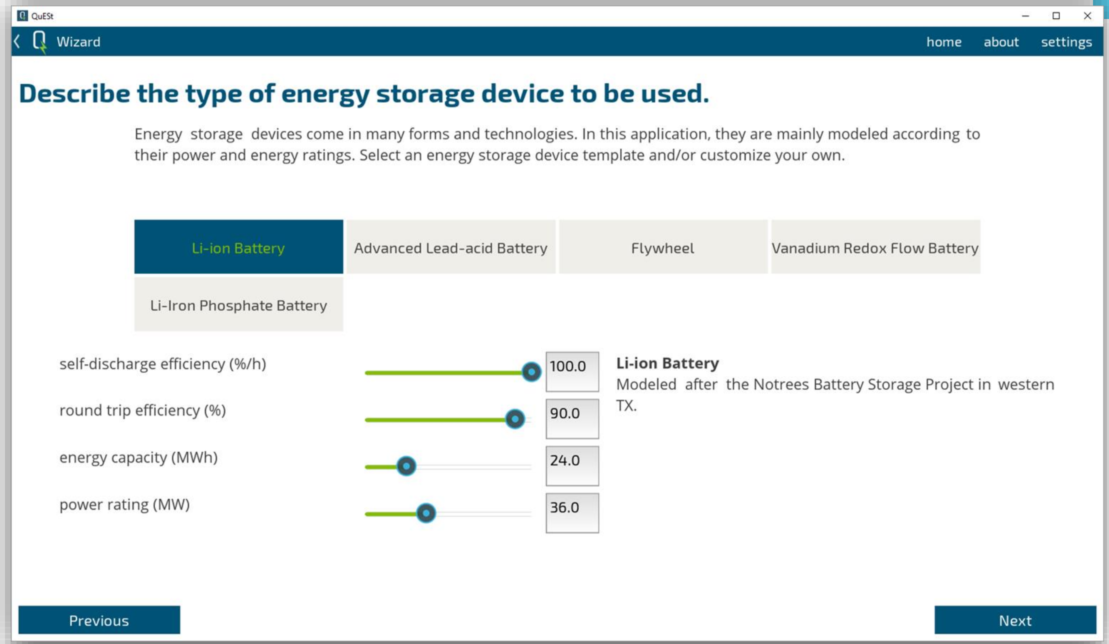
$$0 \le s_i \le \bar{S}$$ state of charge limits

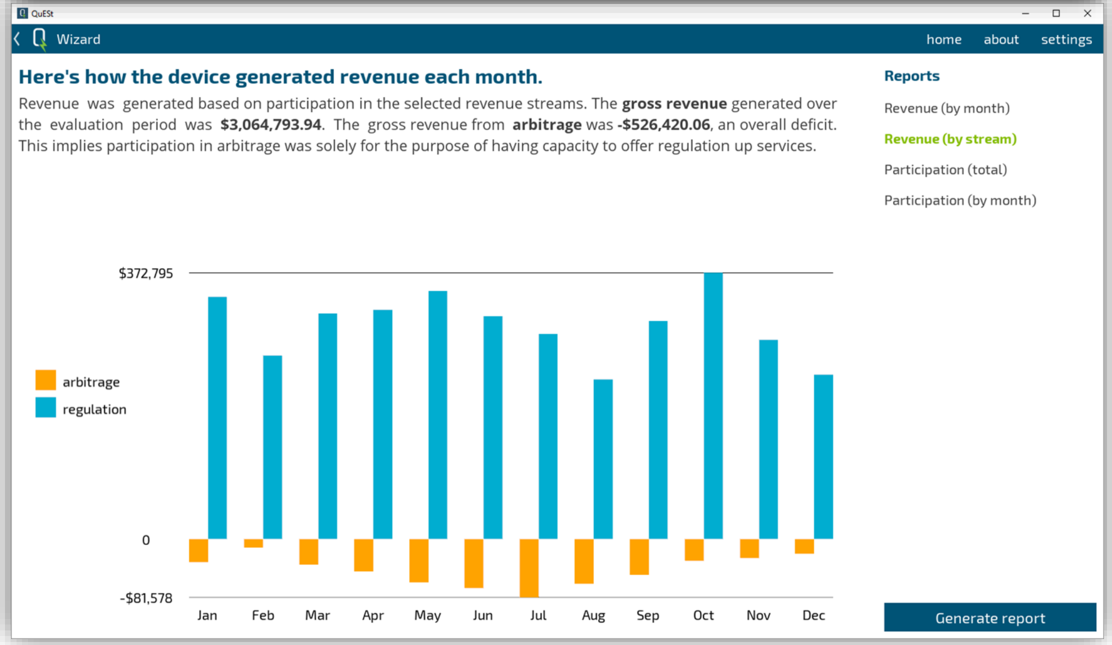
$$q_i^d + q_i^r + q_i^{ru} + q_i^{rd} \le \bar{Q}$$ power/energy charged limits

- Other constraints, such as requiring the final SoC to equal the initial SoC or reserving energy capacity for resiliency applications can be set.
- Varies based on market and available value streams

QuESt – Valuation Application







Energy Storage Valuation – BTM Problem

Given an energy storage device, a utility tariff structure, how would the device minimize the electricity bills for the customers?

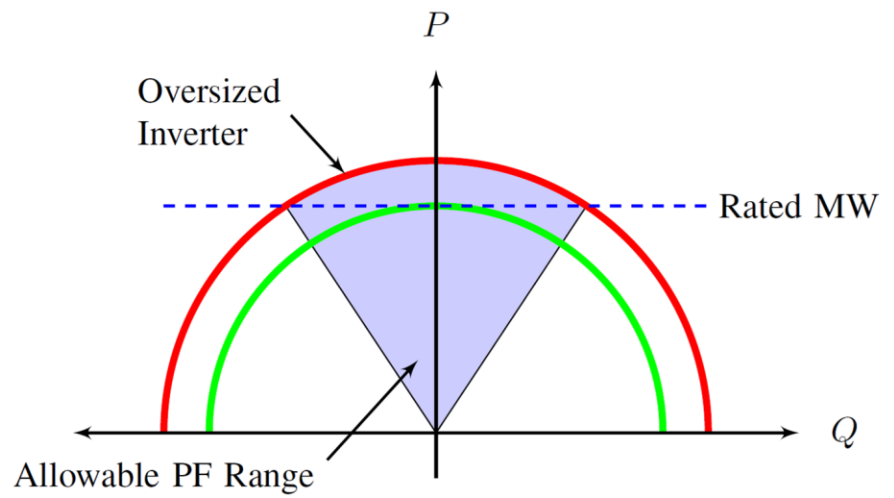
$$\min\{C_E^m + C_N^m + C_D^m\}$$

s.t. energy storage and inverter constraints

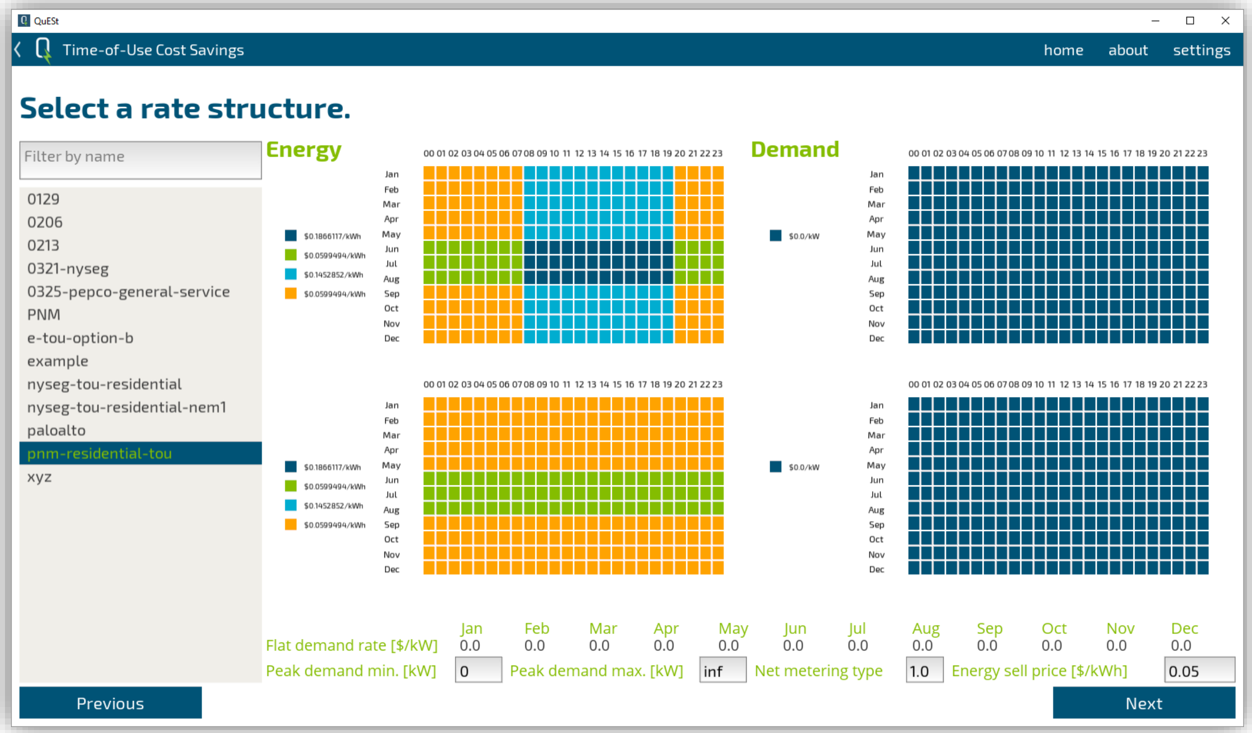
C_E^m is the energy charge of period m

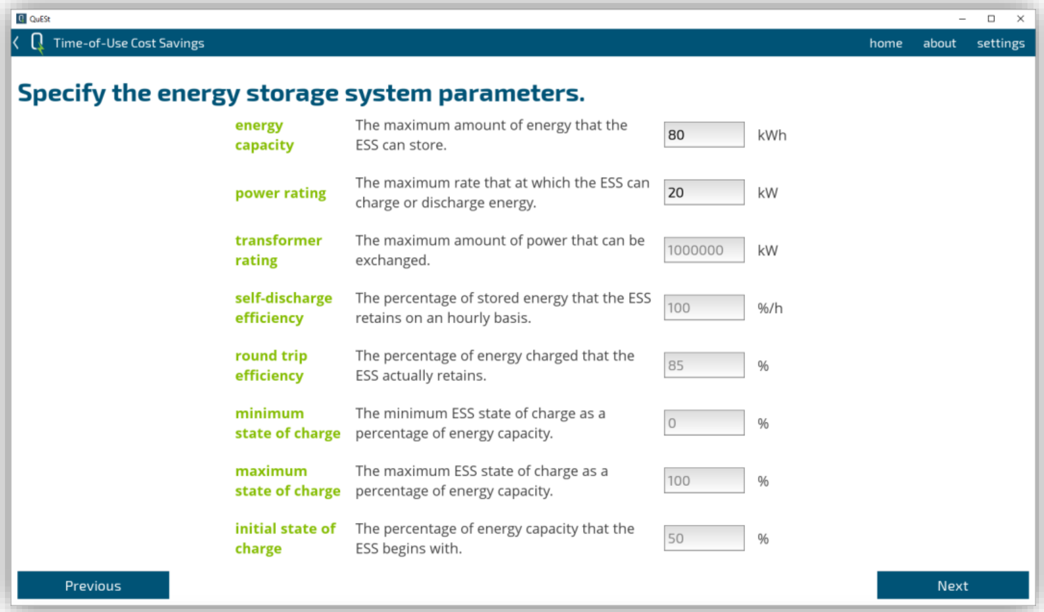
C_D^m is the demand charge of period m

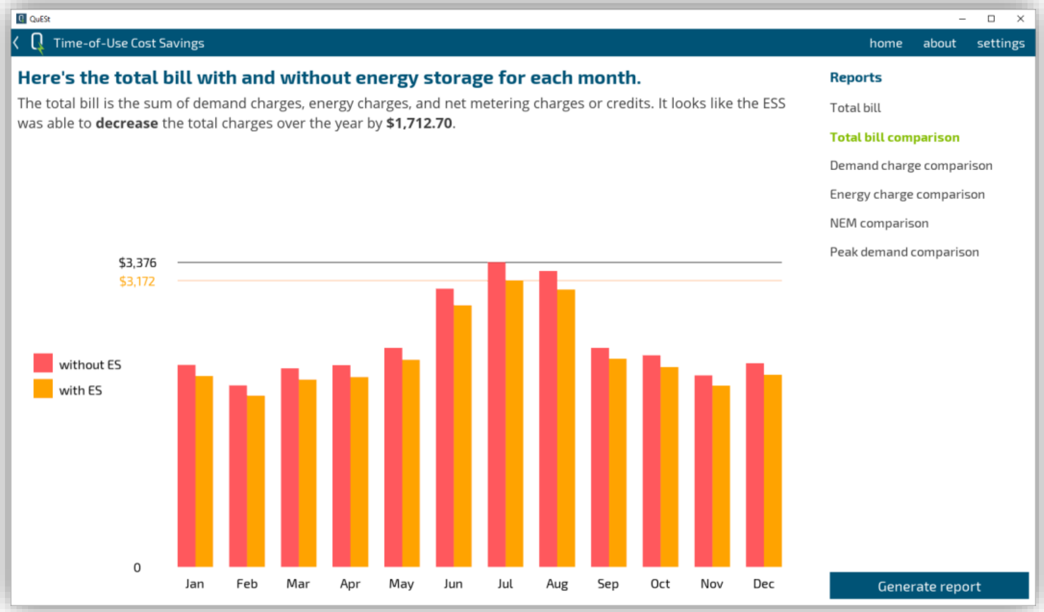
C_N^m (≤ 0) is the net metering charge of period m.



QuESt – BTM Application







QuESt Equity

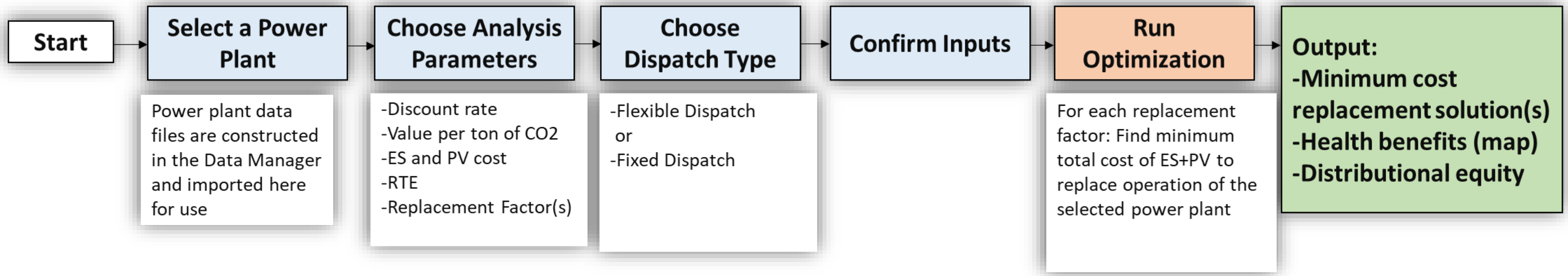
Given a Peaker loading profile, what are the optimal sizes of PV and storage for 1-to-1 replacement of that plant? What are the health and environmental benefits?

Inputs

- Powerplant Data File
- Battery and Analysis Parameters
- Dispatch Type Assumption

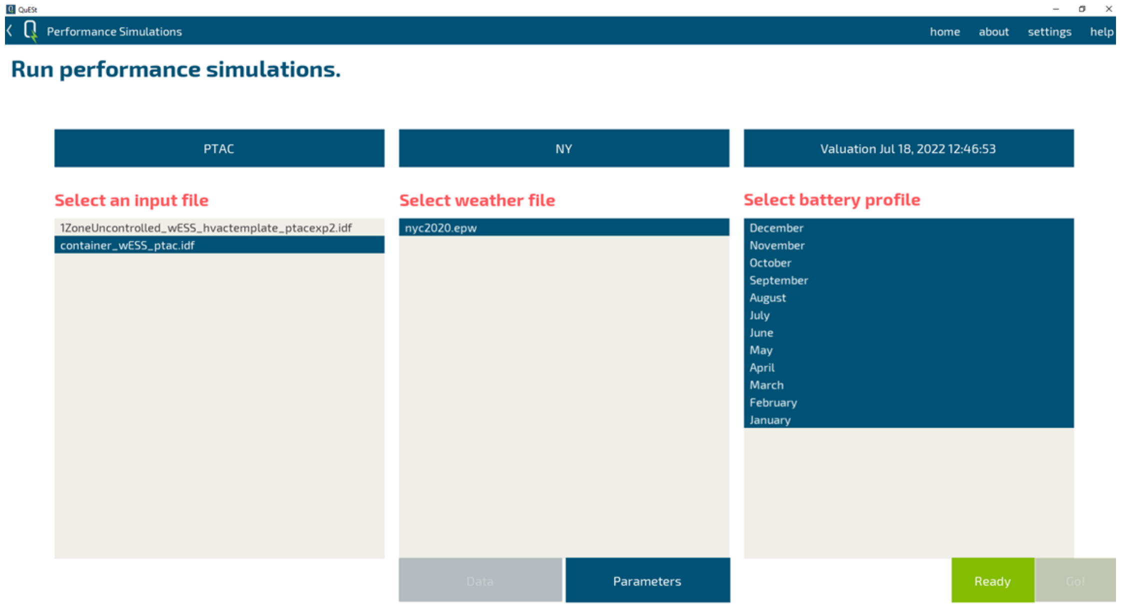
Outputs

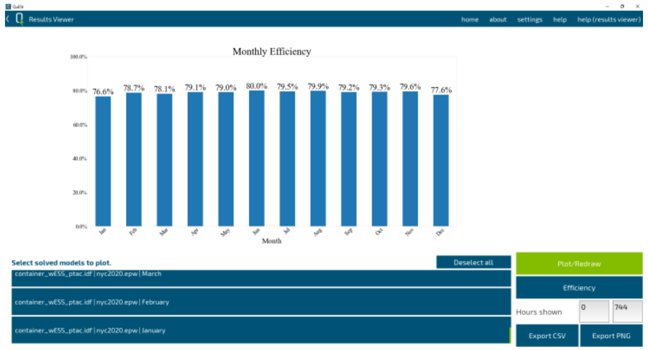
- Minimum capital cost solution(s)
- Health Benefits
- Distributional Impacts



QuESt Performance

Given a charge/discharge profile of a BESS, how much energy is needed to run the HVAC that maintain system temperature within its operating range? How does this affect expected performance and location?





Start
- E+ .idf
- Weather file
- Charge/discharge profile

Simulation parameters
- Battery parameters
- HVAC setpoints
- Insulation

Run simulation
- E+

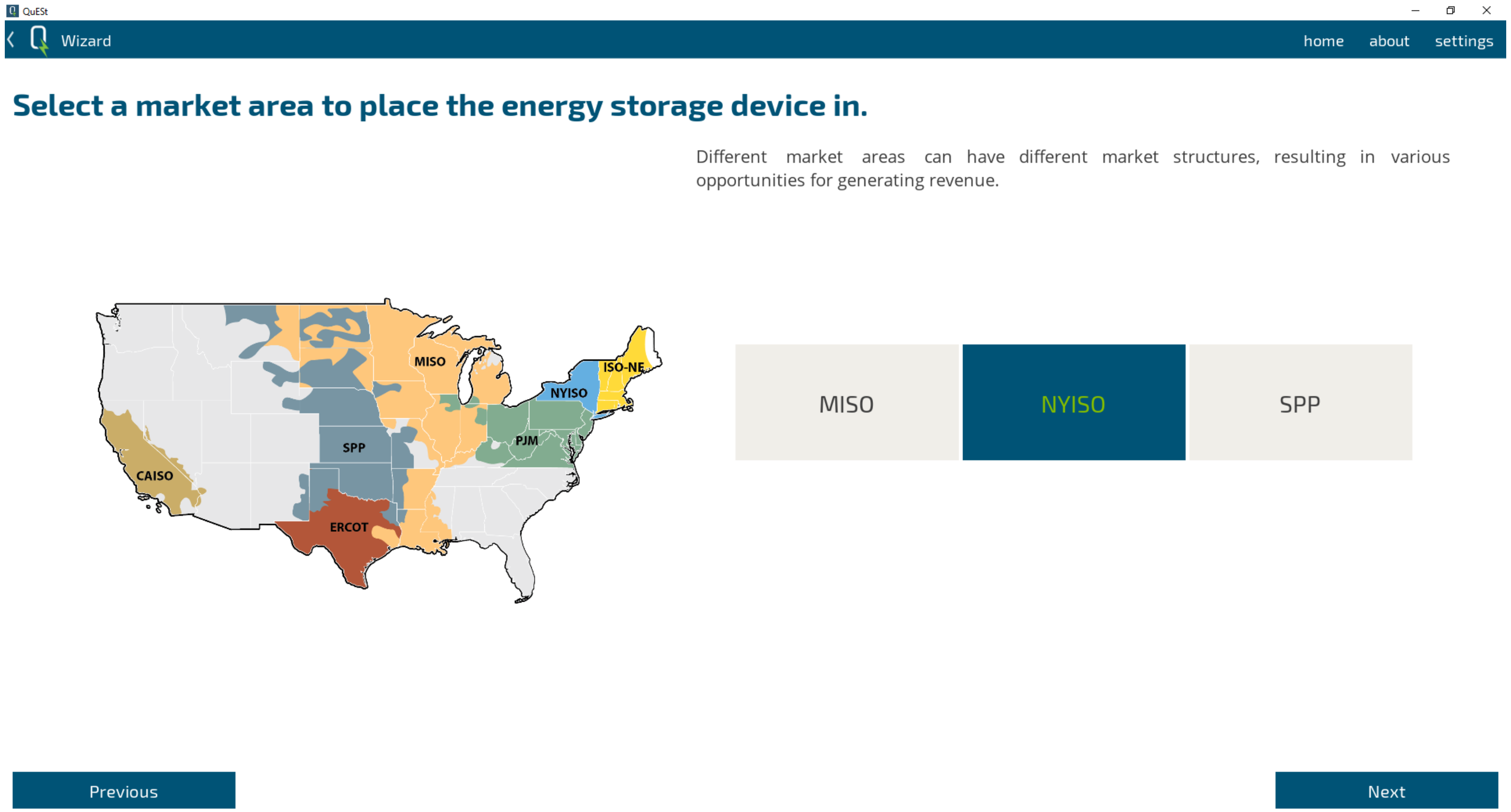
Outputs
- HVAC consumption
- Battery consumption
- System Efficiency

Example – QuESt Valuation and QuESt Performance

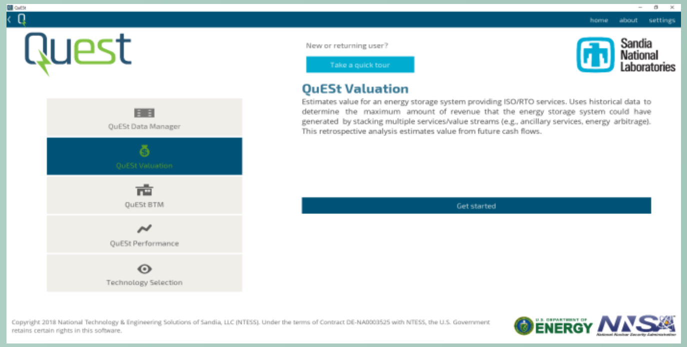
Example: 1MW, 1MWh Li-ion BESS located in NYC

Prerequisites:

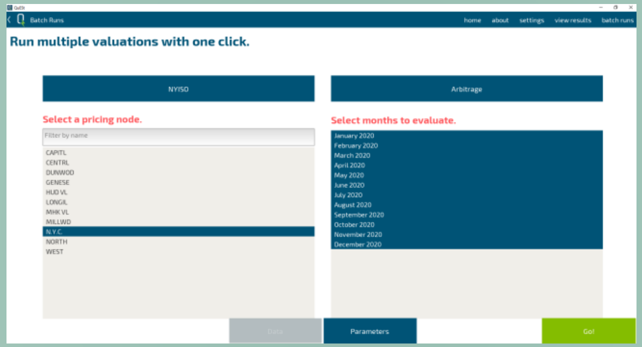
- NYISO NYC zone prices
- NYC weather data
- E+



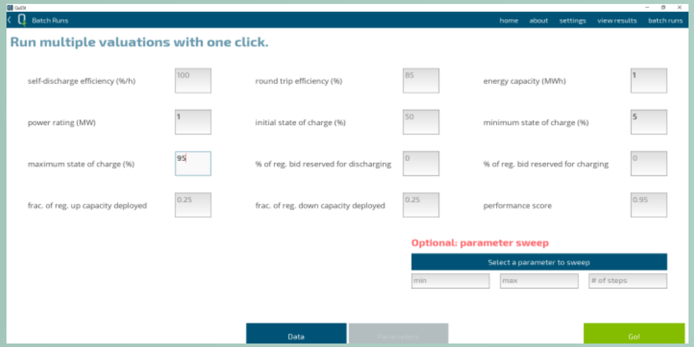
Example – QuESt Valuation and QuESt Performance



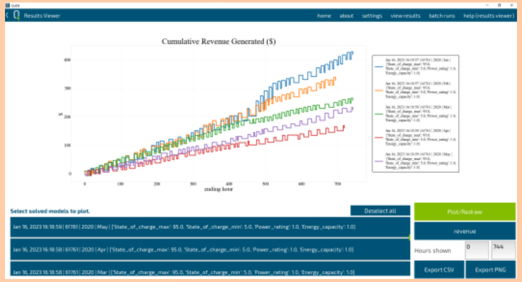
- Navigate to the QuESt Valuation tool.

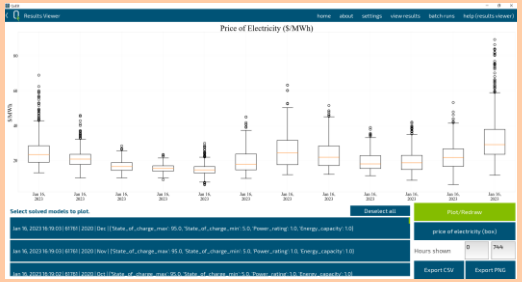


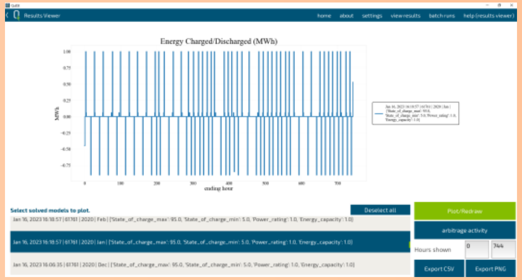
- Click on the Batch Runs Button -> select NYISO from the pull down options -> select N.Y.C. from the node options -> select arbitrage from the pull down options -> select all months of the year.

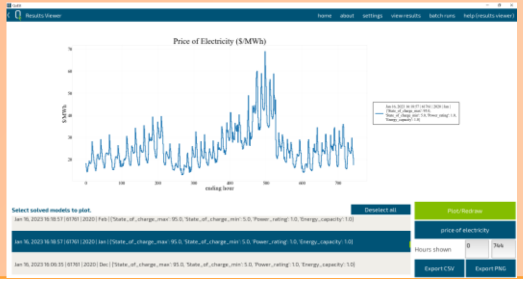


- Click the Parameters tab. Change the energy capacity to 1 MWh and the power rating to 1 MW. Change the minimum state of charge to 5% and the maximum state of charge to 95%.
- Once everything looks correct, click Go! Once the simulations are finished, navigate back to the home page.

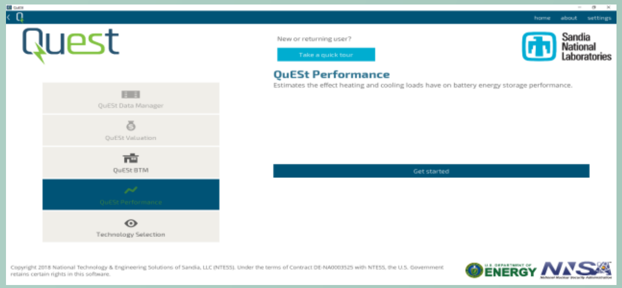




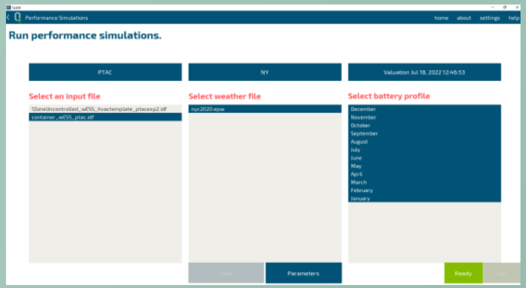




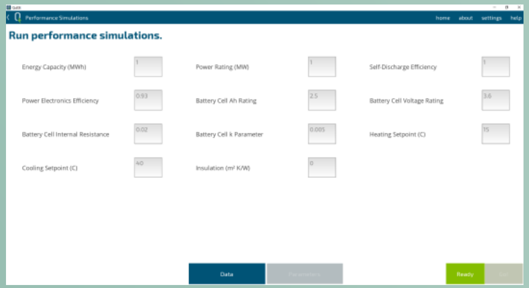
Example – QuESt Valuation and QuESt Performance



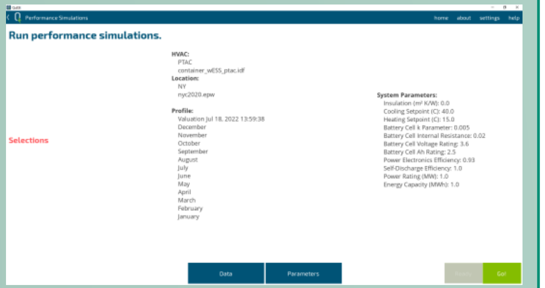
- Navigate to the QuESt Performance tool.



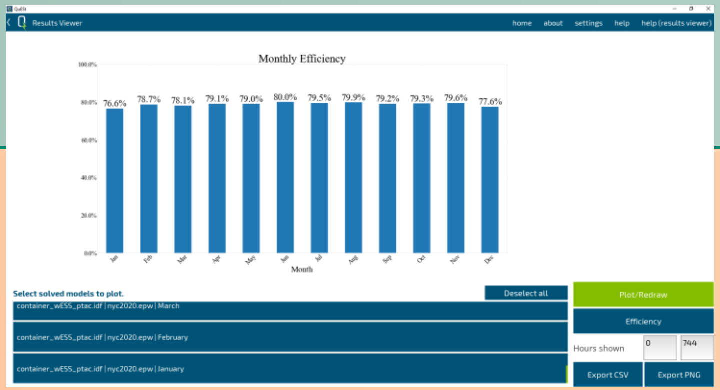
- Enter the Performance Simulations option. Select PTAC from the HVAC options. Select the provided input file describing a BESS in a shipping container. Select NY from the location dropdown. Select the weather file downloaded previously. Select the Valuation run from the Profile dropdown. Select the months available.

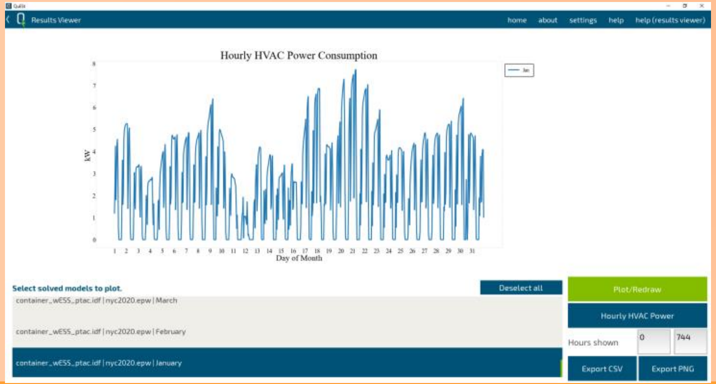


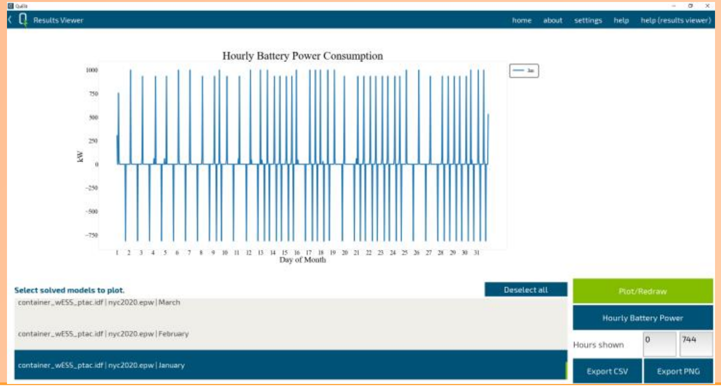
- Click the Parameters tab. Leave the default parameters as is, click the Ready Button.



- The selections made will be displayed. If everything looks correct, press Go!







Acknowledgements

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Thank You!

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Energy Storage Modeling and Valuation Tools

Dexin Wang, Senior Research Engineer

Pacific Northwest National Laboratory

DOE Energy Storage Financing Summit

January 26th, 2023

PNNL Has Assessed Energy Storage and Microgrid Systems at More Than 30 Sites

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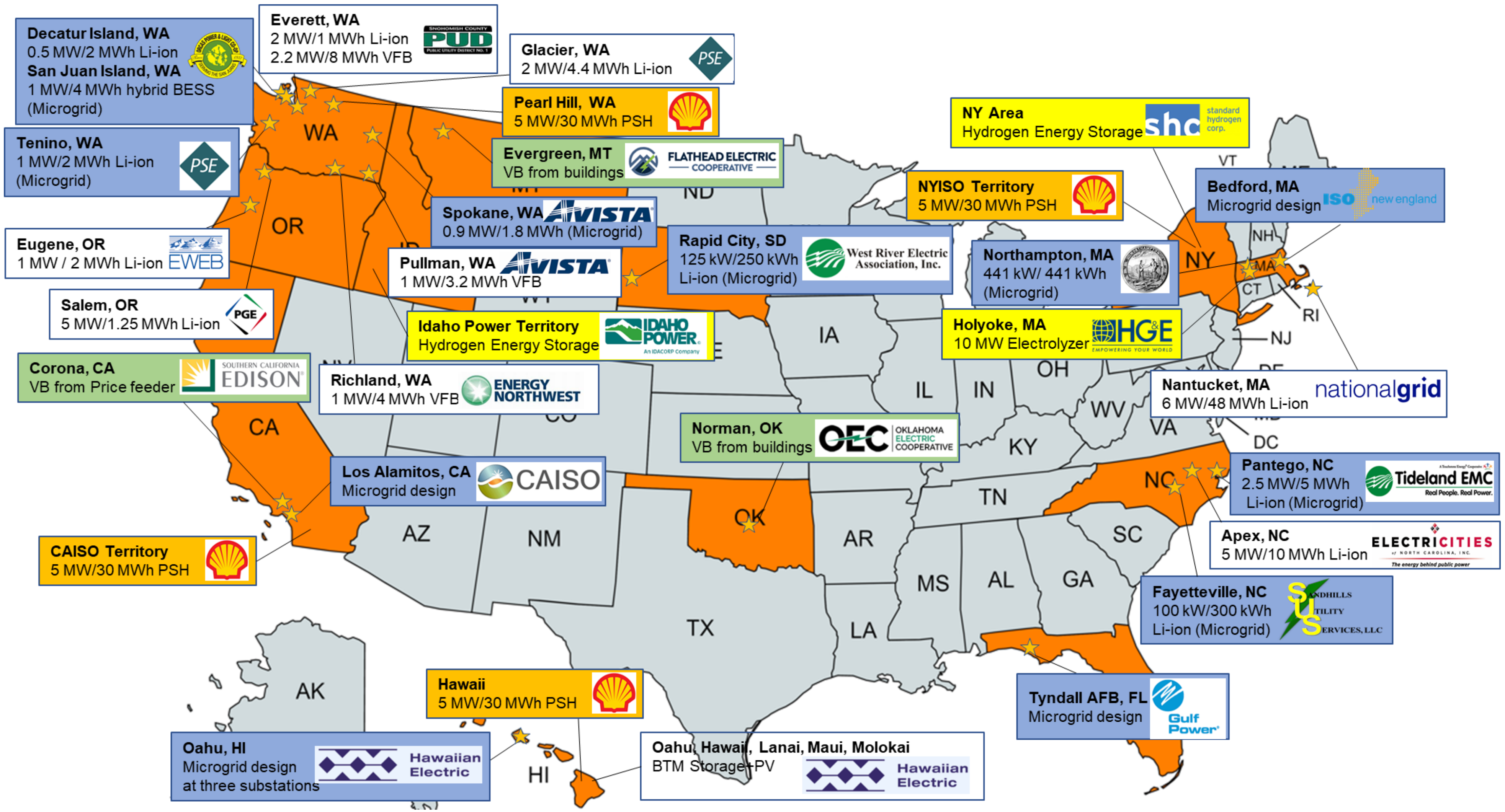


Battery Energy Storage | Microgrids | Hydrogen | Buildings as Storage | Pumped Storage Hydro

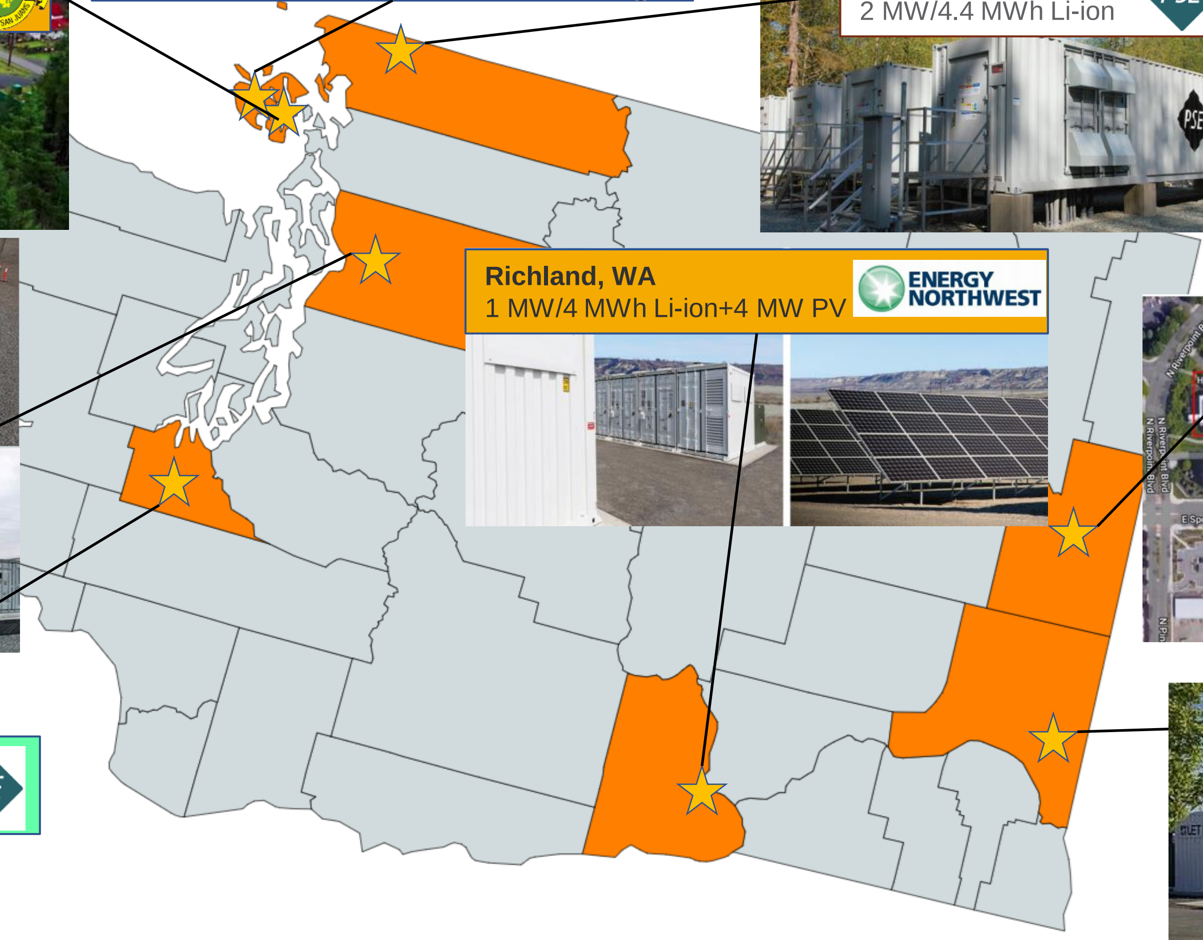
Clean Energy Fund Grid Demonstration Projects

Decatur Island, WA
0.5 MW/2 MWh Li-ion+0.5 MW PV

San Juan Island, WA (Microgrid)
1 MW/4 MWh hybrid BESS+3.2 MW PV

Glacier, WA
2 MW/4.4 MWh Li-ion

Everett, WA
2 MW/1 MWh Li-ion
2.2 MW/8 MWh VFB



Richland, WA
1 MW/4 MWh Li-ion+4 MW PV

Spokane, WA (Microgrid)
0.7 MW/1.8 MWh Li-ion+200 kW PV

Tenino, WA (Microgrid)
1 MW/2 MWh Li-ion+214 kW PV

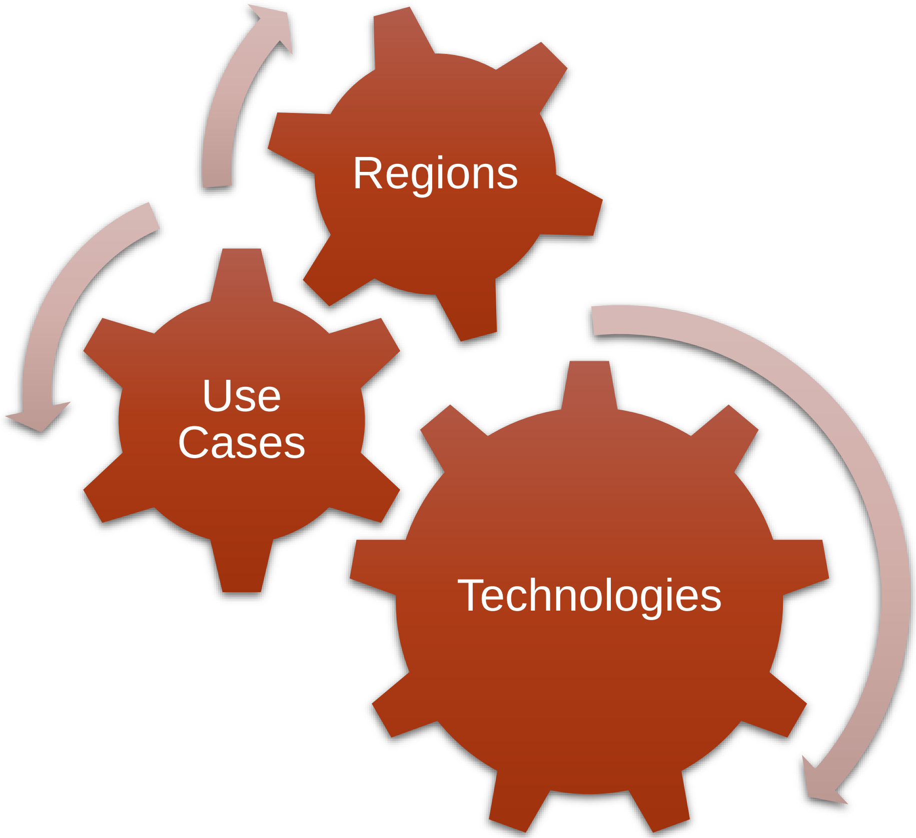
Pullman, WA
1 MW/3.2 MWh VFB

CEF I | CEF II | CEF III

Needs of Energy Storage Analytics

Numerous Factors Affect Storage Valuation

- ESS physical capability
  - Energy storage technology, design, and characteristics
- Use cases
  - Vertically integrated utilities, electricity markets, distribution utilities, and large C&I customers
  - Bulk energy, ancillary service, transmission-level, distribution-level, and end-user services
- Regions and systems
  - Different generation mix, grid infrastructure, market structures/rules, distribution system capacity, and load growth rate



ESET™ Overview

A suite of applications that enable utilities, regulators, vendors, and researchers to model, optimize, and evaluate various energy storage systems for stacked value streams

- Battery Storage Evaluation Tool (BSET)
- Microgrid Asset Sizing considering Cost and Resilience (MASCORE)
- Virtual Battery Assessment Tool (VBAT)
- Pumped-Storage Hydropower Evaluation Tool (PSHET)
- Hydrogen Energy Storage Evaluation Tool (HESET)

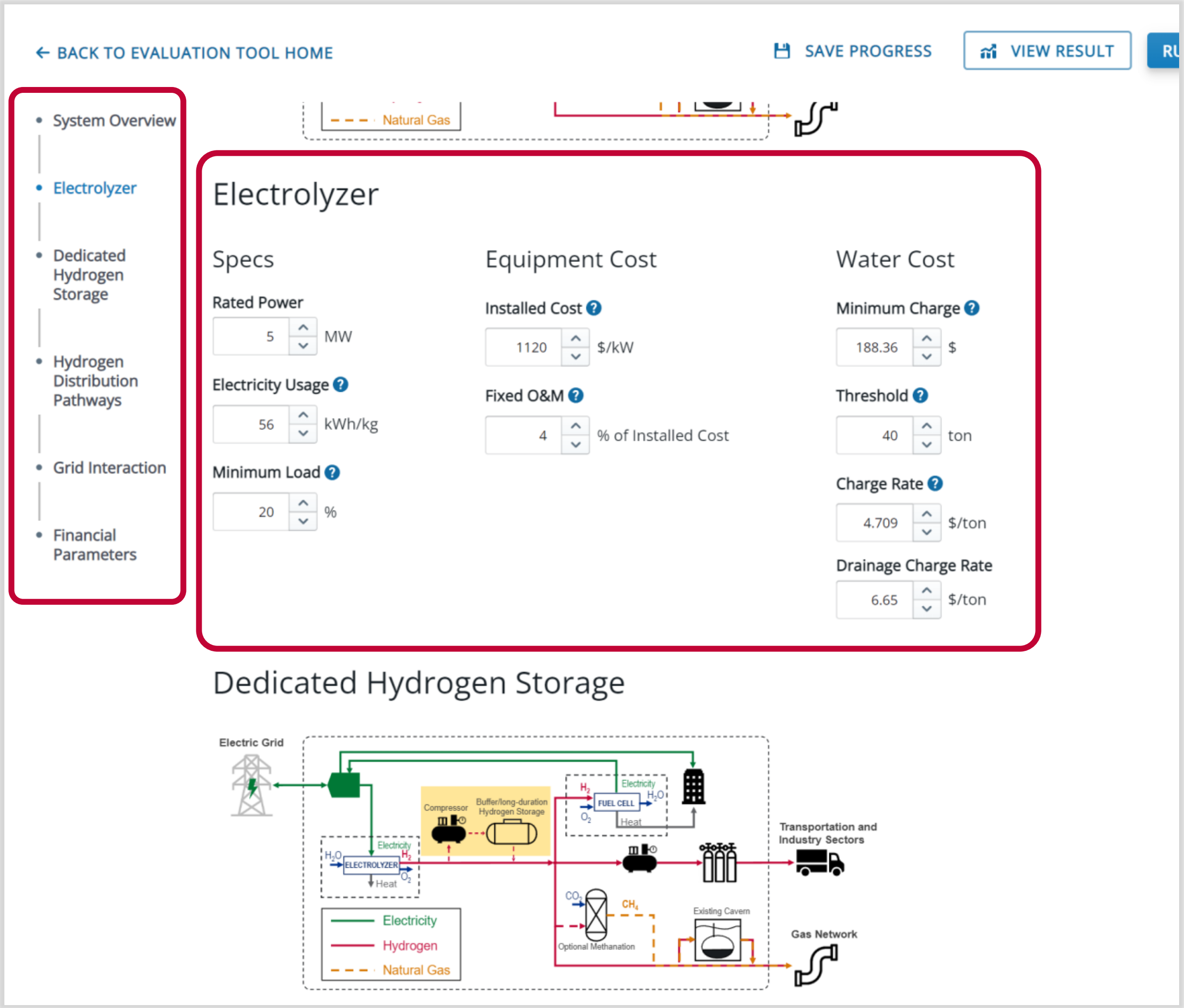
Web-based ESET: https://eset.pnnl.gov

ESET Features

- **Various ESS models**
  - Different energy storage, hybrid, or microgrid systems
  - Appropriate levels of complexity and fidelity
  - Technical characteristics and physical capabilities
- **Advanced optimization and control methods**
  - Technically achievable benefits considering multi-dimensional couplings
  - Economic, environmental, and resilience
- **Built-in databases**
  - Electricity market prices
  - Utility rates
  - Renewables and building loads, and
  - Energy storage cost
- **Improved user experience design**

User Experience Enhancements

- Heuristic evaluation against web application usability principles
  - Home page
  - Navigation
  - Account management
  - Modules
- Improvements
  - Better visibility of system status
  - Better organization of information with visual hierarchy
  - More informative and useful feedback
  - More consistent visual cues across ESET
  - Improved aesthetics and minimalistic design
  - New features that support more flexible inputs and better presentation of results

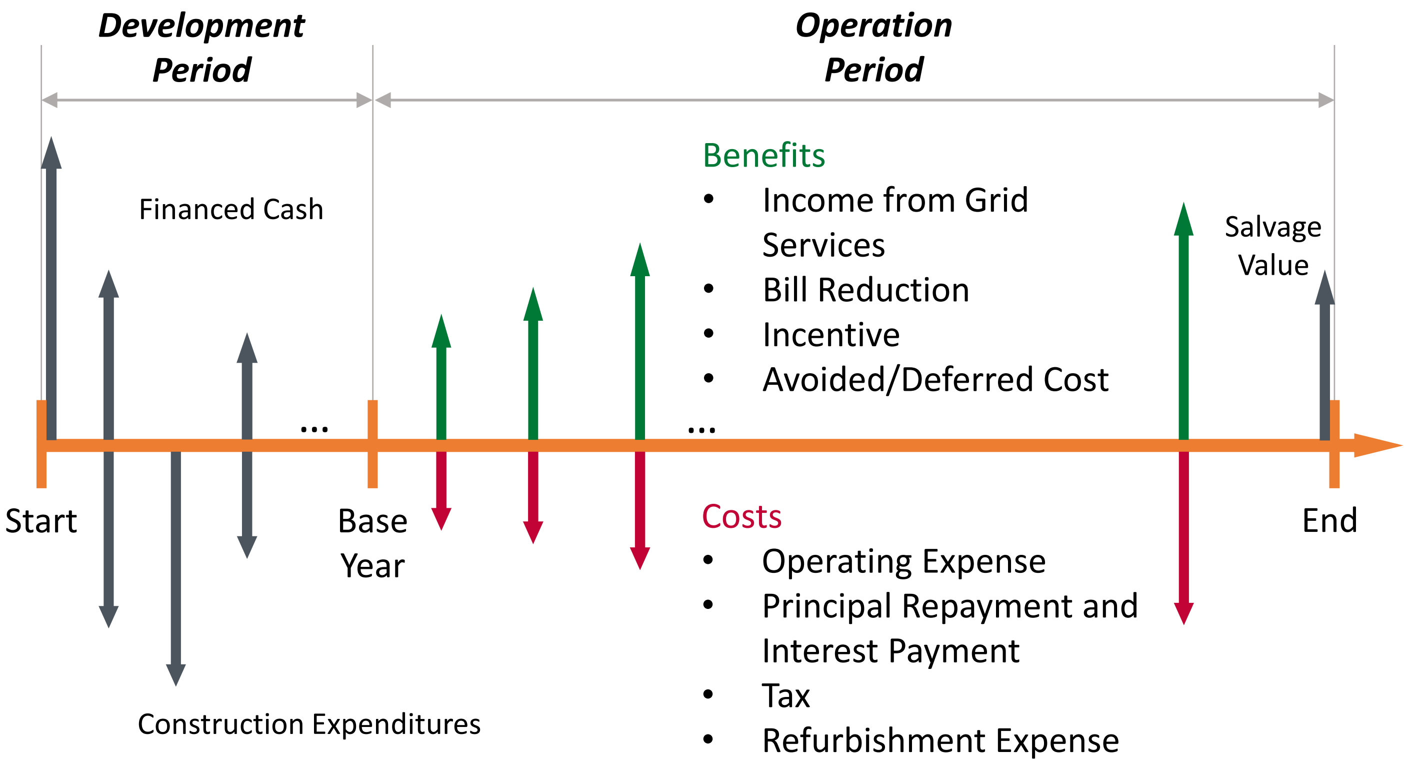


Integrated Databases

- ISO market prices, including NYISO, ERCOT, SPP, ISO-NE, and CAISO (in progress)
  - Energy – LMP
  - Ancillary services: regulation (up, down, and mileage), spin/non-spin reserve
- Utility rate structures
  - *The Utility Rate Database* (URDB) – 3,833 EIA-recognized utility companies
  - Energy and demand charges: flat, time-of-use, tiered
- Typical building load profiles
  - *Commercial and Residential Hourly Load Profiles for all TMY3 Locations in the United States* developed by NREL
- Detailed energy storage cost
  - *Energy Storage Cost and Performance Database* developed by PNNL

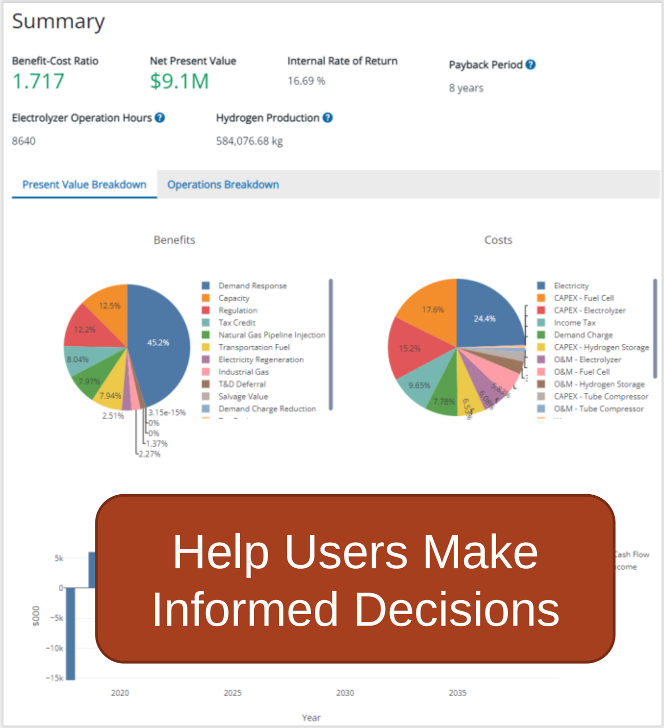
Comprehensive Cost-Benefit Analysis Engine

- Typical Cash Flow for ESS Projects



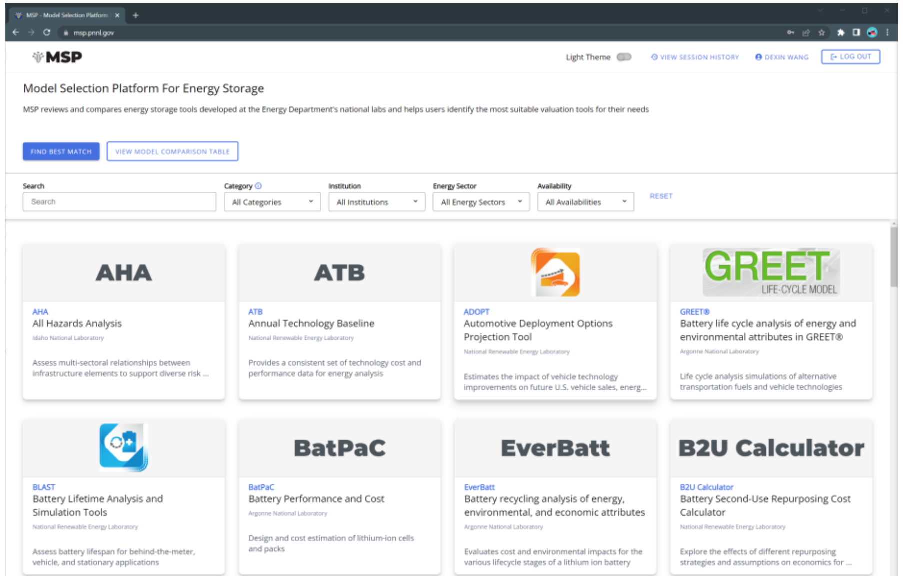
Results

- BCR, NPV, IRR
- Itemized PV Benefits and Costs
- Net income over time
- Free cash flow over time



Model Selection Platform for Energy Storage

- Not easy to tell
  - How are they different in terms of functionalities and capabilities?
  - Which one should I choose?
- MSP reviews and compares a list of tools and suggests the best-suited tools based on users' needs and requirements
- The core of MSP selection wizard is based on:
  - Specification discovery procedure
  - Scoring engine
- Progress in the last year
  - Includes 64 tools (up from 5 in previous release)
  - Production cost modeling (PCM) tools in selection wizard and comparison table

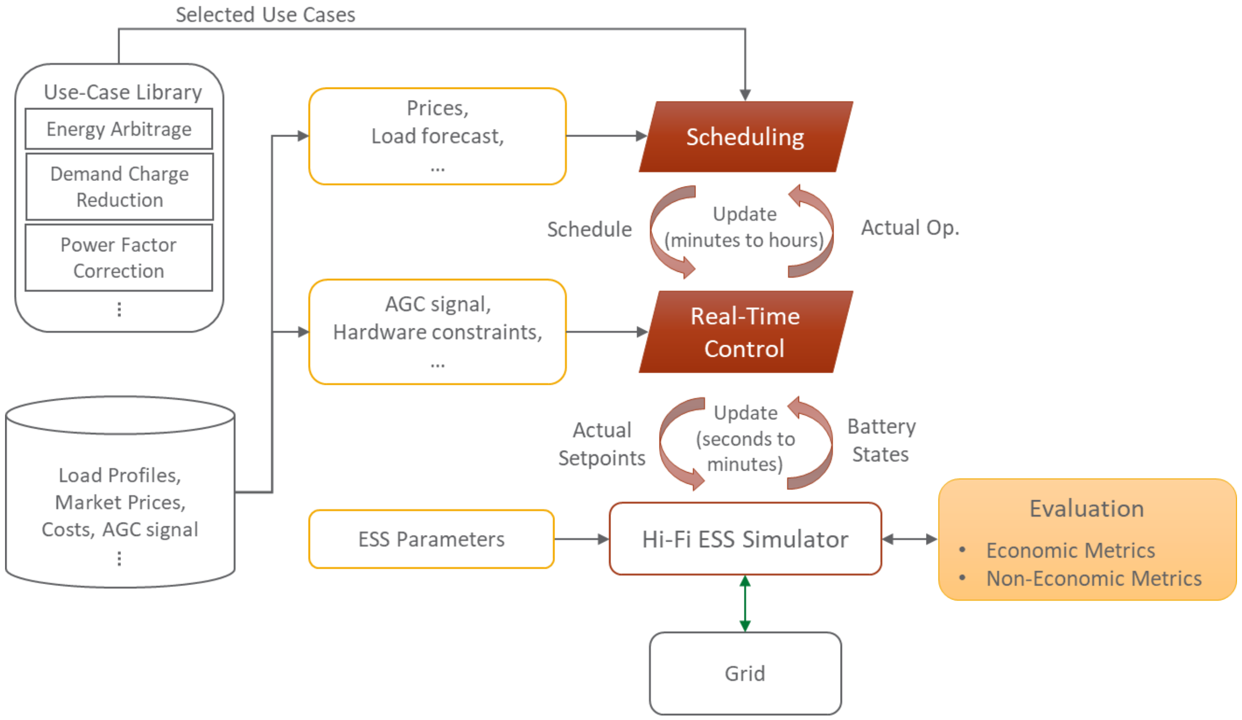


https://msp.pnnl.gov

ES-Control

ES-Control is a platform for evaluation and testing of energy storage control strategies and algorithms with diversified time scales in a realistic setting, considering deployment options, use cases, and applications.

- Sandbox environment for modeling, control, simulation, and evaluation
- Representative built-in control strategies with adjustable parameters
- Open API for customized control
- Diversified energy storage models with different levels of complexity and fidelity
- Built-in database of energy storage costs, market prices, utility tariffs, etc.



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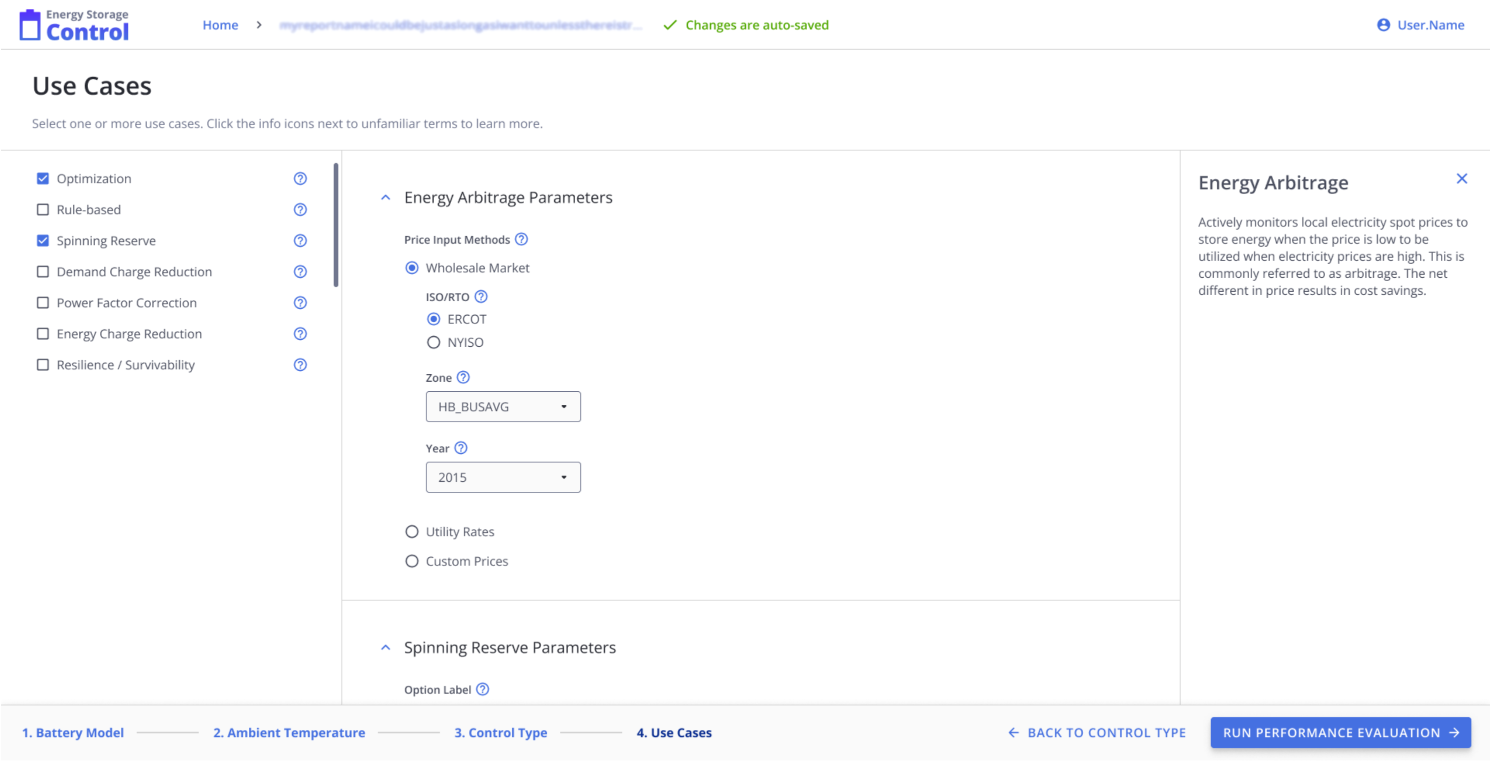
ES-Control (cont.)

- A web-based application
- Microservices architecture for rapid iteration and scalability
- Off-the-shelf AWS services for fast development and industry standard security



Conclusions and Future Work

- System design and project development require appropriate energy storage models with a good balance between fidelity and complexity
- Advanced modeling and analytical methods and tools are required to define technically achievable benefits
  - Integrated forecasting and stochastic dispatch for modeling and addressing uncertainties
  - Ensemble machine learning for enhanced long-duration energy storage scheduling
  - Risk-aware scheduling to better balance economic and resilience benefits
- Additional research is needed to properly select, size, and value storage with different durations for future decarbonized grid
  - Electrification of transportation, building, and industry
  - Extreme weather conditions
  - Policy design and incentive mechanisms

Acknowledgments

Dr. Imre Gyuk
Eric Hsieh
Vinod Siberry

Bob Kirchmeier
Jeremy Berke

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

Pacific Northwest
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Thank You

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https://www.pnnl.gov/energy-storage
https://eset.pnnl.gov/
https://msp.pnnl.gov/