

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)



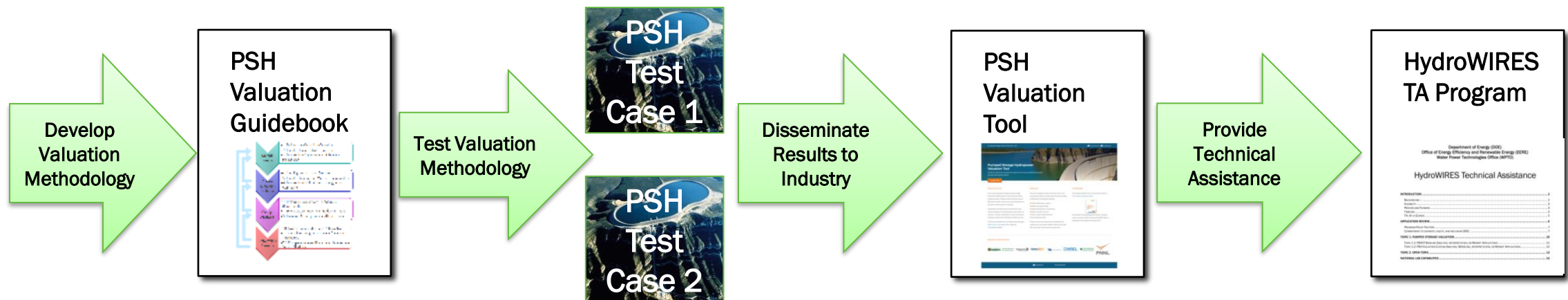
Pacific Northwest National Laboratory (PNNL)

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

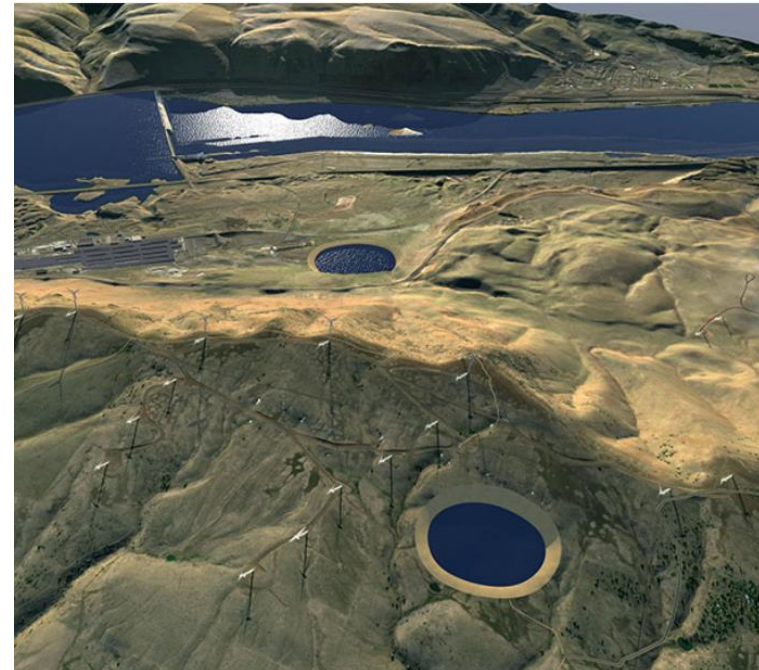
- 400 MW, quaternary technology
- Closed loop
- Site near Casper, WY



CIP & Rye Development*

Goldendale Energy Storage Project

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



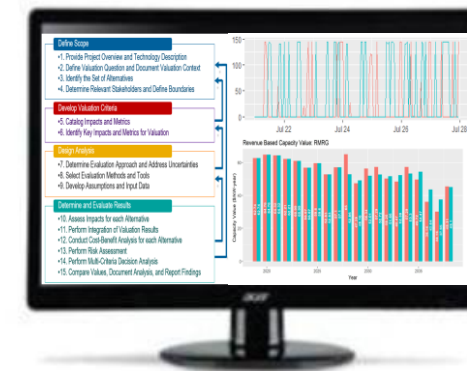
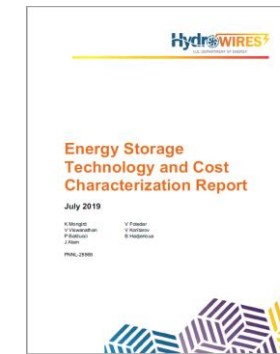
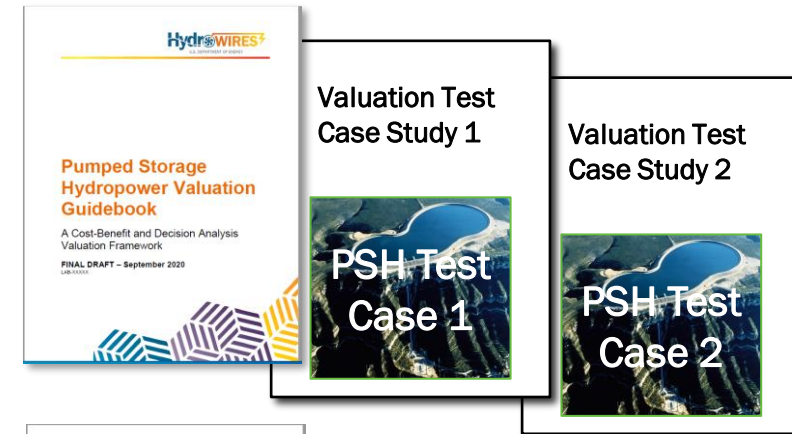
*CIP = Copenhagen Infrastructure Partners

Key Products of the PSH Valuation Project

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

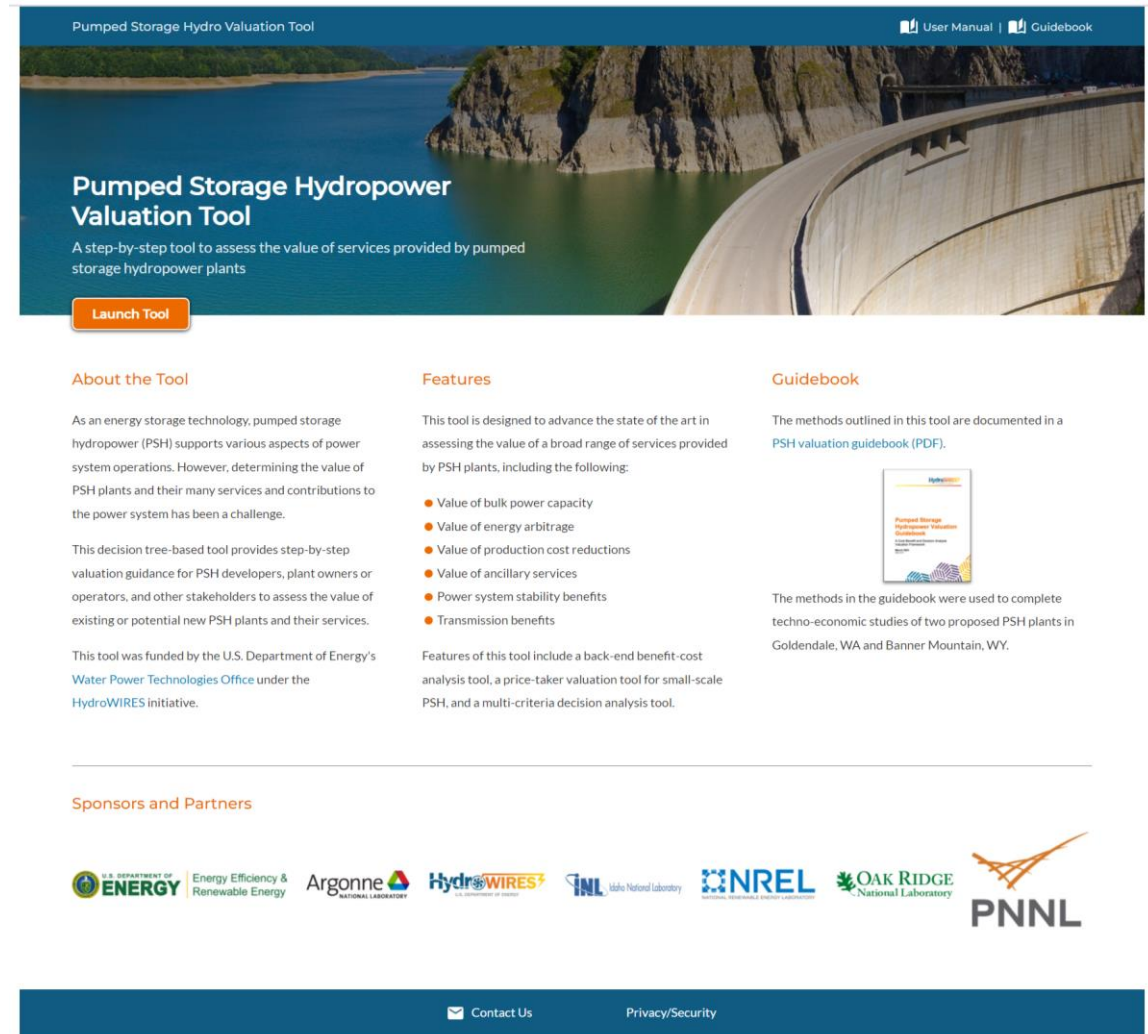
- Energy storage cost and performance study (published)

- 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



The screenshot shows the home page of the Pumped Storage Hydro Valuation Tool. The header includes the title "Pumped Storage Hydro Valuation Tool" and links for "User Manual" and "Guidebook". The main content area features a large image of a dam and a reservoir, with the title "Pumped Storage Hydropower Valuation Tool" and a subtitle "A step-by-step tool to assess the value of services provided by pumped storage hydropower plants". A "Launch Tool" button is prominently displayed. Below this, there are three columns of text: "About the Tool" describing the tool's purpose and funding, "Features" listing various services and benefits, and "Guidebook" explaining the methodology and its application in case studies. At the bottom, there is a "Sponsors and Partners" section with logos for the U.S. Department of Energy, Argonne National Laboratory, HydroWIREs, INEL, NREL, Oak Ridge National Laboratory, and PNNL. A footer contains "Contact Us" and "Privacy/Security" links.

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

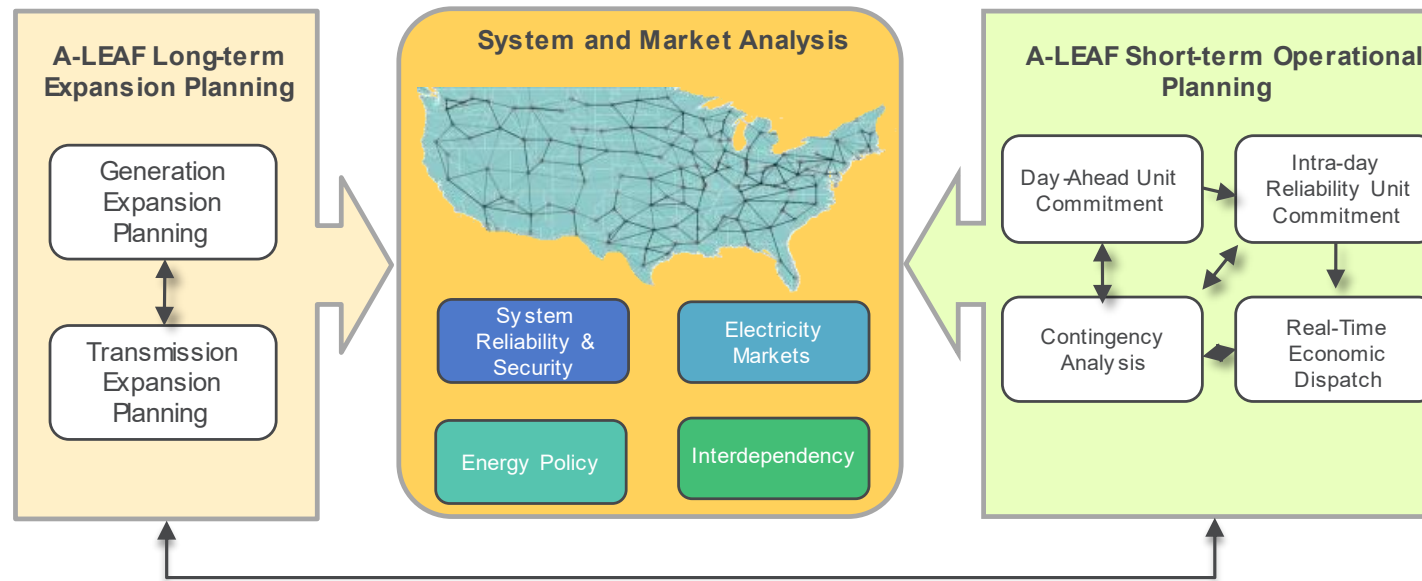
- Choosing among different alternatives with multiple attributes
- Many PSH impacts are not easily monetized and must be expressed in physical units or qualitatively
- How to compare different alternatives that are described by both monetized and non-monetized impacts?
- A decision-support system can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

Entered Optimization Goal and Bounds of Measurement Scale														
Computed Performance Index Scores														
				Alternative 1					Alternative 2					Alternative 3
		Lower Bound	Upper Bound	Goal										
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		
					Average									
					Value	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

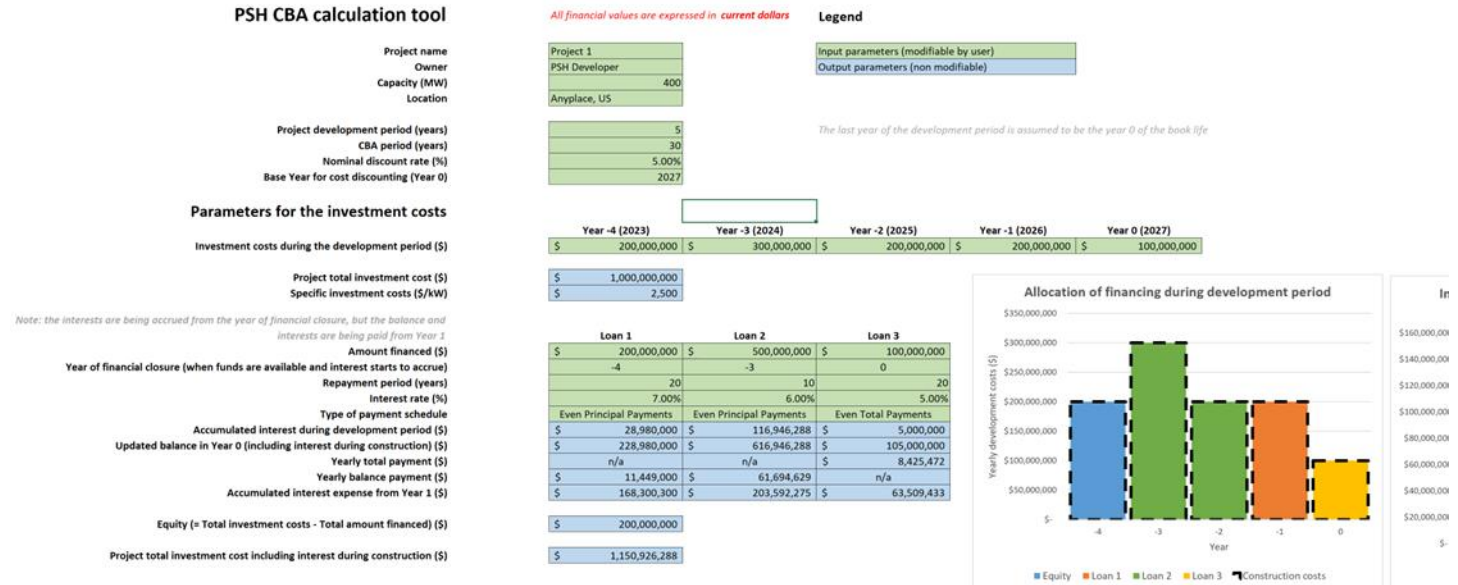
- **A-LEAF is embedded as an option**
 - Users can choose the current approach for estimating PSH values using multiple external tools or select the A-LEAF option
- **Data**
 - Users can use the default national scale dataset provided in A-LEAF
 - The tool supports users as they define input data for 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
- 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



PSHVT BCA Calculator

Thank you! Questions?

Contact:

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Energy Storage, DER, and Microgrid Project Valuation

EPRI DER-VET™ Analysis in Action

Eva Gardow

evgardow@epri.com

Technical Executive | EPRI

January 26, 2023

The Challenges of Storage, DER*, & Microgrid Modeling

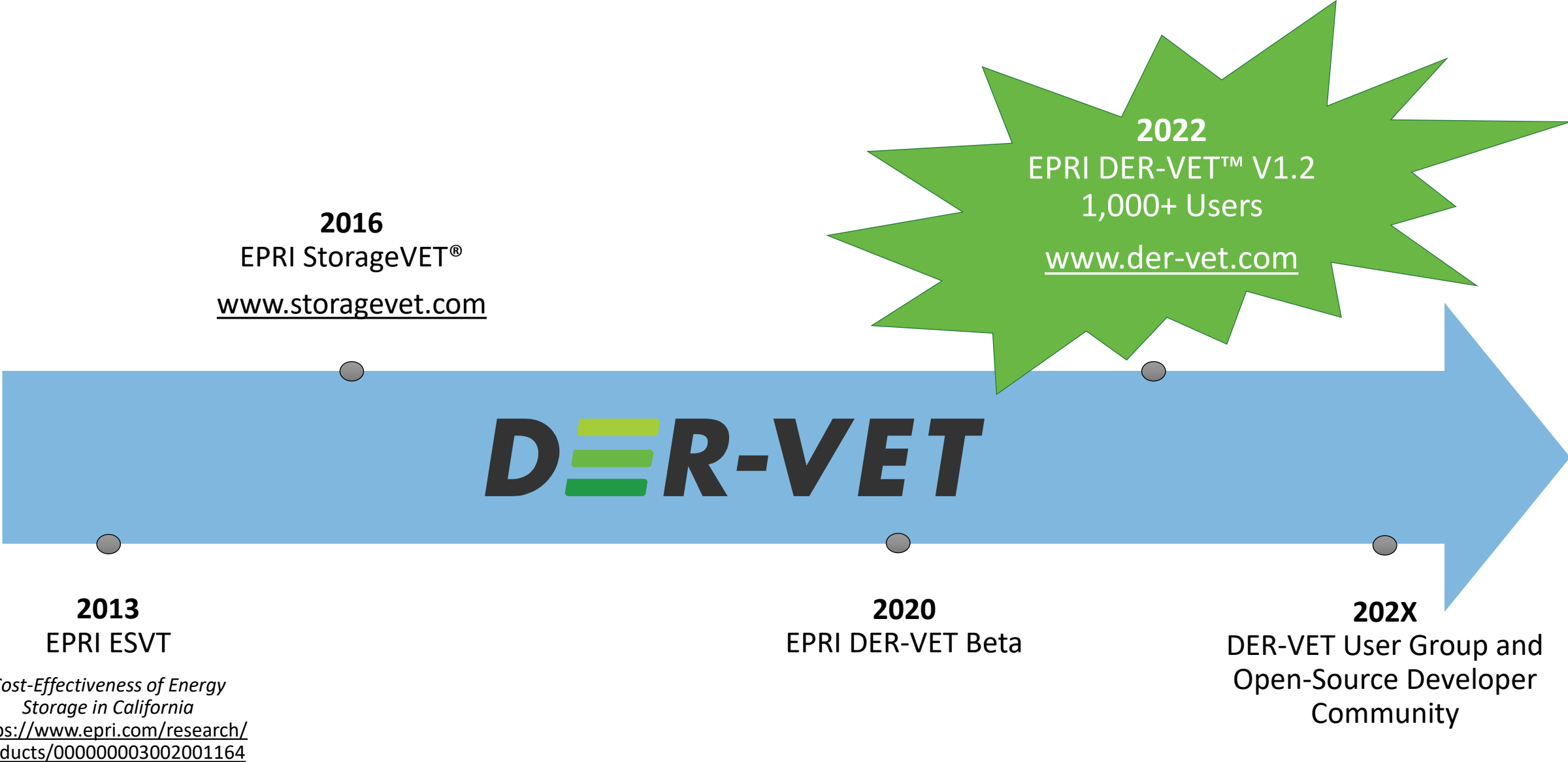
- Today's energy storage, DER, and microgrid deployments demand robust analysis for strategic planning
- Valuation of energy storage requires project-level analyses for specific applications and locations
- This is a complex co-optimization, decision-making process

*DER: Distributed Energy Resources



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

DER-VET's Past, Present, and Future



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

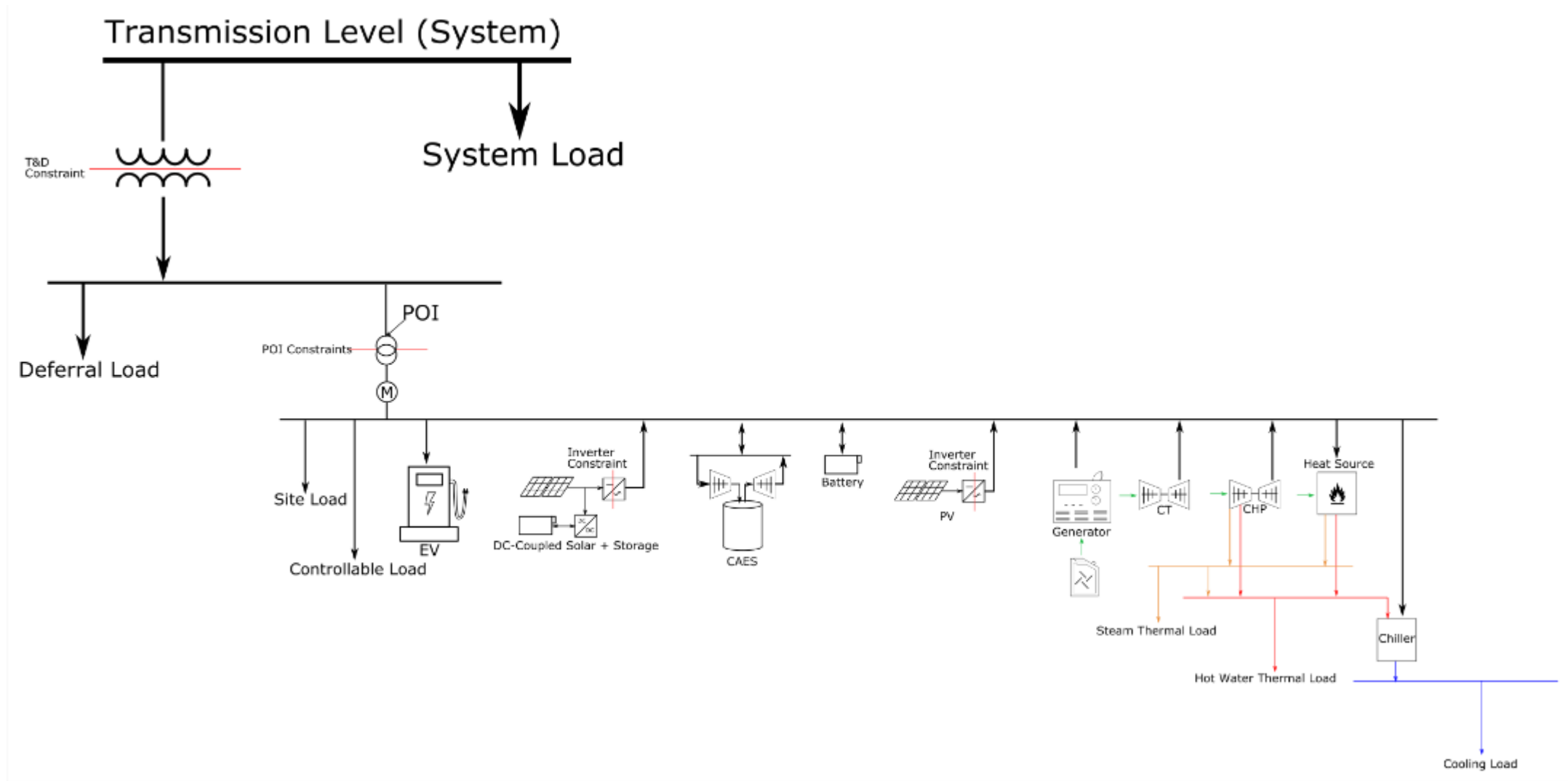
- Download the tool for free as it was developed with California Energy Commission funding
- [Software Release: DER-VET™ Version 1.2 \(Updated July 11, 2022\)](#)
- [DER-VET™ Overview Presentation \(September 2022\)](#)
- [DER VET User Guide](#)



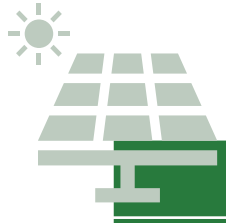
- **Get Involved**

- 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

The screenshot shows the 'Project Configuration' window in DER-VET. The interface includes a sidebar with navigation options: Project Configuration, Services, Distributed Energy Resources, and CalEnviroScreen. The main content area is titled 'Project Configuration' and contains several sections:

- Name:** CAISO Pre-Defined Case
- Start Year:** 2020 (Year the project starts.)
- Analysis Window:**
 - Analysis Horizon Mode:** User-defined (selected), The shortest DER lifetime, The longest DER lifetime. Description: Define when to end cost benefit analysis. Choose it yourself, or by the lifetimes of your equipment.
 - Analysis Horizon:** 10 years. Description: The number of years the analysis will go for. The analysis will not consider equipment lifetime or anything else when determining the number of years to run for.
- Time Series Data:**
 - Data Year (Baseline):** 2020. Description: Commonly the project start year. Data for additional years will be escalated from this value.
 - Timestep:** 60 minutes. Description: What is the frequency of the time-series data?
- Grid Domain:** Generation (selected), Transmission, Distribution, Customer. Description: Which grid domain or location the project will be connected to. Please refer to documentation for further guidance on which services are available in your selected domain.
- Ownership:** Customer, Utility, 3rd Party (selected). Description: Who owns the assets?
- Run Configuration:**
 - Output Folder:** Select folder. Description: Folder where output files will be saved (optional).

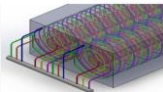

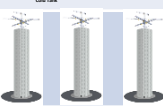


DER-VET Dispatch Results Example





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

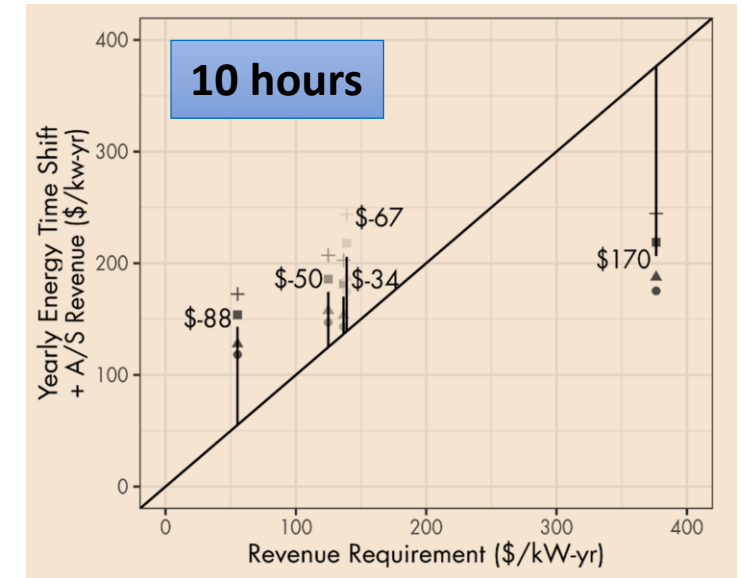
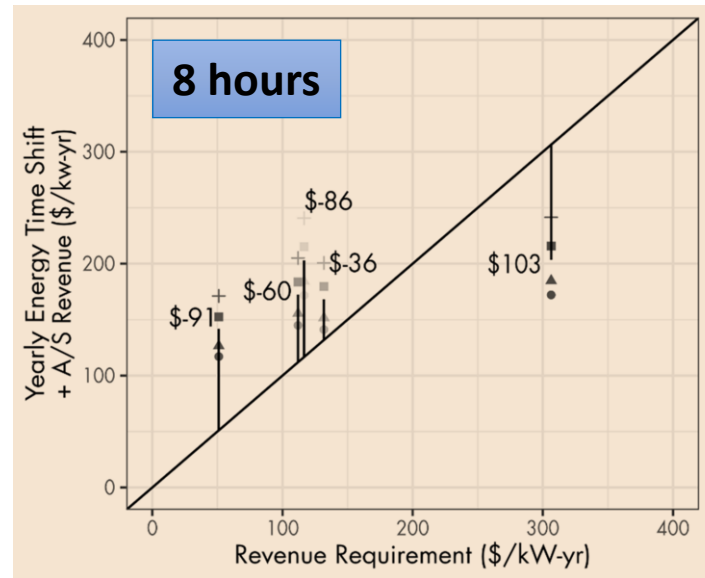
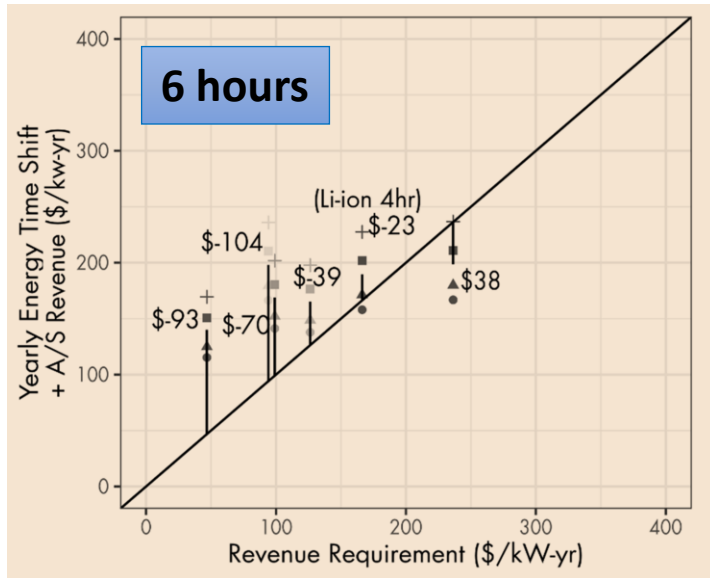
Sensitivities

- 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

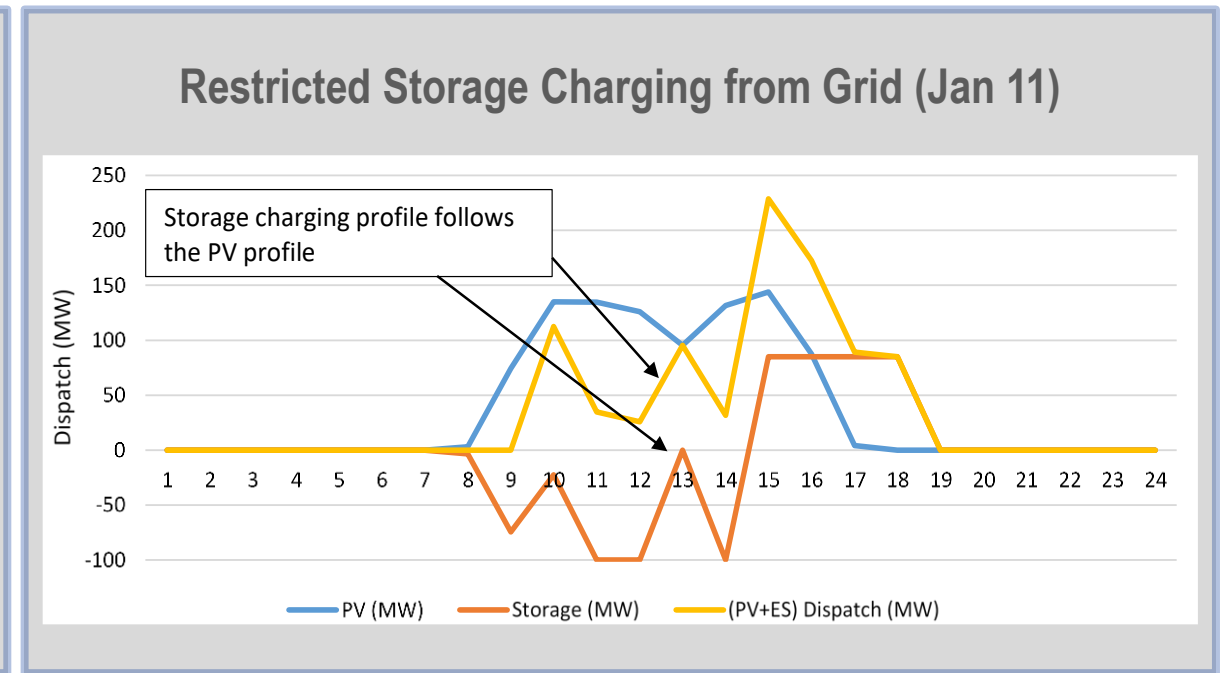
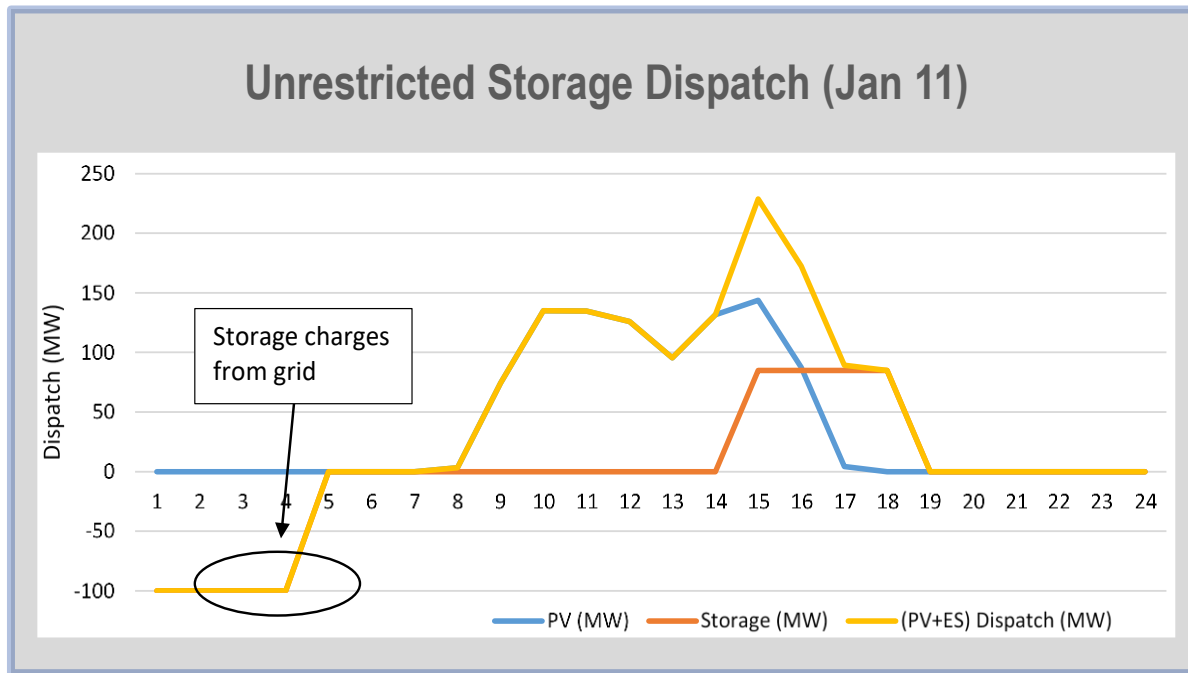
- Los Angeles Department of Water and Power (LADWP) required to study and procure energy storage
 - 100 MW, 4-hour battery energy storage system
 - 200 MW solar PV
 - Power Purchase Agreement (PPA) able to claim Federal Investment Tax Credit (FITC) incentive

	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=00000003002013007>

LADWP Case Results - Dispatch

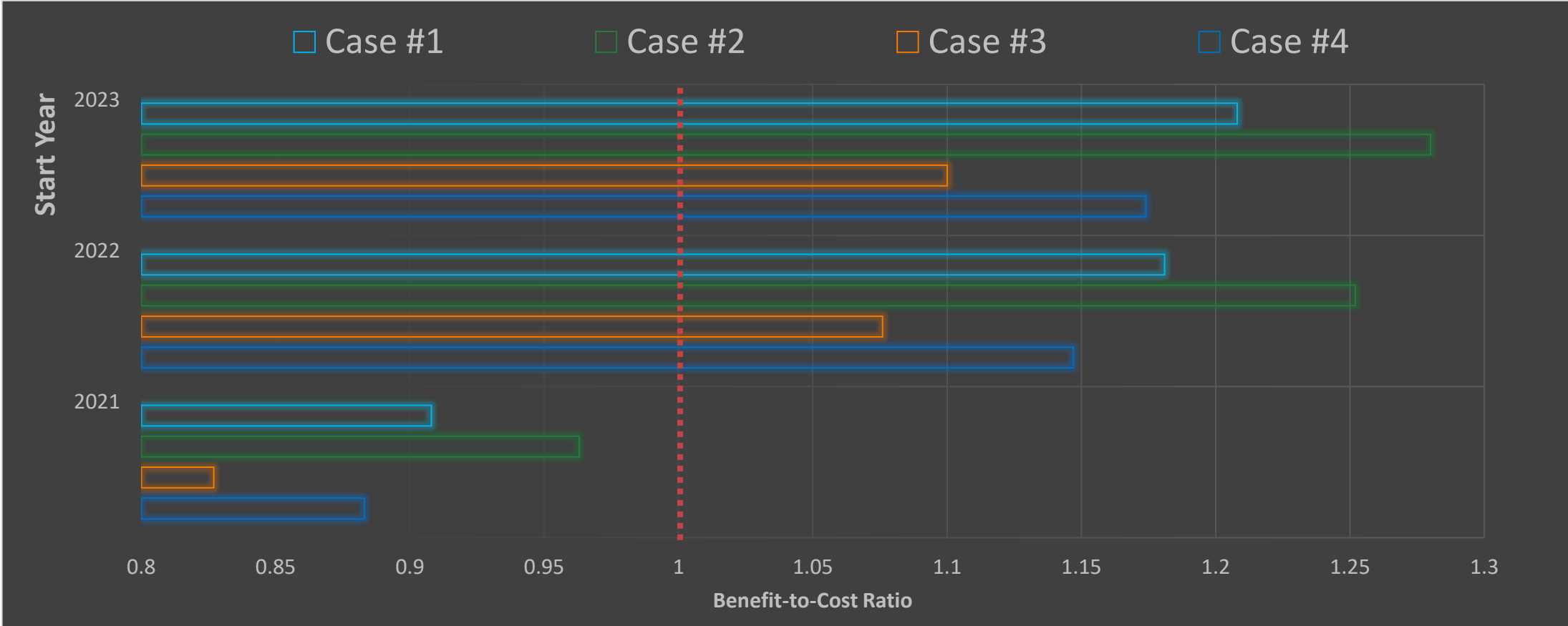
- Impact of grid charging constraints:



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

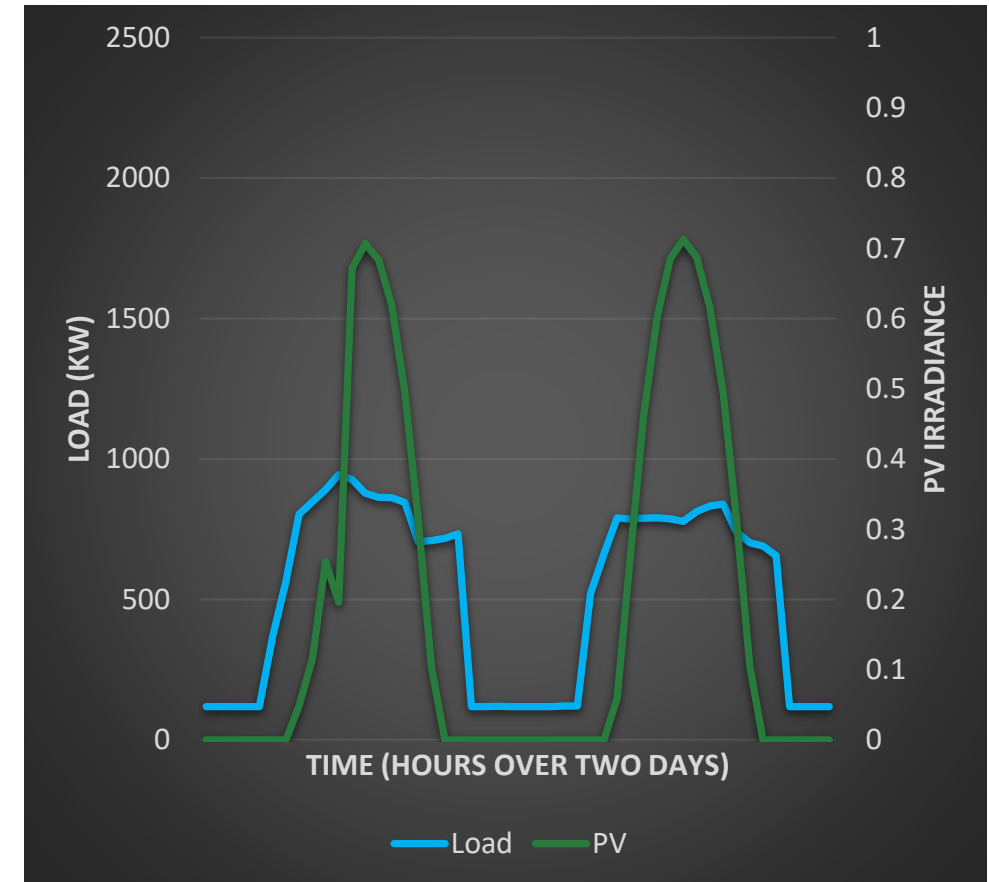




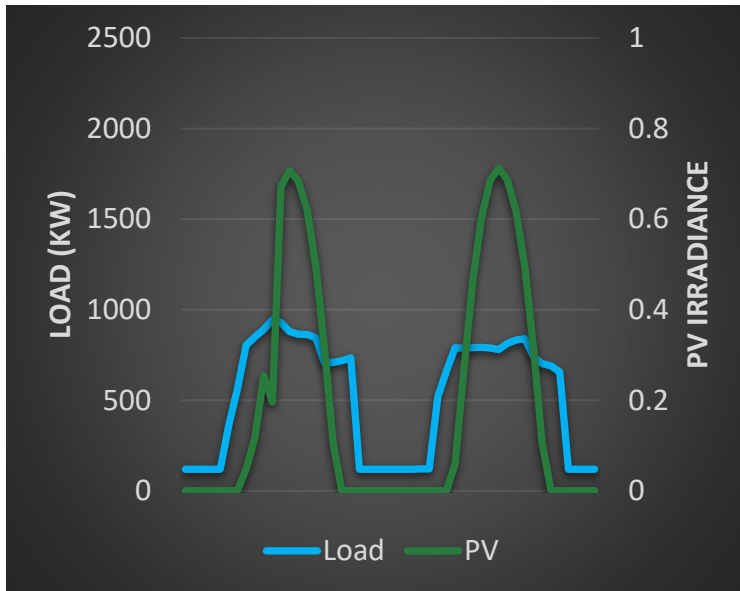
Microgrid Design for California Public Service Power Shutoffs (PSPS) Events

Microgrid Design - DER-VET Modeling Assumptions

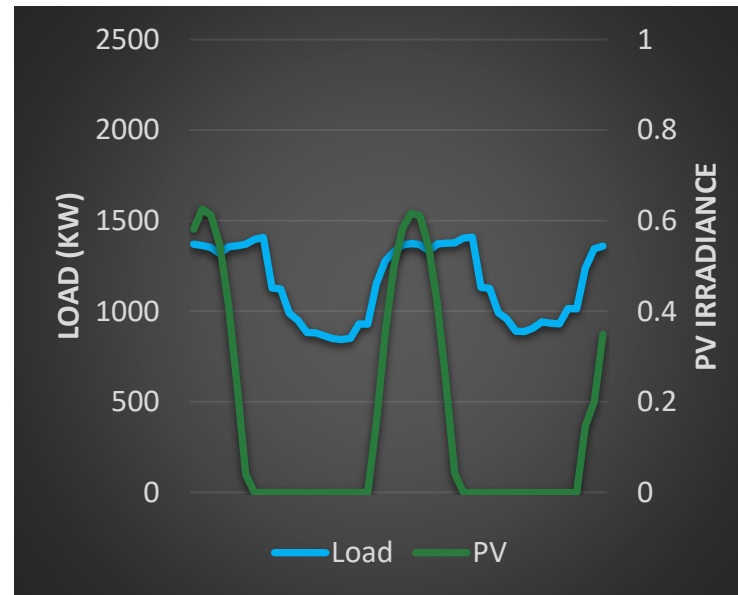
- Identify potential Public Safety Power Shutoff (PSPS) planned events and duration in California
- Solar PV plus battery energy storage microgrid technologies
- Initial storage state of charge at the start of outage event is 100% with advanced PSPS notifications



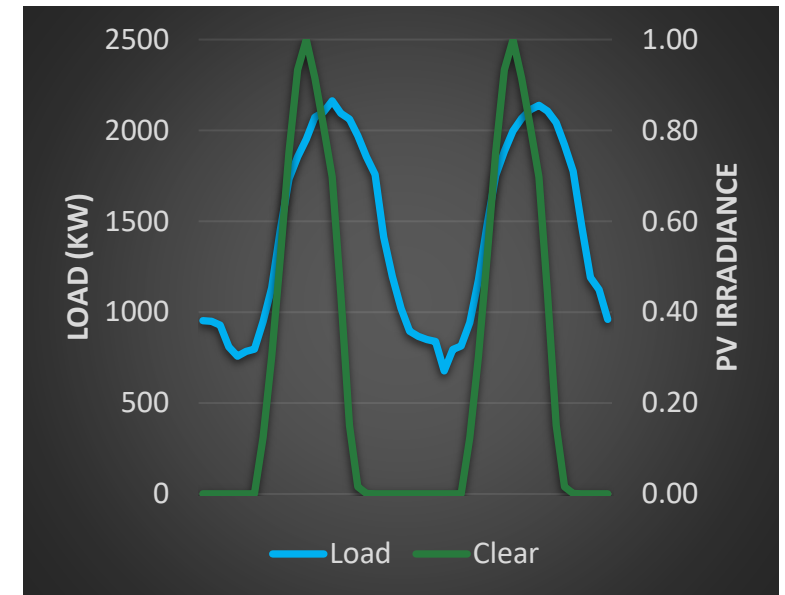
Load and PV Profile



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



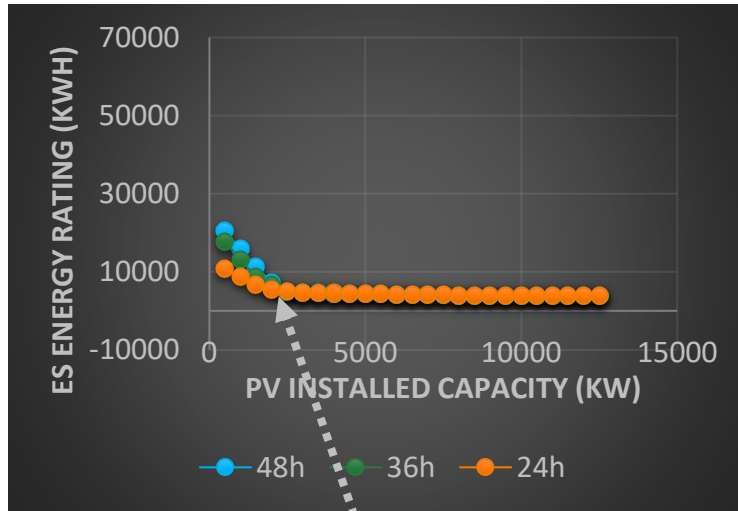
Peak load – 1.4 MW
24hr load requirement – 28MWh
36hr load requirement – 43MWh
48hr load requirement – 55MWh



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

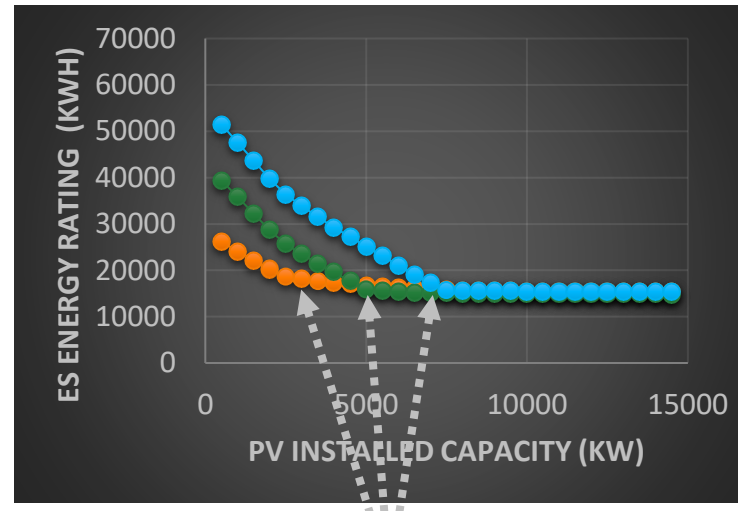
Microgrid Sizing Results

LA – Sec School



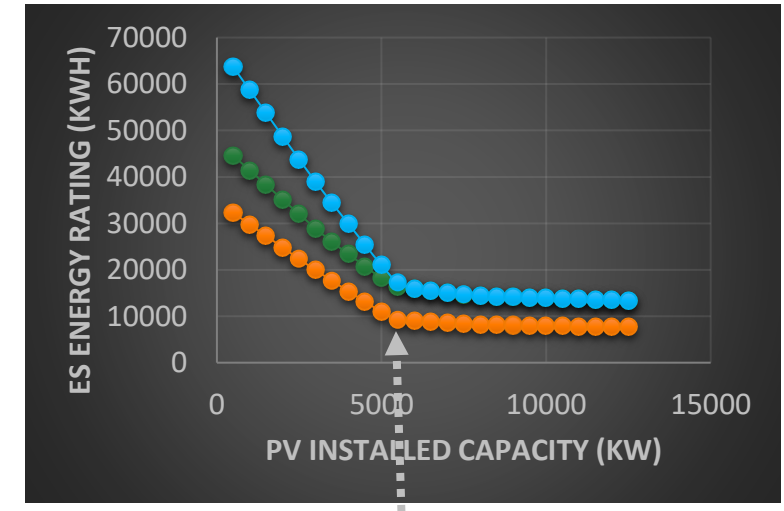
2.5MW PV +
0.735MW/4.9MWh ES

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

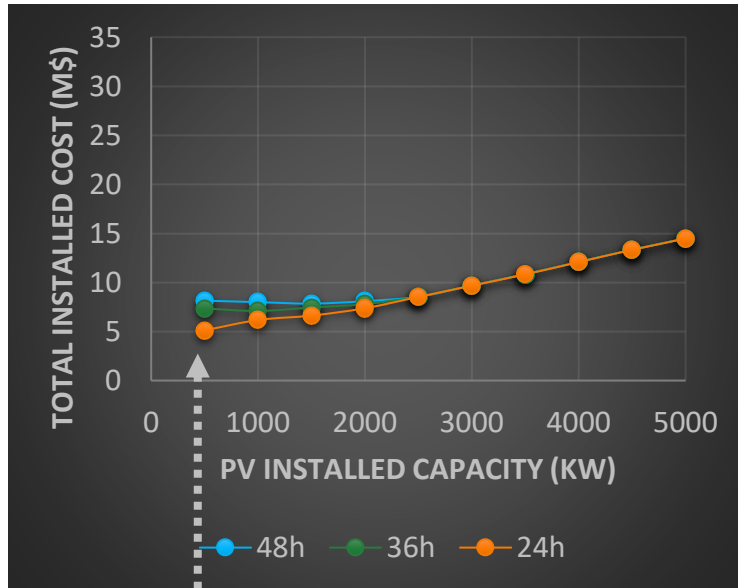


24h – 5.5MW PV+1.9MW/9.2MWh ES
36h – 5.5MW PV+1.9MW/17.2MWh ES
48h – 5.5MW PV + 2 MW/17.2MWh ES

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.

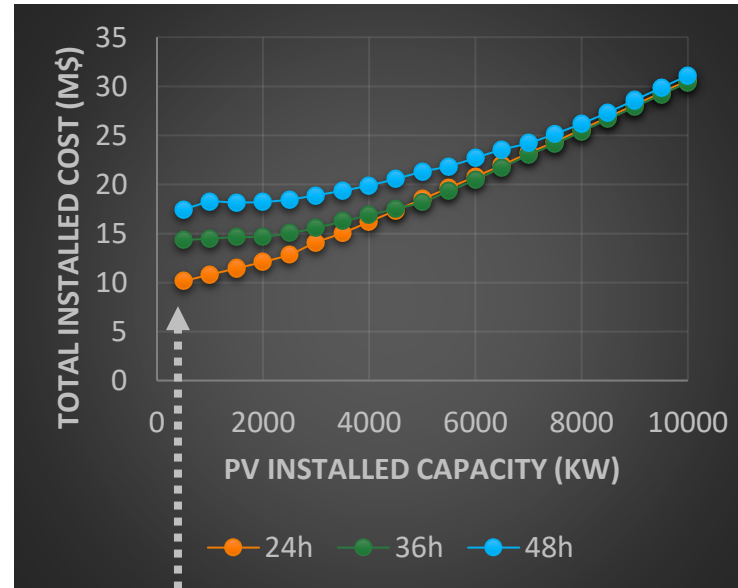
Microgrid Cost Summary

LA – Sec School



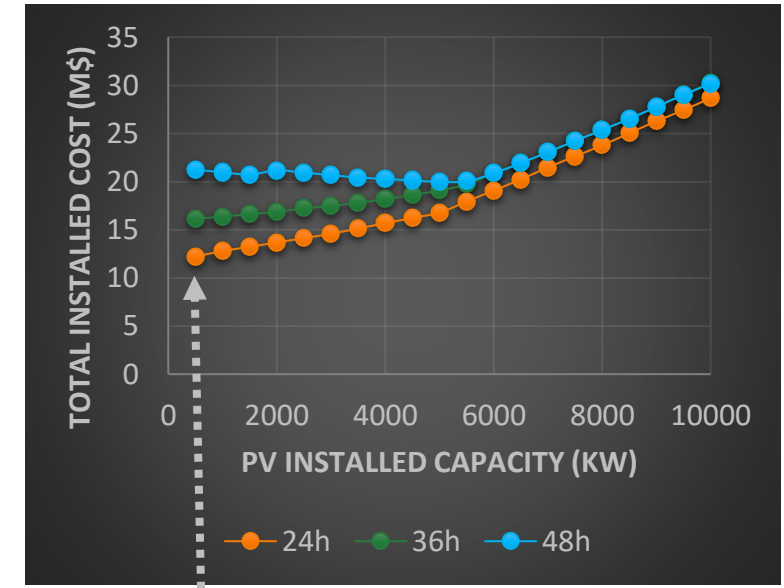
Min Cost of covering 24, 36, and 48hr outage – \$5M, \$7M, and \$8M

LA - Hospital



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

SCE Feeder



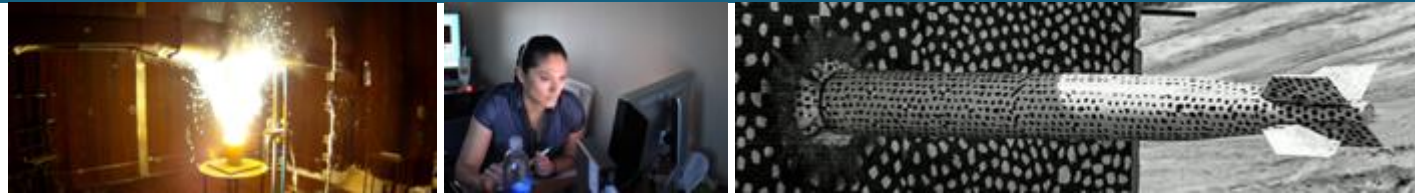
Min Cost of covering 24, 36, and 48hr outage – \$12M, \$16M, and \$22M



Together...Shaping the Future of Energy®



QuEST: Evaluation of Energy Storage



PRESENTED BY

Walker Olis

2023 DOE ENERGY STORAGE FINANCING SUMMIT



Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

- 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



QuEST

home about settings

Quest

New or returning user?
Take a quick tour

Sandia National Laboratories

QuEST Valuation
Estimates value for an energy storage system providing ISO/RTO services. Uses historical data to determine the maximum amount of revenue that the energy storage system could have generated by stacking multiple services/value streams (e.g., ancillary services, energy arbitrage). This retrospective analysis estimates value from future cash flows.

Get started

QuEST Data Manager

QuEST Performance

QuEST Valuation

Technology Selection

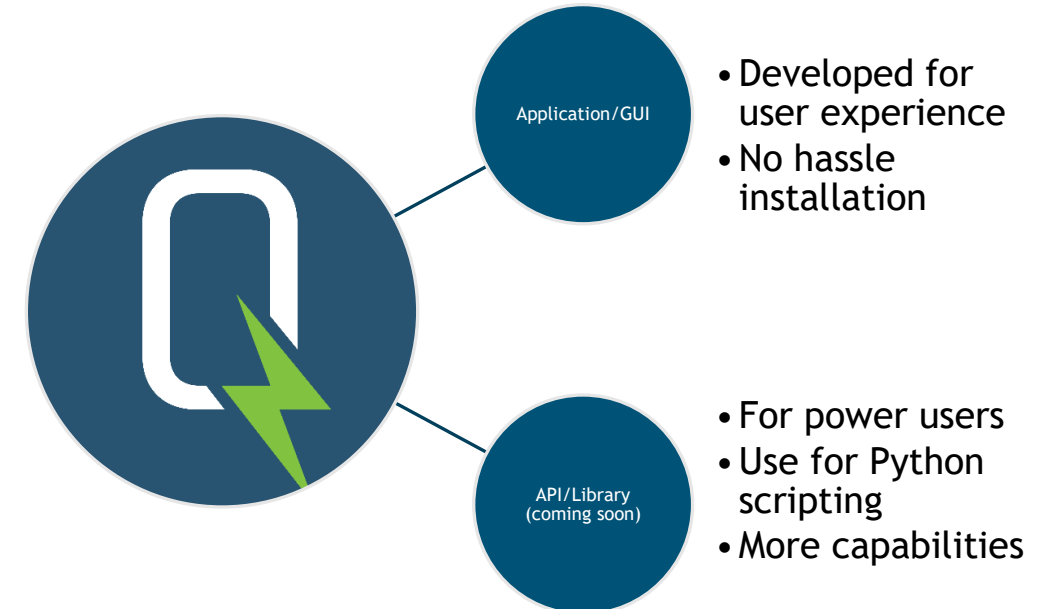
QuEST BTM

QuEST Equity

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

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U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration



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

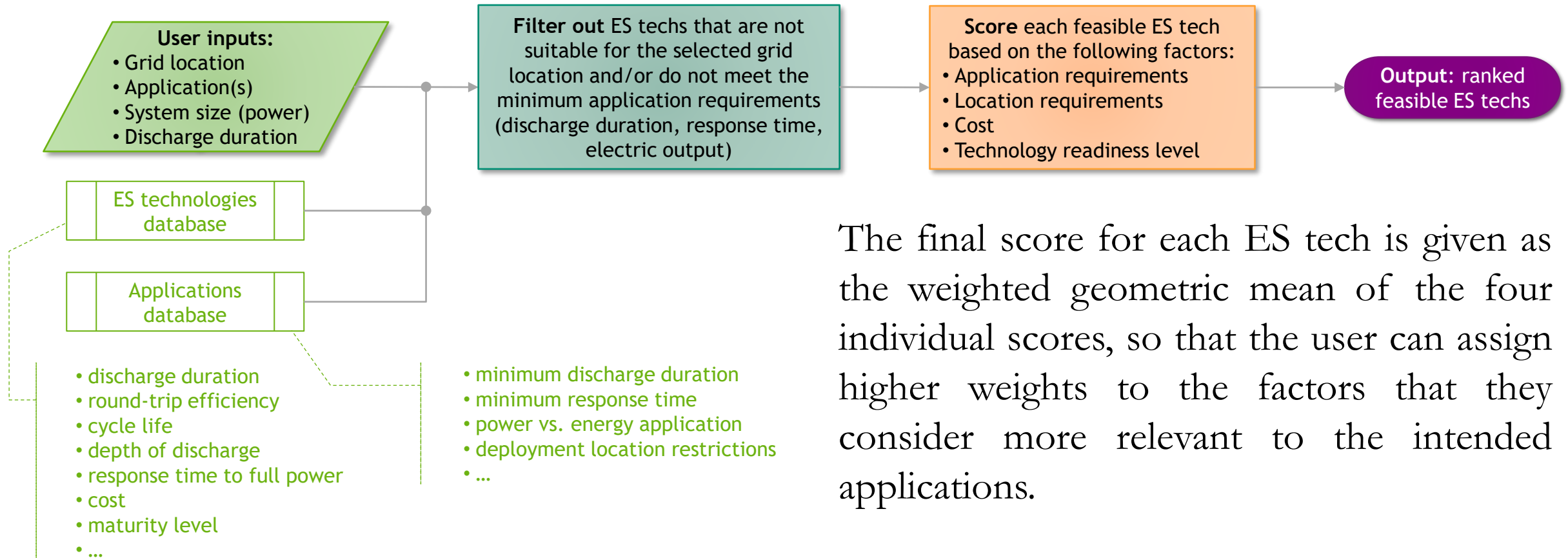
Energy Storage Technology Selection



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)



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



Welcome to the energy storage technology selection wizard!

This wizard will guide you through the process of identifying feasible energy storage technologies for a given project. Based on user inputs and pre-loaded databases that contain parameters to characterize multiple energy storage technologies and their grid applications, this tool identifies which storage technologies do not satisfy the minimum application requirements (such as discharge duration and response time). Then, the remaining feasible technologies are ranked to indicate their compatibility to the desired project.

The flowchart below depicts an overview of the steps performed during the energy storage technology selection analysis.

User inputs:

- Grid location
- Application(s)*
- System size (power)*
- Discharge duration*

1st filter: remove ES techs that are not suitable for the selected grid location

2nd filter: remove ES techs that are not suitable for the selected application (based on discharge duration, response time, electric output)

Scoring: for each ES tech vs. application pair, assign a score for each of the following factors:

- Application requirements
- Location requirements
- Cost
- Technology readiness level

Scoring: compute combined feasibility score considering the previous factors

Output: ranked feasible ES techs

*These inputs have default values according to the selected grid location

[Get started](#)

Energy Storage Technology Selection Application

Energy storage technologies feasibility

The plot below indicates whether each energy storage technology is a feasible option for your project.

	Grid location	Application requirements	Feasible?
Compressed-air energy storage	x	✓	x
Flow battery - Iron	✓	✓	✓
Flow battery - Zinc bromide	✓	✓	✓
Flywheel - Long duration	✓	✓	✓
Flywheel - Short duration	✓	x	x
Lead-acid	✓	✓	✓
Lead-carbon	✓	✓	✓
Lithium-ion	✓	✓	✓
Lithium-ion iron phosphate	✓	✓	✓
Lithium-ion nickel-manganese-cobalt	✓	✓	✓
Nickel	✓	✓	✓
Pumped hydro storage	x	✓	x
Sodium	✓	✓	✓
Vanadium redox flow	✓	✓	✓
Zinc	✓	✓	✓

Summary of user selections:

- Grid location: BTM: commercial/industrial
- Application: Retail TOU energy charges
- System size: 100 kW
- Discharge duration: 4 hrs

[Previous](#) [Next](#)

Energy Storage Technology Selection Application

Ranking of feasible energy storage technologies

The plot below depicts the feasibility score of each energy storage technology for your project; higher scores indicate a better match between a technology and the requirements of your project. The *Adjustments* box allows users to modify some settings used for computing the total feasibility scores.

Summary of user selections:

- Grid location: BTM: commercial/industrial
- Application: Retail TOU energy charges
- System size: 100 kW
- Discharge duration: 4 hrs

Adjustments

Weights for each category:

- Application: 1.00
- Location: 1.00
- Cost: 1.00
- Maturity: 1.00

Target cost: 1000 \$/kWh \$/kW

[Update scores](#)

[Previous](#) [Next](#)

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:

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

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

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

state of charge definition

state of charge limits

power/energy charged limits

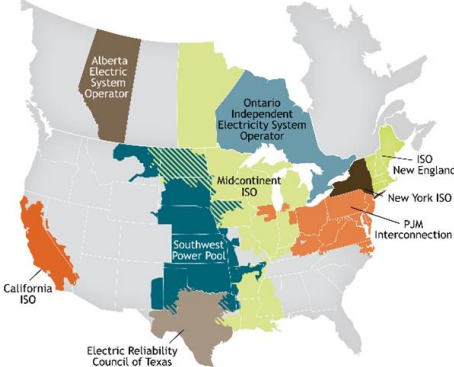
- Other constraints, such as requiring the final SoC to equal the initial SoC or reserving energy capacity for resiliency applications can be set.
- Varies based on market and available value streams

QuESt – Valuation Application

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

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

round trip efficiency (%) 90.0

energy capacity (MWh) 24.0

power rating (MW) 36.0

Previous Next

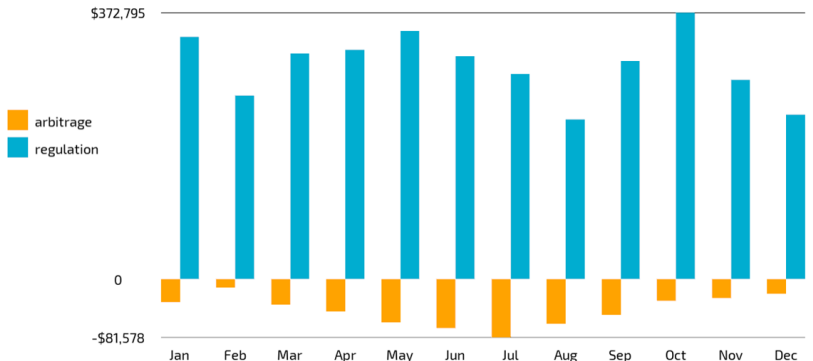
QuESt Wizard home about settings

Here's how the device generated revenue each month.

Revenue was generated based on participation in the selected revenue streams. The **gross revenue** generated over the evaluation period was **\$3,064,793.94**. The gross revenue from **arbitrage** was **-\$526,420.06**, an overall deficit. This implies participation in arbitrage was solely for the purpose of having capacity to offer regulation up services.

Reports

- Revenue (by month)
- Revenue (by stream)**
- Participation (total)
- Participation (by month)



Generate report

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

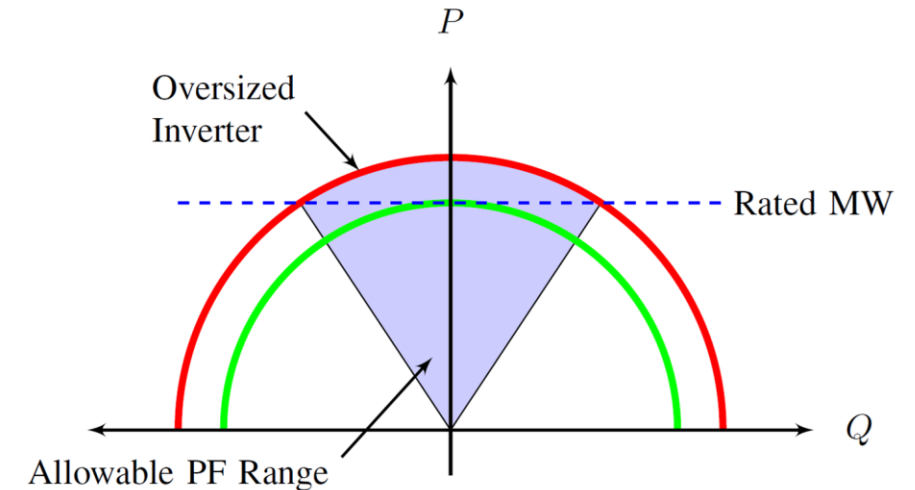
$$\min\{C_E^m + C_N^m + C_D^m\}$$

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

$C_N^m (\leq 0)$ is the net metering charge of period m .



QuESt – BTM Application



Time-of-Use Cost Savings

Select a rate structure.

Filter by name

- 0129
- 0206
- 0213
- 0321-nyseg
- 0325-pepco-general-service
- PNM
- e-tou-option-b
- example
- nyseg-tou-residential
- nyseg-tou-residential-nem1
- paloalto
- pnm-residential-tou**
- xyz

Energy

00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Demand

00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Flat demand rate [\$/kW] Jan 0.0 Feb 0.0 Mar 0.0 Apr 0.0 May 0.0 Jun 0.0 Jul 0.0 Aug 0.0 Sep 0.0 Oct 0.0 Nov 0.0 Dec 0.0

Peak demand min. [kW] Peak demand max. [kW] Net metering type Energy sell price [\$/kWh]

Time-of-Use Cost Savings

Specify the energy storage system parameters.

- energy capacity** The maximum amount of energy that the ESS can store. kWh
- power rating** The maximum rate that at which the ESS can charge or discharge energy. kW
- transformer rating** The maximum amount of power that can be exchanged. kW
- self-discharge efficiency** The percentage of stored energy that the ESS retains on an hourly basis. %/h
- round trip efficiency** The percentage of energy charged that the ESS actually retains. %
- minimum state of charge** The minimum ESS state of charge as a percentage of energy capacity. %
- maximum state of charge** The maximum ESS state of charge as a percentage of energy capacity. %
- initial state of charge** The percentage of energy capacity that the ESS begins with. %

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Time-of-Use Cost Savings

Here's the total bill with and without energy storage for each month.

The total bill is the sum of demand charges, energy charges, and net metering charges or credits. It looks like the ESS was able to **decrease** the total charges over the year by **\$1,712.70**.

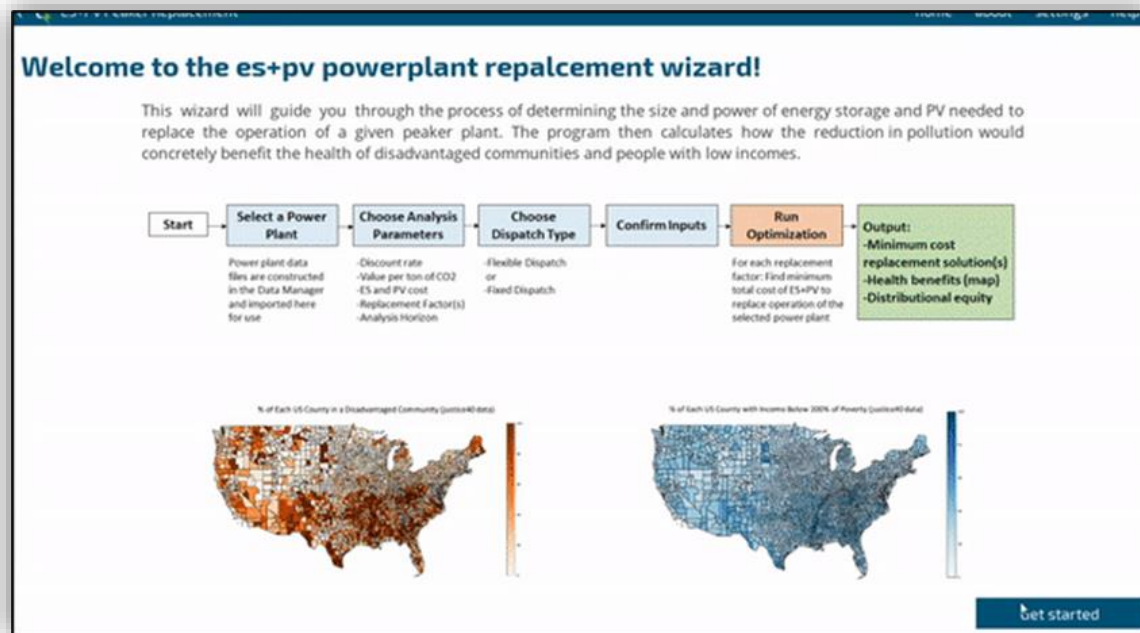
Month	without ES	with ES
Jan	\$3,376	\$3,172
Feb	\$3,376	\$3,172
Mar	\$3,376	\$3,172
Apr	\$3,376	\$3,172
May	\$3,376	\$3,172
Jun	\$3,376	\$3,172
Jul	\$3,376	\$3,172
Aug	\$3,376	\$3,172
Sep	\$3,376	\$3,172
Oct	\$3,376	\$3,172
Nov	\$3,376	\$3,172
Dec	\$3,376	\$3,172

Reports

- Total bill
- Total bill comparison**
- Demand charge comparison
- Energy charge comparison
- NEM comparison
- Peak demand comparison

Generate report

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?

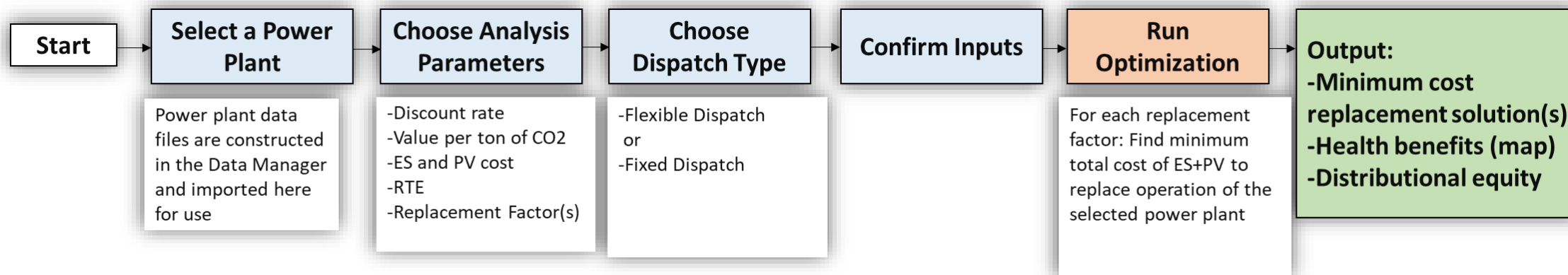


Inputs

- 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?



QuEST Performance Simulations

Run performance simulations.

PTAC NY Valuation Jul 18, 2022 12:46:53

Select an input file

- 1ZoneUncontrolled_wESS_hvactemplate_ptacexp2.idf
- container_wESS_ptac.idf

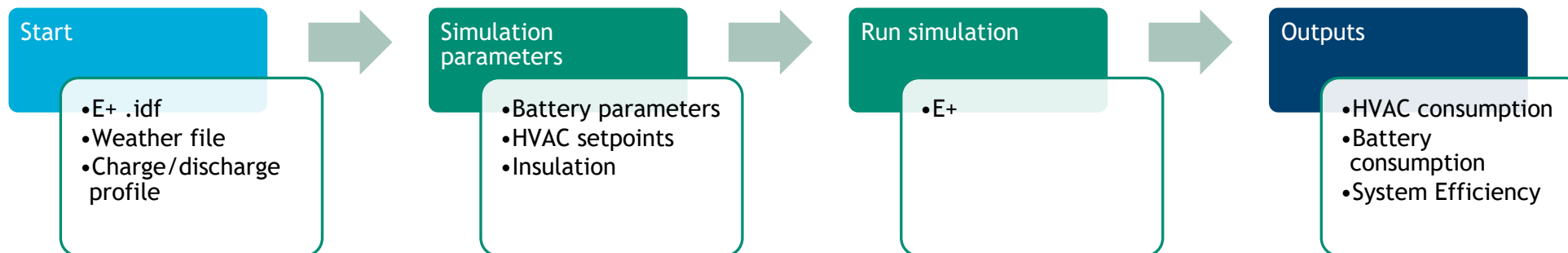
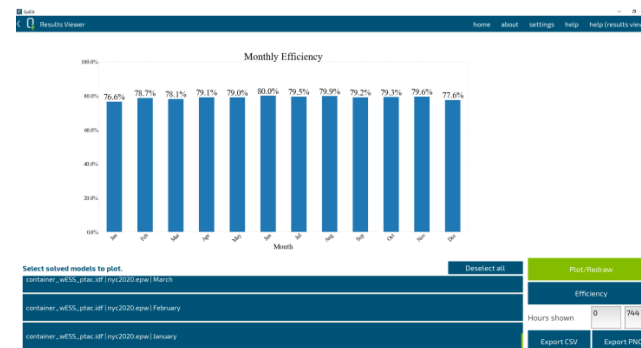
Select weather file

- nyc2020.epw

Select battery profile

- December
- November
- October
- September
- August
- July
- June
- May
- April
- March
- February
- January

Data Parameters Ready Go!





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

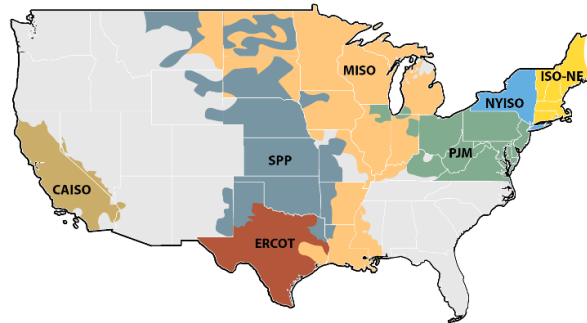
Prerequisites:

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



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

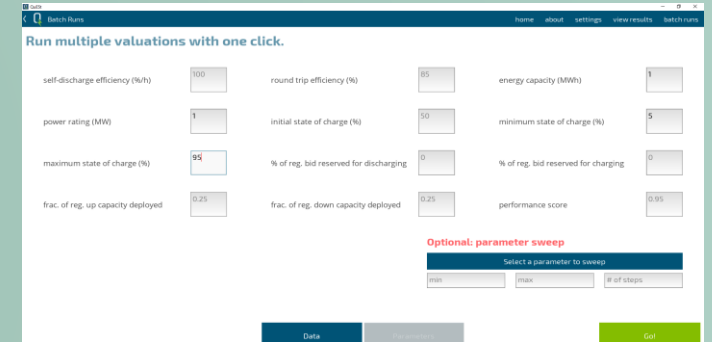
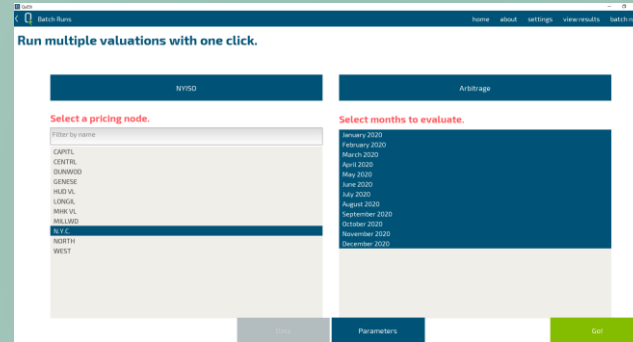
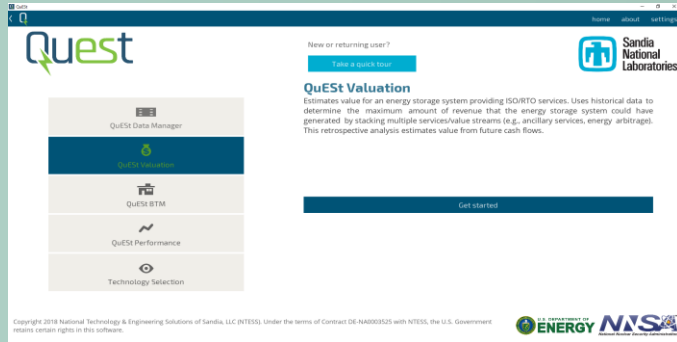
Different market areas can have different market structures, resulting in various opportunities for generating revenue.



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Example – QuEST Valuation and QuEST Performance

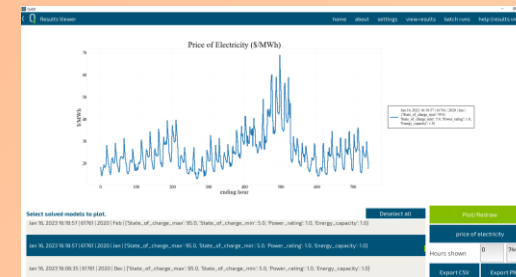
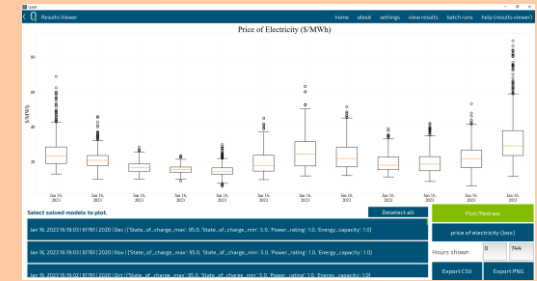
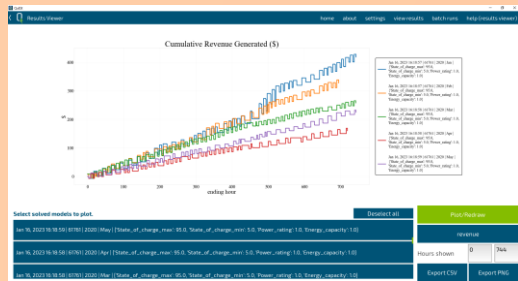


• Navigate to the QuEST Valuation tool.

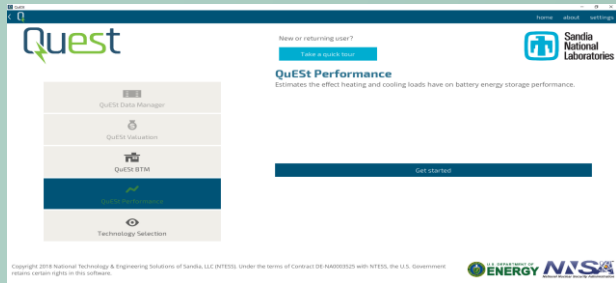
• Click on the Batch Runs Button -> select NYISO from the pull down options -> select N.Y.C. from the node options -> select arbitrage from the pull down options -> select all months of the year.

• 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 3% and the maximum state of charge to 95%.

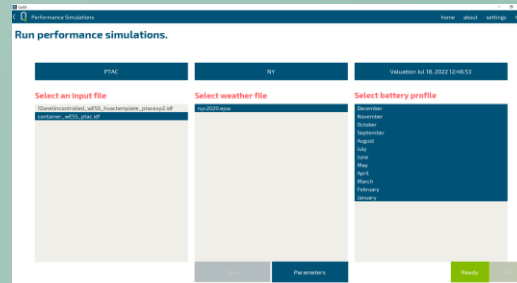
• Once everything looks correct, click Go! Once the simulations are finished, navigate back to the home page.



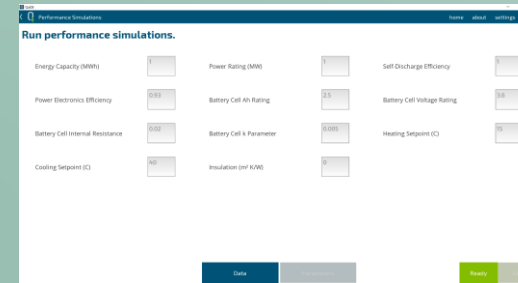
Example – QuEST Valuation and QuEST Performance



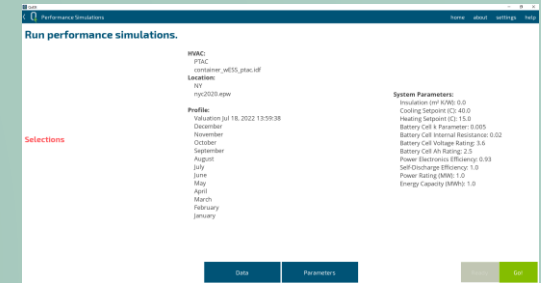
- Navigate to the QuEST Performance tool.



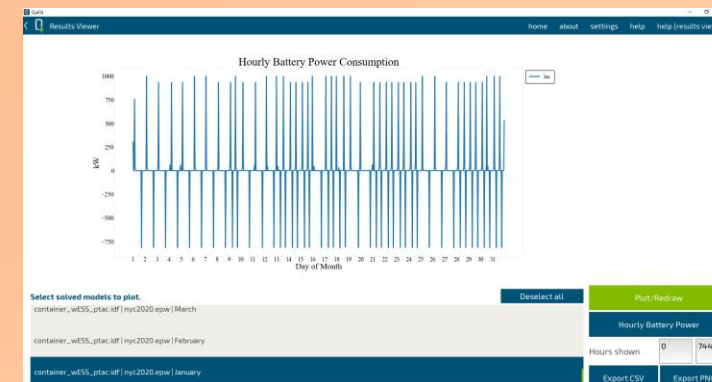
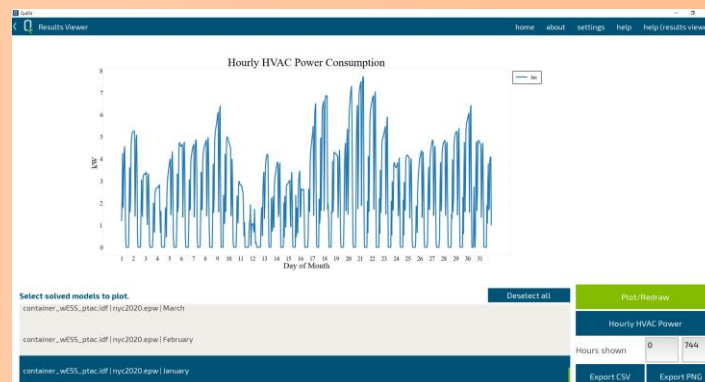
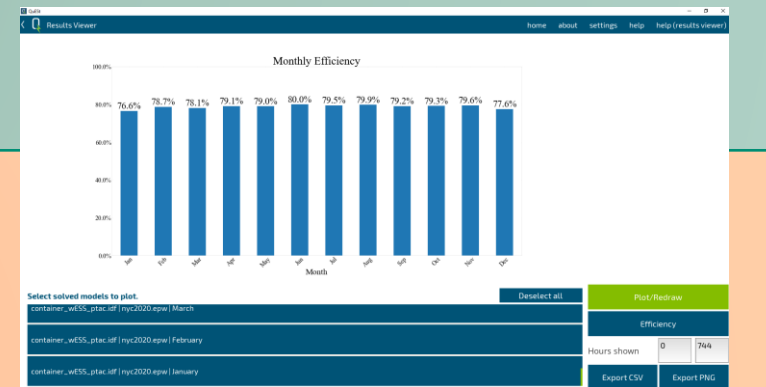
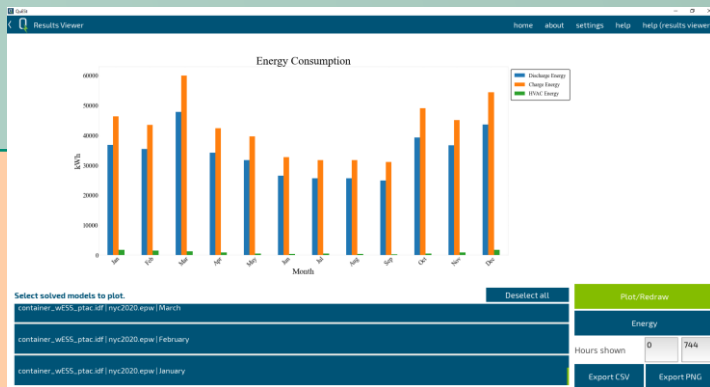
- Enter the Performance Simulations option. Select PTAC from the HVAC options. Select the provided input file describing a BESS in a shipping container. Select NY from the location dropdown. Select the weather file downloaded previously. Select the Valuation run from the Profile dropdown. Select the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



Sandia National Laboratories

Thank You!

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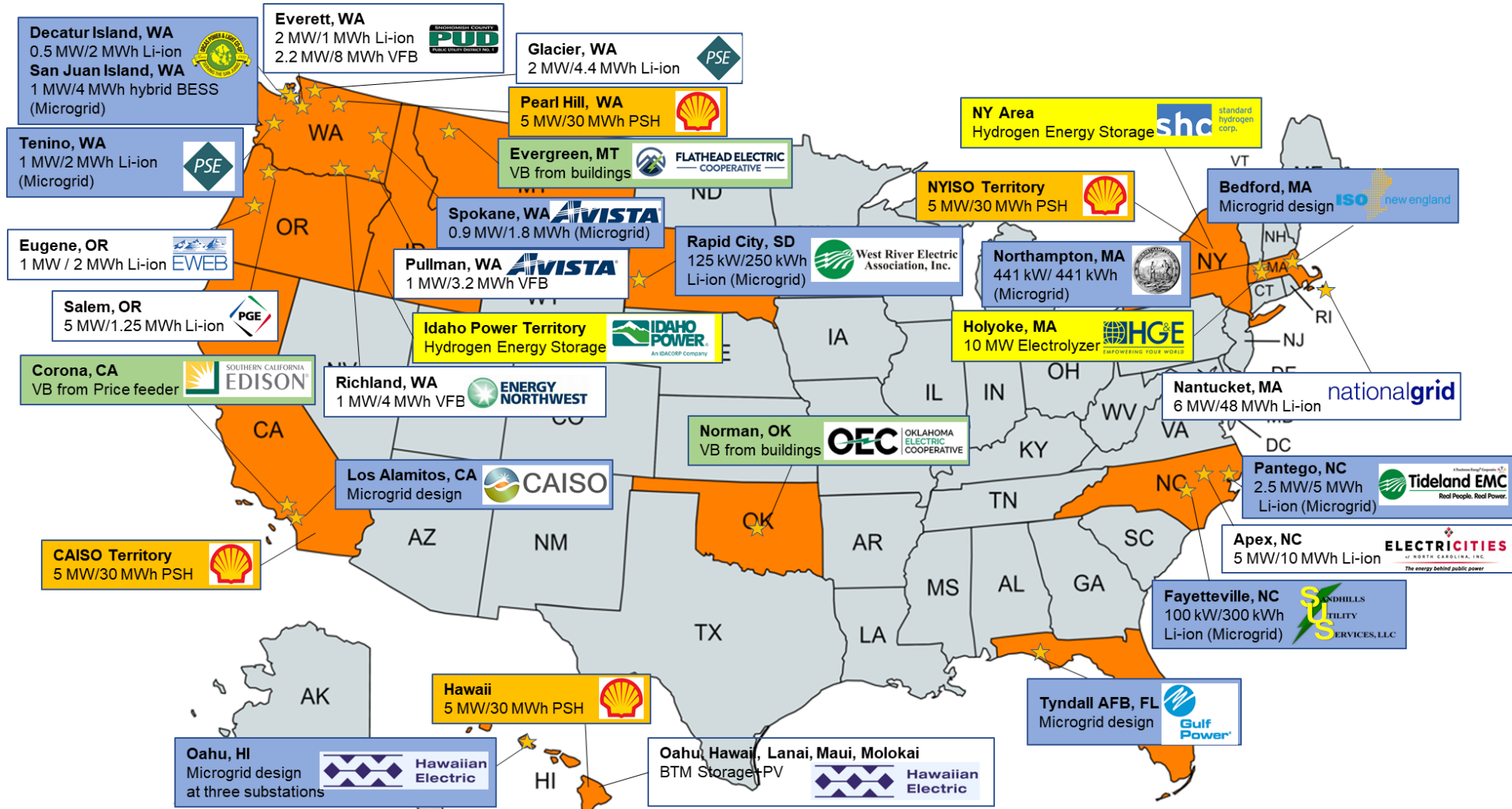
Energy Storage Modeling and Valuation Tools

Dexin Wang, Senior Research Engineer
Pacific Northwest National Laboratory

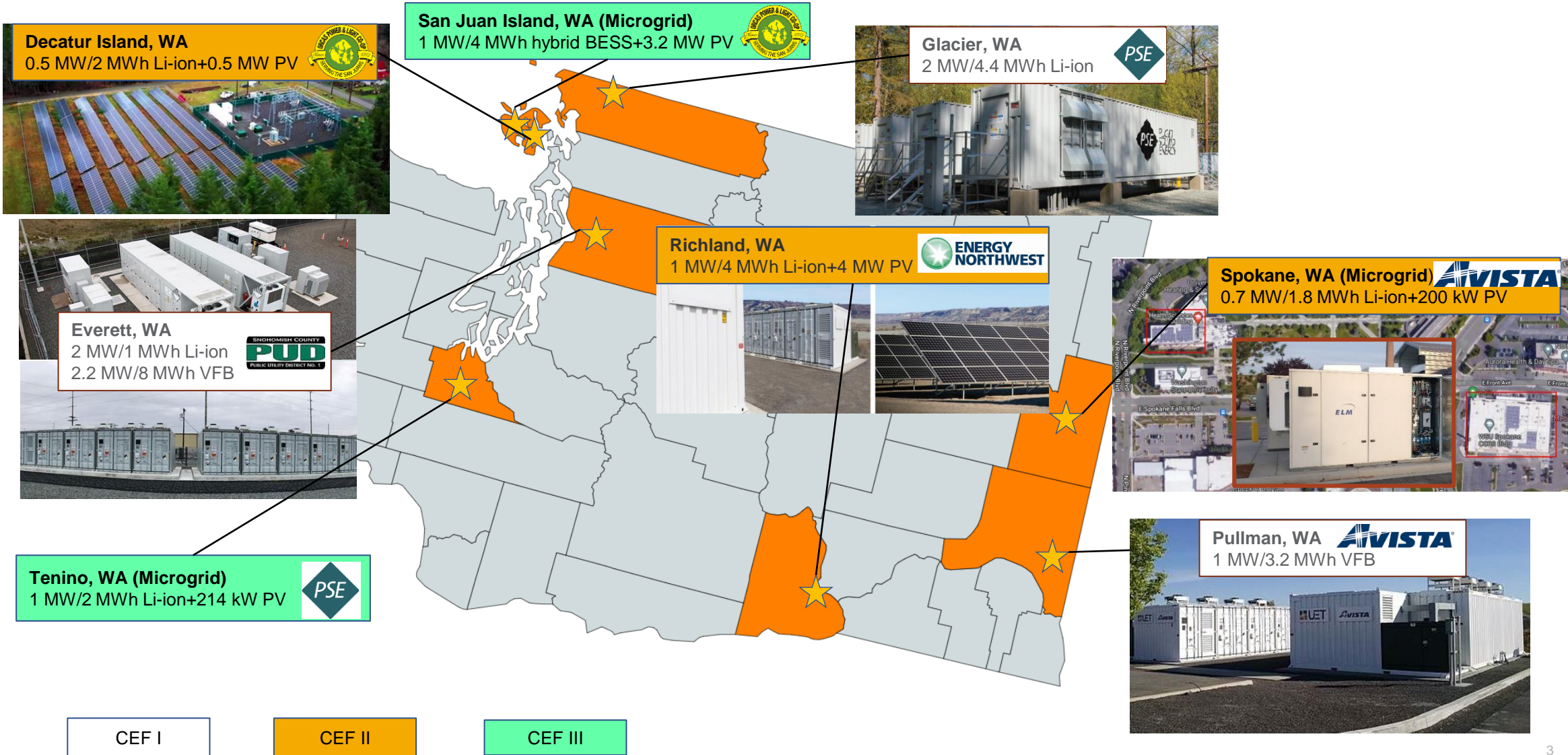
DOE Energy Storage Financing Summit
January 26th, 2023



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



Clean Energy Fund Grid Demonstration Projects



CEF I

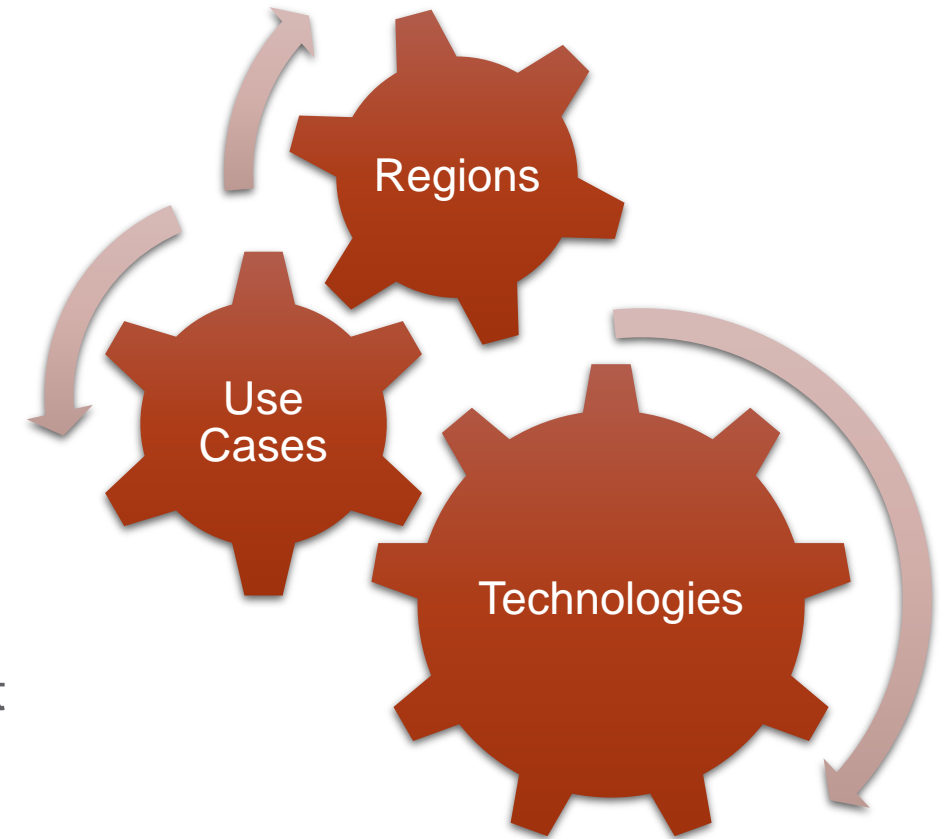
CEF II

CEF III

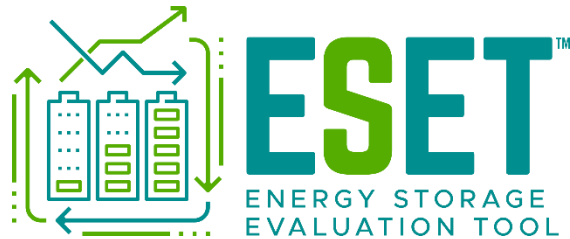
Needs of Energy Storage Analytics

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)

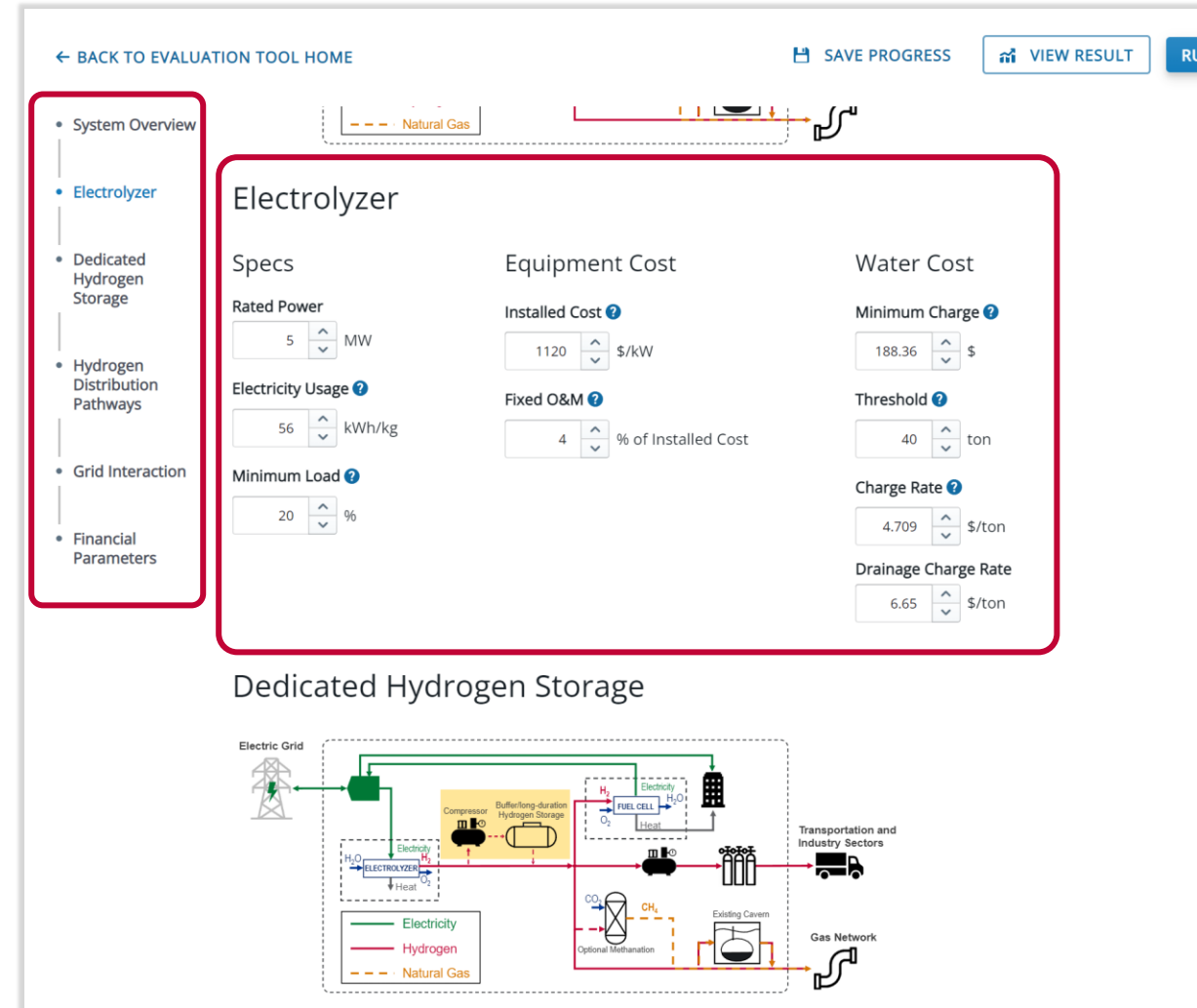


ESET Features

- **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



The screenshot displays the ESET web application interface. At the top, there are navigation links: "← BACK TO EVALUATION TOOL HOME", "SAVE PROGRESS", "VIEW RESULT", and "RL". A sidebar on the left contains a menu with the following items: "System Overview", "Electrolyzer" (highlighted in blue), "Dedicated Hydrogen Storage", "Hydrogen Distribution Pathways", "Grid Interaction", and "Financial Parameters".

The main content area is titled "Electrolyzer" and is enclosed in a red border. It is divided into three columns of adjustable parameters:

- Specs:**
 - Rated Power: 5 MW
 - Electricity Usage: 56 kWh/kg
 - Minimum Load: 20 %
- Equipment Cost:**
 - Installed Cost: 1120 \$/kW
 - Fixed O&M: 4 % of Installed Cost
- Water Cost:**
 - Minimum Charge: 188.36 \$
 - Threshold: 40 ton
 - Charge Rate: 4.709 \$/ton
 - Drainage Charge Rate: 6.65 \$/ton

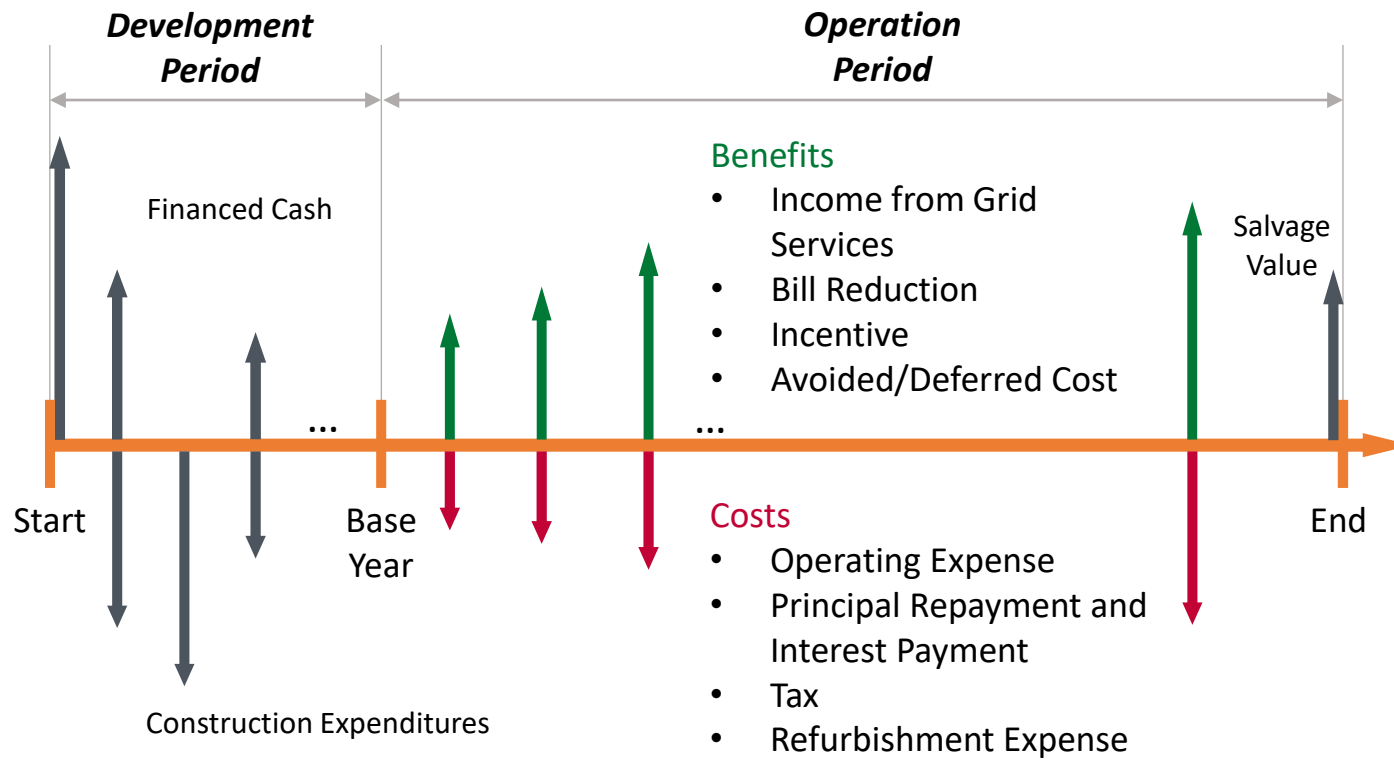
Below the configuration panel is a diagram titled "Dedicated Hydrogen Storage". The diagram illustrates the flow of energy and materials through the system. It shows the "Electric Grid" providing power to an "ELECTROLYZER" (which uses H₂O and Electricity to produce H₂ and O₂). The H₂ is then compressed and stored in "Buffer/long-duration Hydrogen Storage". From there, it can be used in a "FUEL CELL" (which produces Electricity and Heat) or sent to "Transportation and Industry Sectors". Alternatively, the H₂ can be converted to CH₄ via "Optional Methanation" and stored in an "Existing Cavern" before being distributed through a "Gas Network". A legend at the bottom of the diagram identifies the flow lines: green for Electricity, red for Hydrogen, and orange for Natural Gas.

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

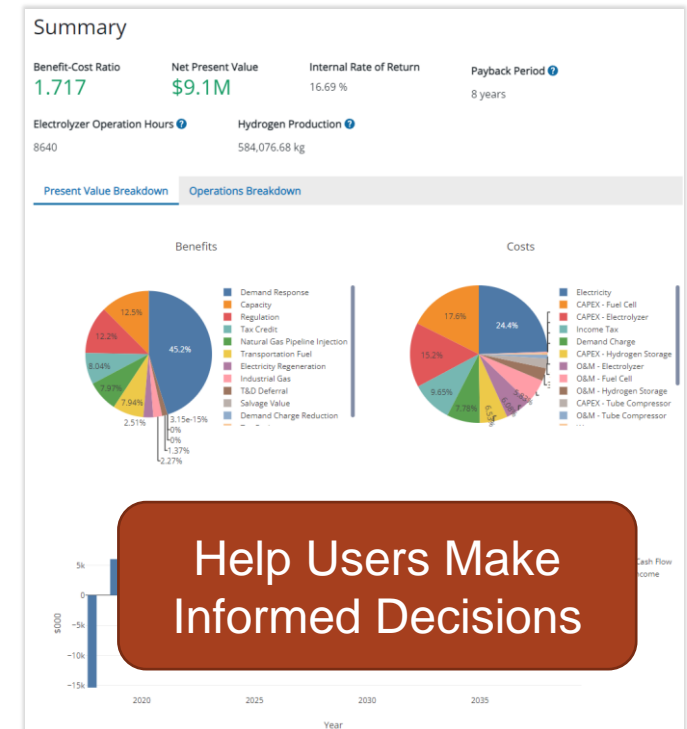
Comprehensive Cost-Benefit Analysis Engine

• Typical Cash Flow for ESS Projects



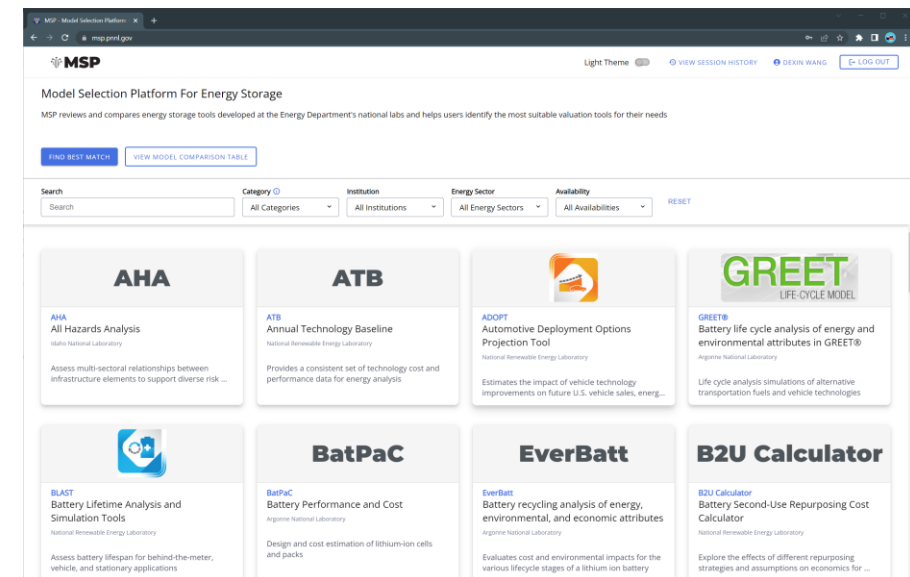
Results

- 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

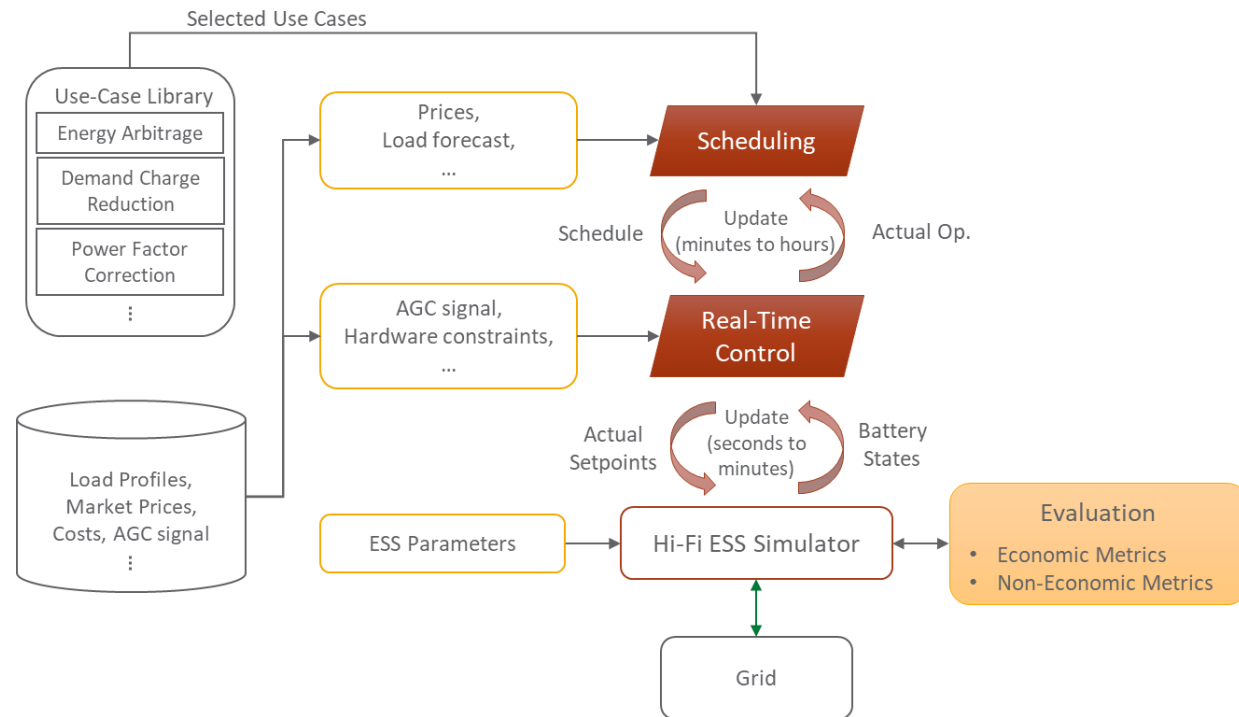


<https://msp.pnnl.gov>

ES-Control

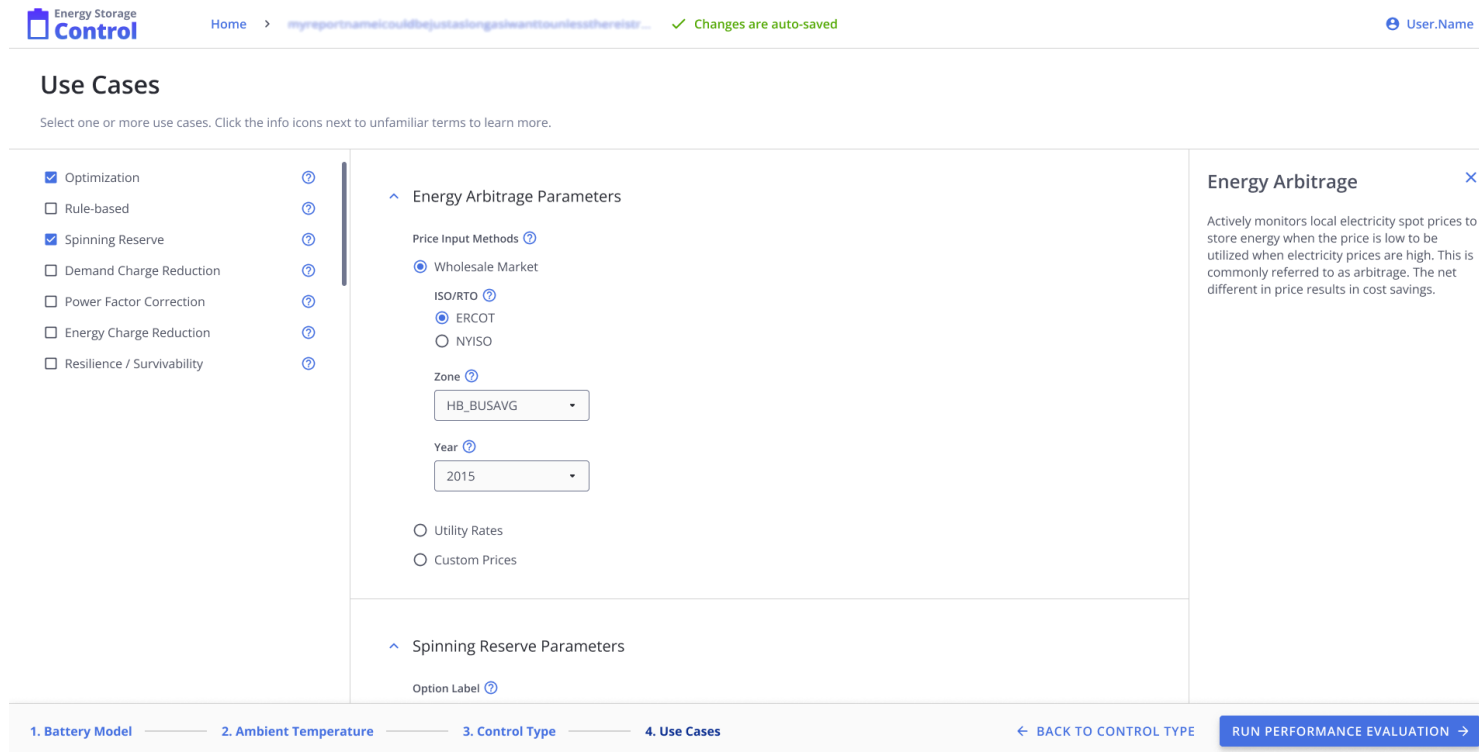
ES-Control is a platform for evaluation and testing of energy storage control strategies and algorithms with diversified time scales in a realistic setting, considering deployment options, use cases, and applications.

- 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.



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



The screenshot shows the ES-Control web application interface. At the top, there is a navigation bar with the "Energy Storage Control" logo, a breadcrumb trail "Home > myreportnamecouldbejustaslongaswewanttoincludehere", a green status message "Changes are auto-saved", and a user profile icon labeled "User.Name".

The main content area is titled "Use Cases" and includes a sub-instruction: "Select one or more use cases. Click the info icons next to unfamiliar terms to learn more." On the left, a list of use cases is shown with checkboxes and info icons: Optimization (checked), Rule-based, Spinning Reserve (checked), Demand Charge Reduction, Power Factor Correction, Energy Charge Reduction, and Resilience / Survivability.

The central panel is titled "Energy Arbitrage Parameters" and contains the following settings:

- Price Input Methods: Wholesale Market (selected)
- ISO/RTO: ERCOT (selected), NYISO
- Zone: HB_BUSAVG (dropdown menu)
- Year: 2015 (dropdown menu)
- Utility Rates (radio button)
- Custom Prices (radio button)

Below this panel is the "Spinning Reserve Parameters" section, which currently shows "Option Label" with an info icon.

On the right side, a sidebar titled "Energy Arbitrage" with a close button (X) contains a descriptive text: "Actively monitors local electricity spot prices to store energy when the price is low to be utilized when electricity prices are high. This is commonly referred to as arbitrage. The net different in price results in cost savings."

At the bottom, a navigation bar shows four steps: "1. Battery Model", "2. Ambient Temperature", "3. Control Type", and "4. Use Cases" (the current step). To the right of the steps are two buttons: "← BACK TO CONTROL TYPE" and "RUN PERFORMANCE EVALUATION →".

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



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>

Bob Kirchmeier
Jeremy Berke



Thank You

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(509) 372-6231

<https://www.pnnl.gov/energy-storage>

<https://eset.pnnl.gov/>

<https://msp.pnnl.gov/>

