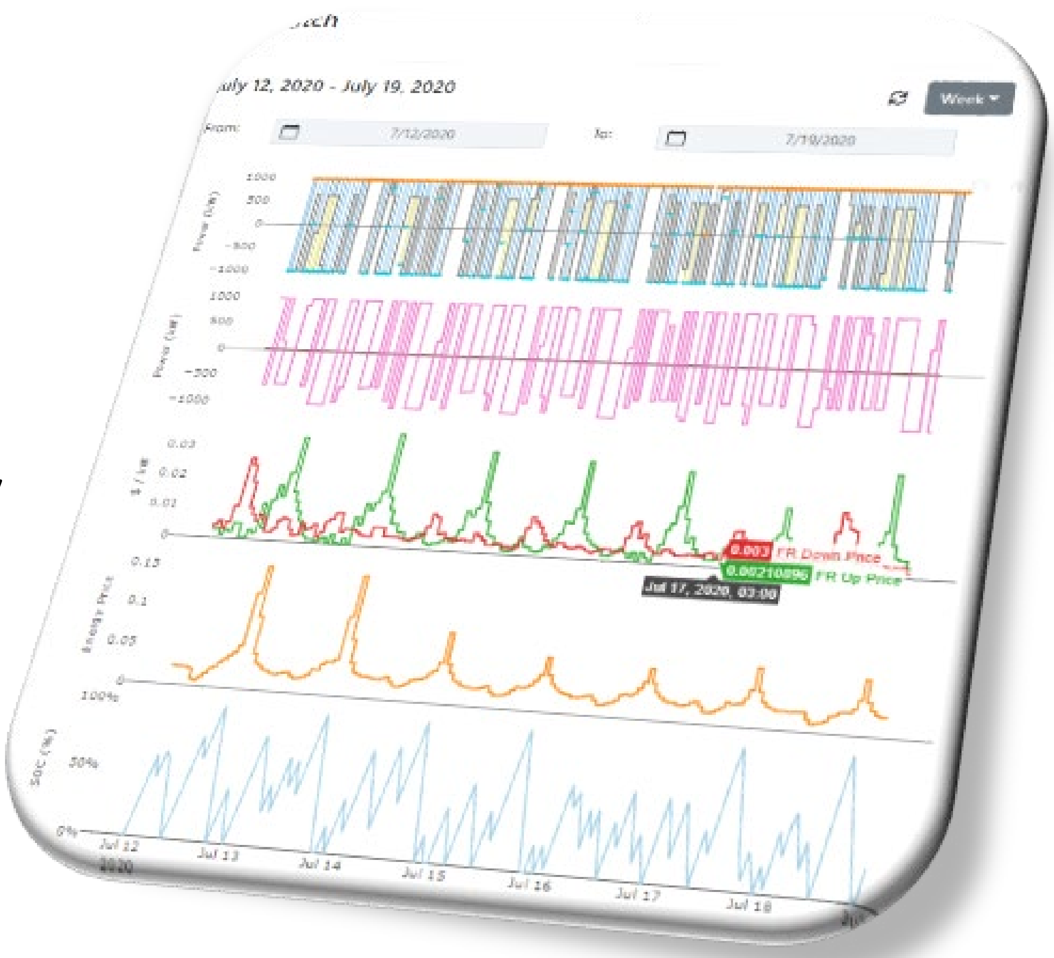
Energy Storage, DER, and Microgrid Project Valuation

EPRI DER-VET™ Analysis in Action

October 2021

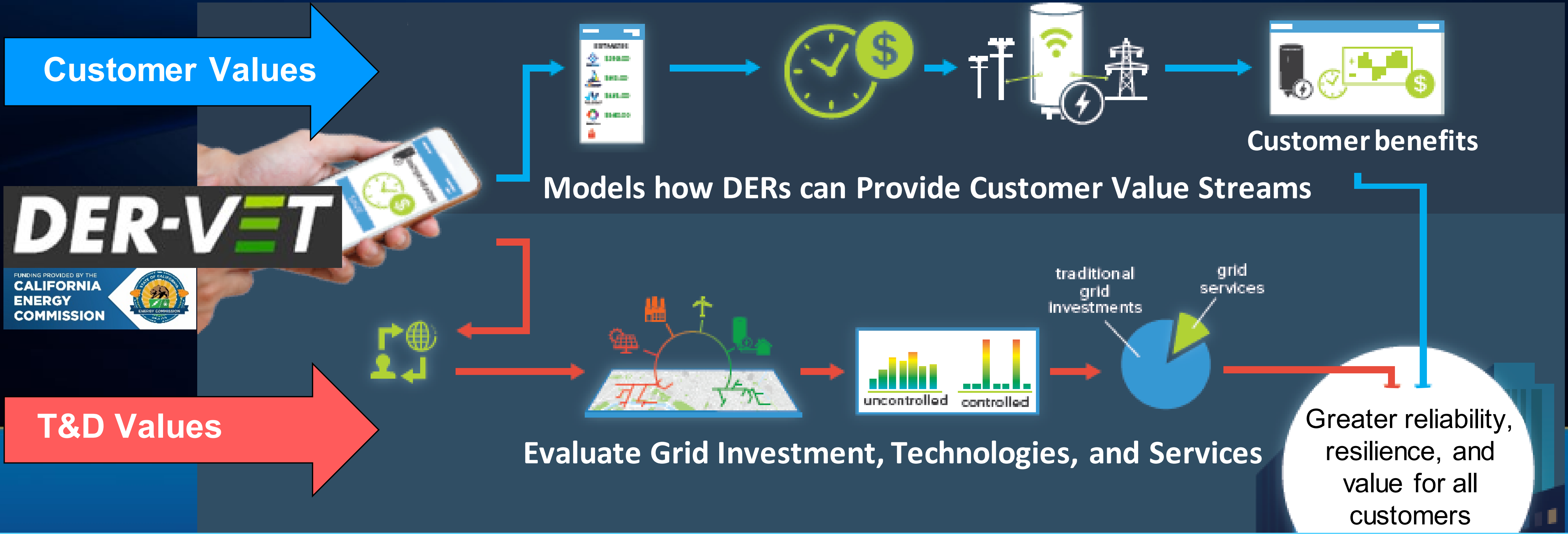
Storage, DER, and Microgrid Modeling Challenges

- Benefit stacking is appealing…
  - More services = more value
  - More services = more requirements → But can they be satisfied?
- Value of storage requires technology and site-specific analysis
- Complex co-optimization and decision-making process



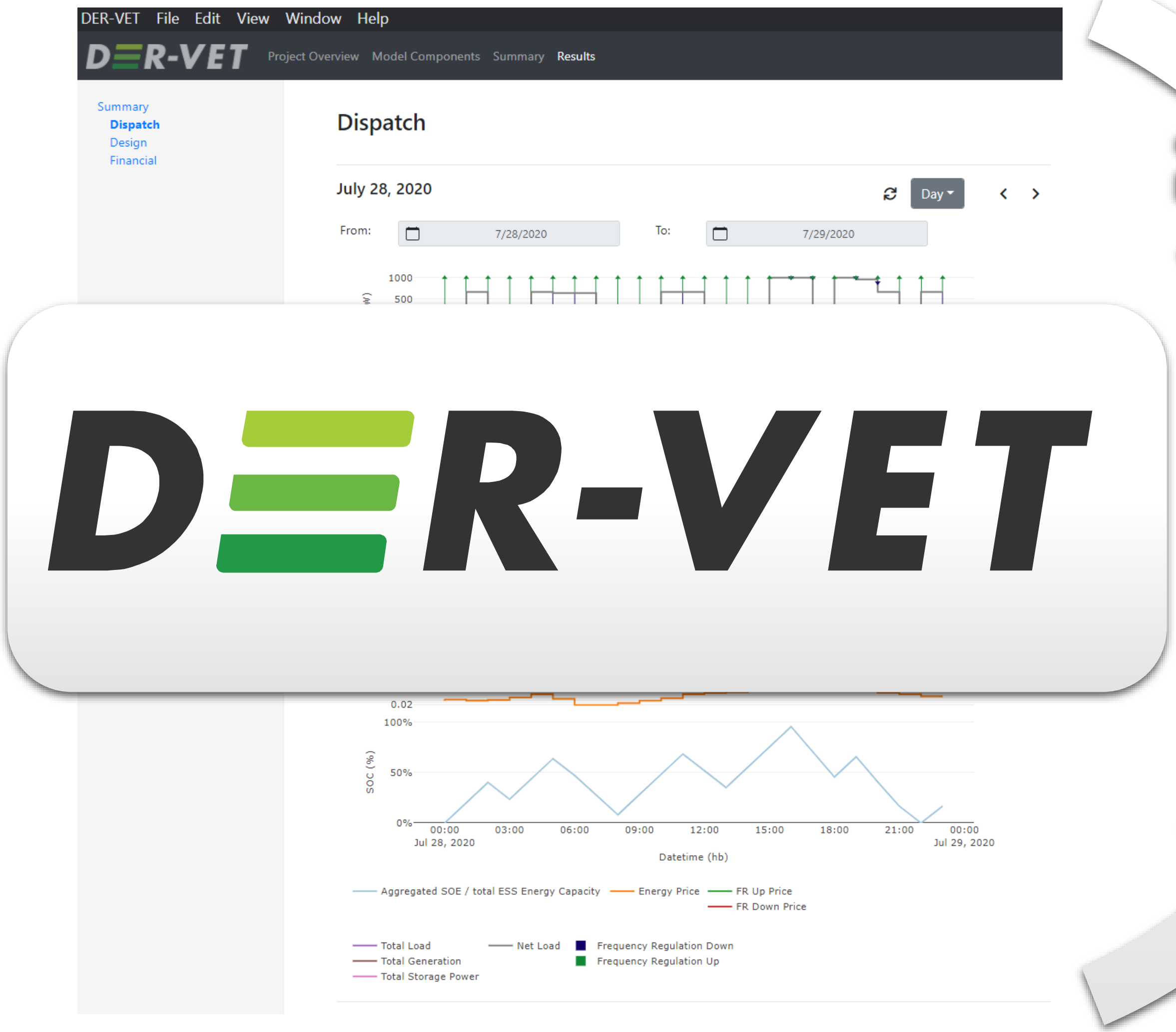
EPRI's DER-VET™ (2021) and StorageVET® (2016 & 2019) address these challenges

The Solution: Validated, Transparent, and Accessible DER Valuation and Optimization Tool (DER-VET™)



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

DER-VET™ Value Proposition



Bridges industry gaps in project-level energy storage, DER, and microgrid analysis

Creates a common communication tool among all stakeholders

Gives multiple analysis perspectives for every user and market

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

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

2020
EPRI DER-VET Beta

2021
EPRI DER-VET™ V1.1
500+ Users

www.der-vet.com

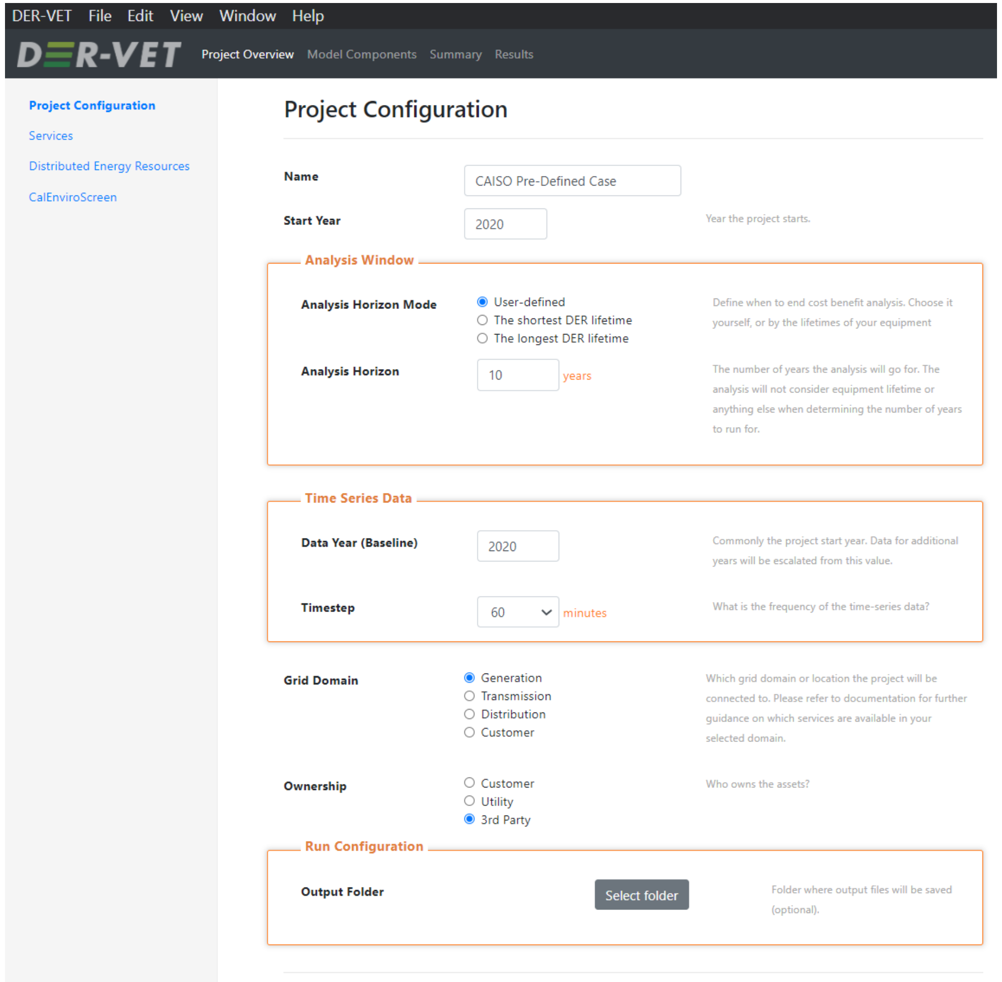
202X
DER-VET User Group and Open-Source Developer Community

Access DER-VET now at www.der-vet.com

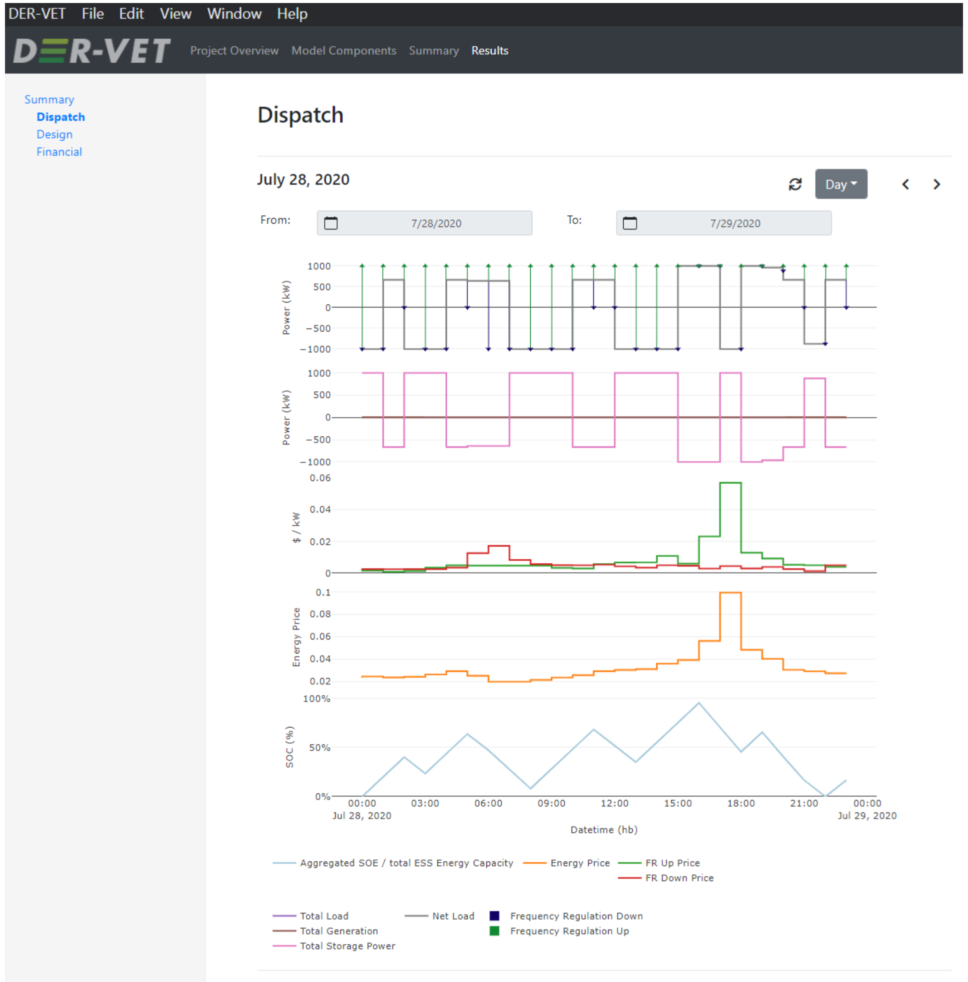
DER-VET Architecture and Features

Input and Output Examples in DER-VET

DER-VET Project Configuration Example

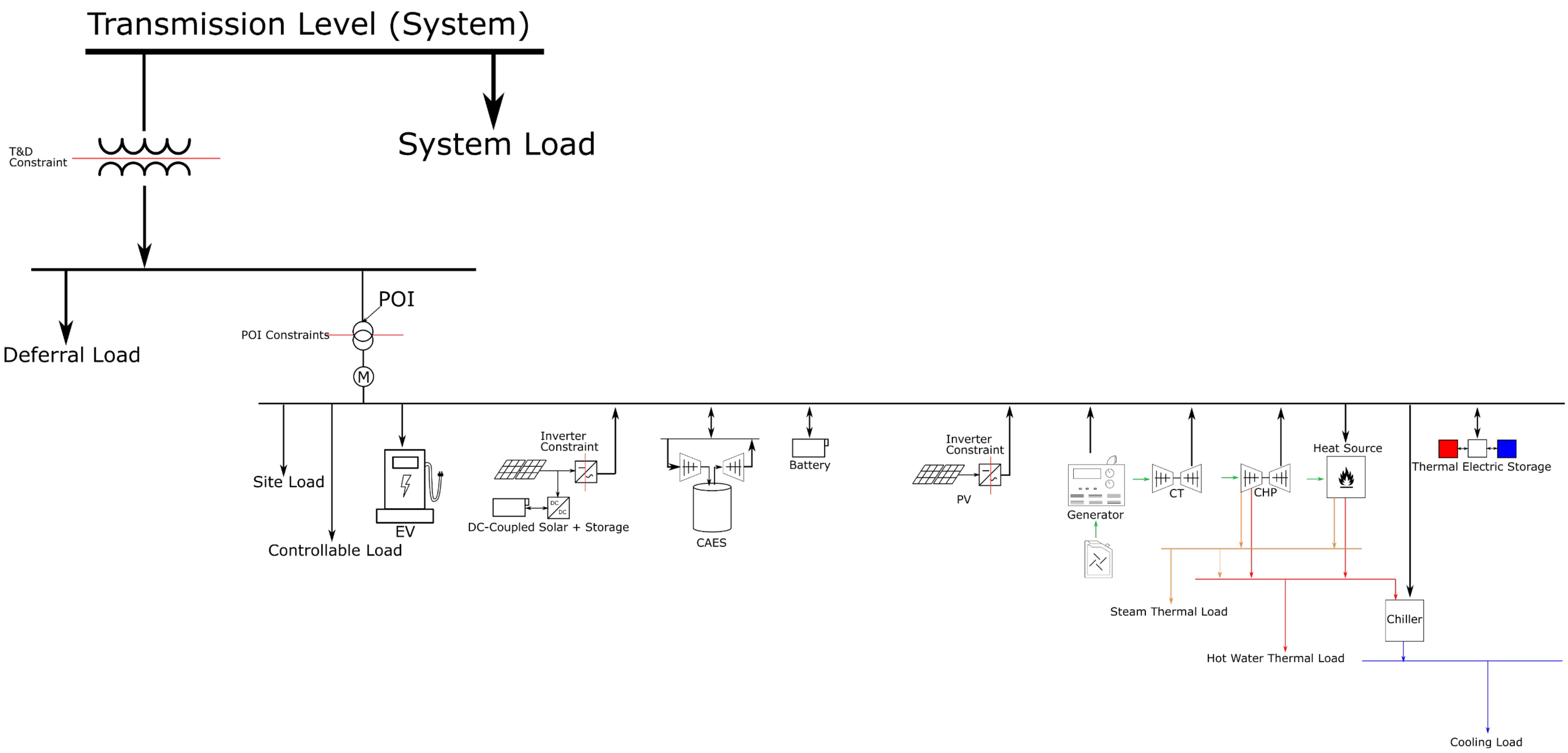


DER-VET Dispatch Results Example



www.epri.com

Technologies in DER-VET



Services in DER-VET

Bulk Market Services

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

T&D Services

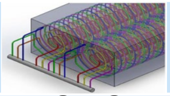
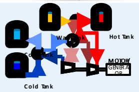
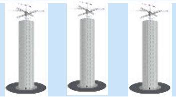
- Upgrade Deferral
- Reliability/Resilience

Customer Services

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

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

- Modeling Inputs
  - Round-Trip Efficiency (RTE) (Total AC power generated / total AC energy consumed)
  - Capital Costs (Anticipated costs for power [$/kW] & energy [$/kWh])
  - Operating Costs (Dwell energy losses, maintenance, and augmentation)
  - Startup Energy (Energy consumed during startup)

DER-VET Base Case and Sensitivities

Base

- All technologies were run using the original pricing curves in each region for the 6-, 8-, and 10-hour duration cases (Li-ion batteries were also run at their prevalent 4-hour duration case)

Sensitivities

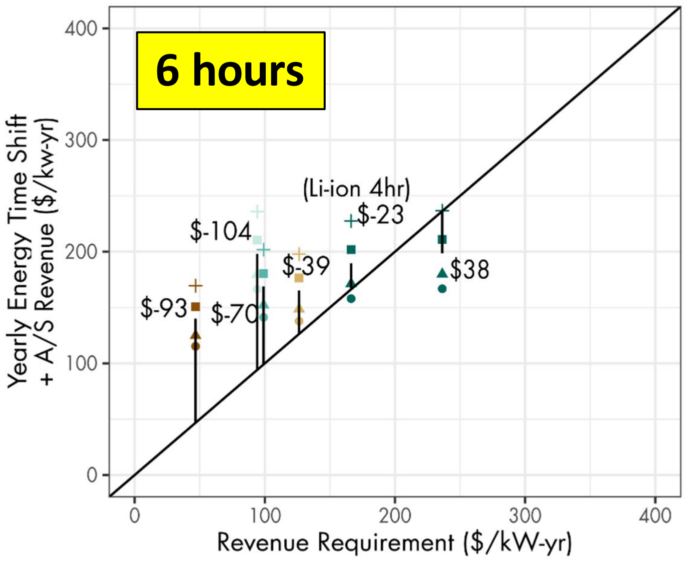
- Capital costs were adjusted +10% / -30%
- Energy prices were modified (mod) from their original (orig)
- RTE was adjusted +/- 5% points

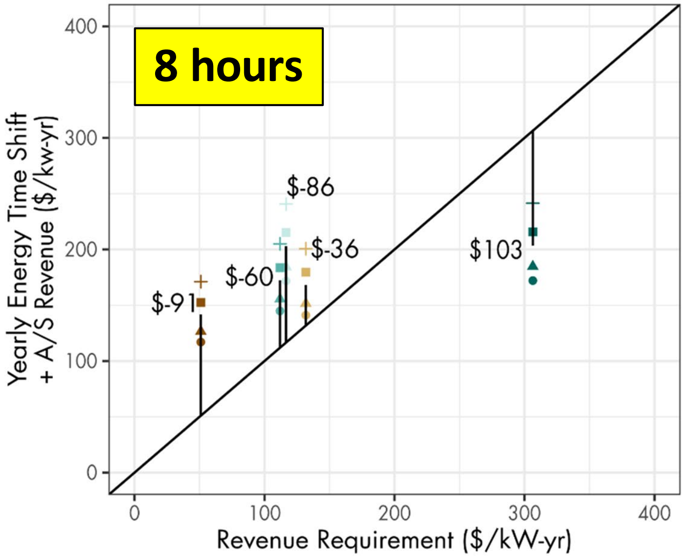
18 Cases per Technology per Hours of Duration

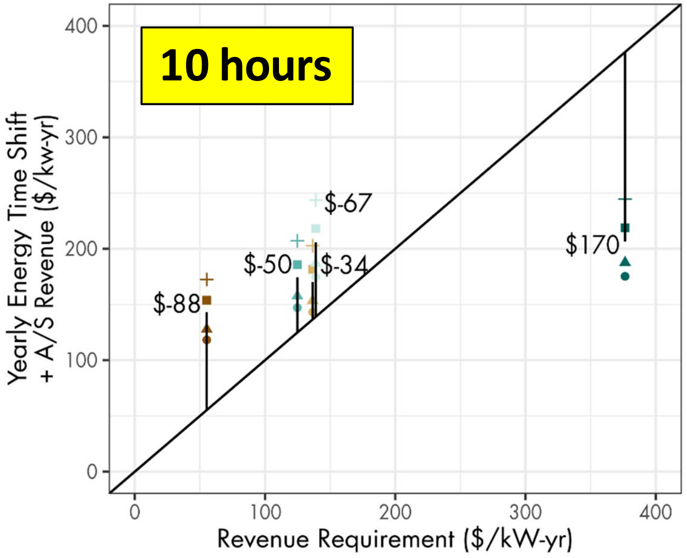
Pricing	Orig	Orig	Orig	Orig	Orig	Orig	Orig	Orig	Orig
RTE	Base	Base	Base	High	High	High	Low	Low	Low
Costs	Base	High	Low	Base	High	Low	Base	High	Low
Pricing	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod
RTE	Base	Base	Base	High	High	High	Low	Low	Base
Costs	Base	High	Low	Base	High	Low	Base	High	Base

Significant number of DER-VET cases: 1728 total

DER-VET Results: Tech Duration vs. Revenue Requirements







Revenue Requirement ($/kW-yr)

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

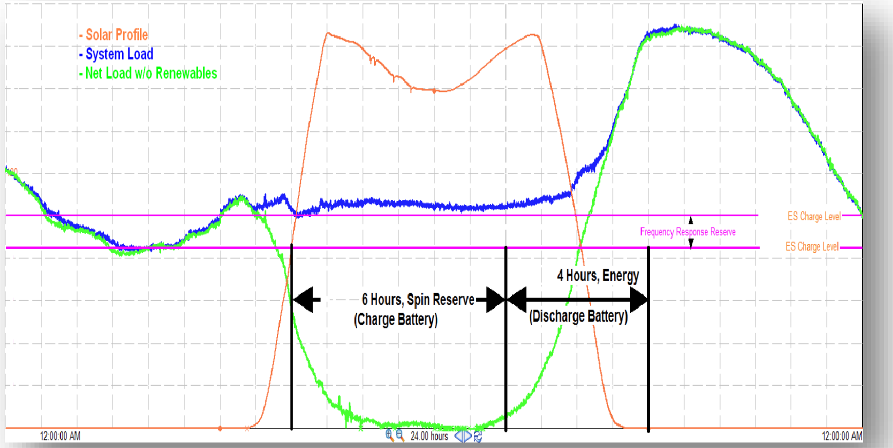
Transmission Solar + Energy Storage Case Study

LADWP Energy Storage Project #1

- Los Angeles Department of Water and Power (LADWP) was required to meet its California Senate Bill SB801 requirements to procure energy storage

- The study considers a 100 MW, 4-hour battery energy storage system paired with a 200 MW solar PV facility to be procured through a Power Purchase Agreement (PPA) with a third-party developer who would be able to claim Federal Investment Tax Credit (FITC) incentive

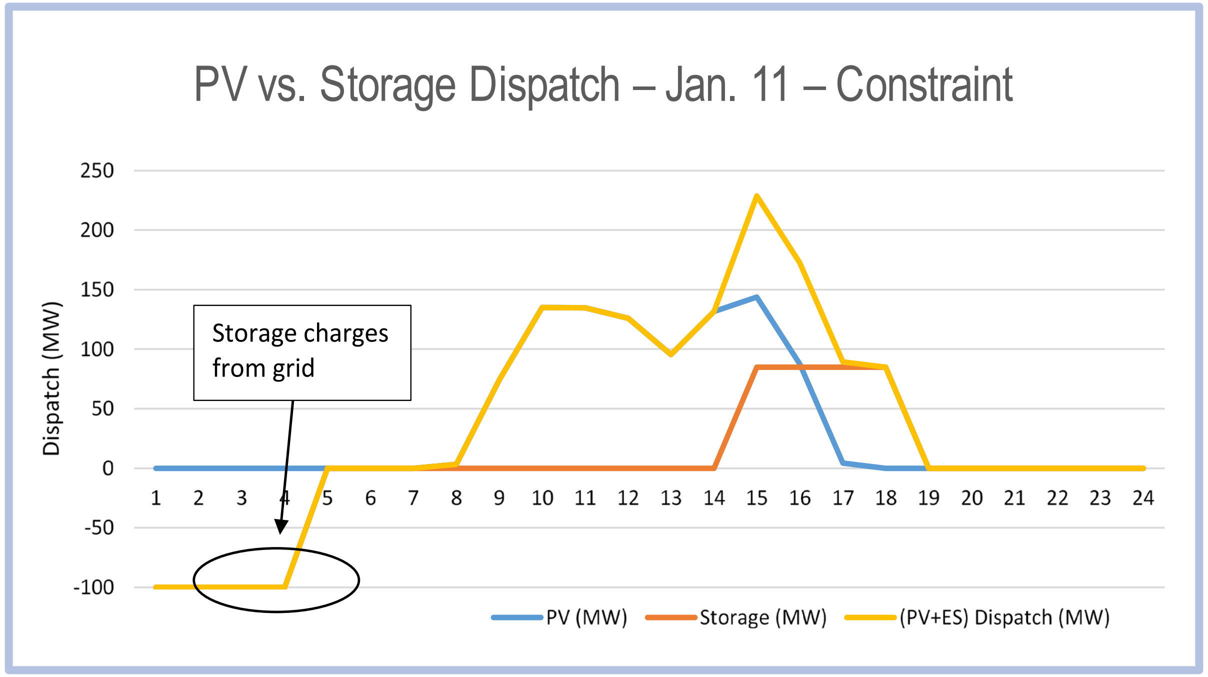
	Provide Energy Time Shift and Spinning Reserve	Restrict Charging from Grid	Restrict Charging from Grid and Discharge Min	Provide Frequency Response
Case #1	✓		✓	
Case #2	✓		✓	✓
Case #3	✓	✓		
Case #4	✓	✓		✓

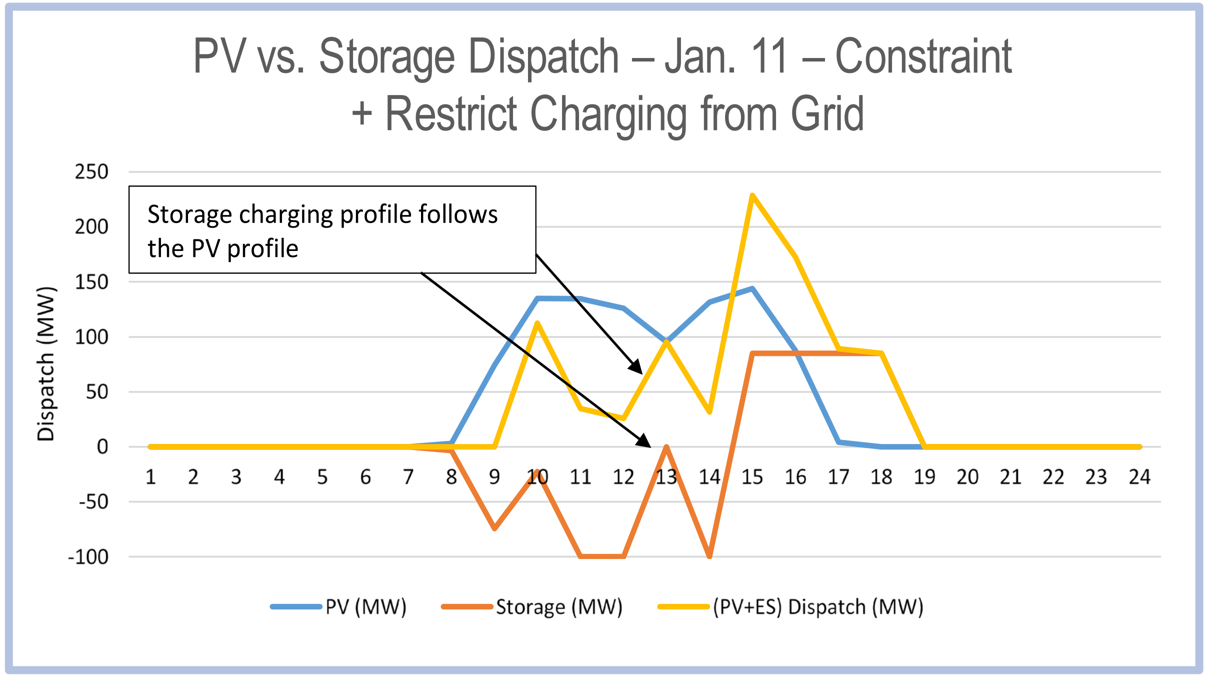


LADWP Full Report: *Integrating Energy Storage System with Photovoltaic Generation: Analysis within Los Angeles Department of Water and Power (LADWP) Service Territory to Meet SB801 Requirements at* http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002013007

LADWP Case Results - Dispatch

- Impact of grid charging constraints



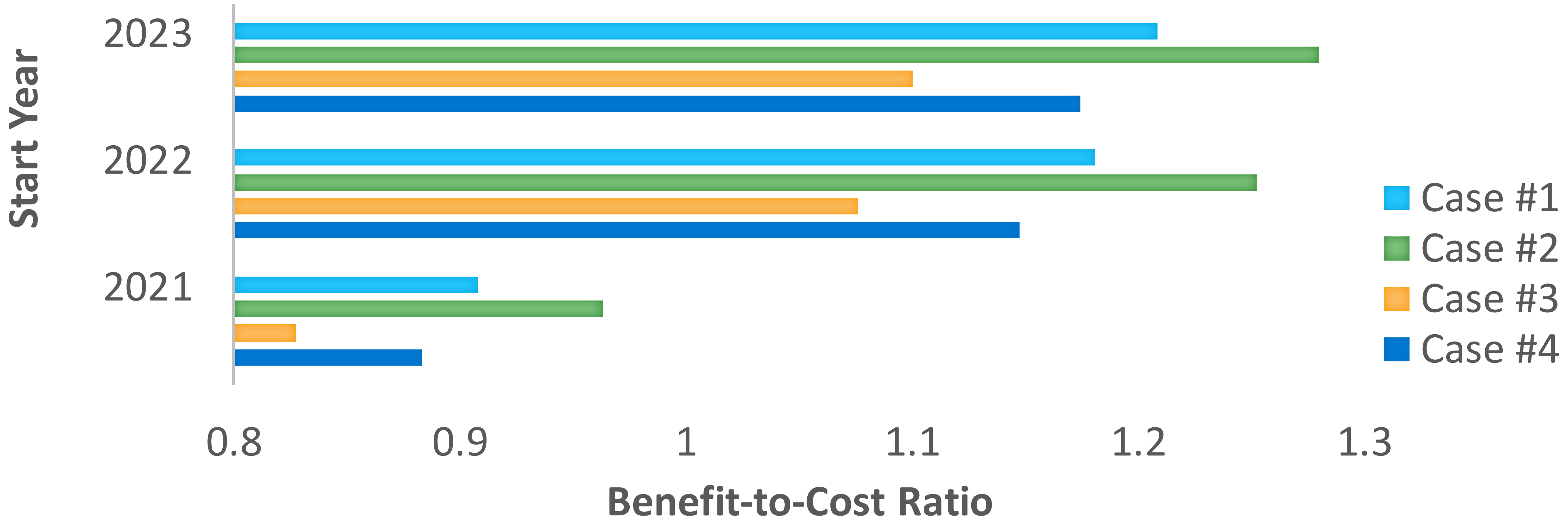


DER-VET Optimized Dispatch Outputs

EPRI

LADWP Case Results - CBA

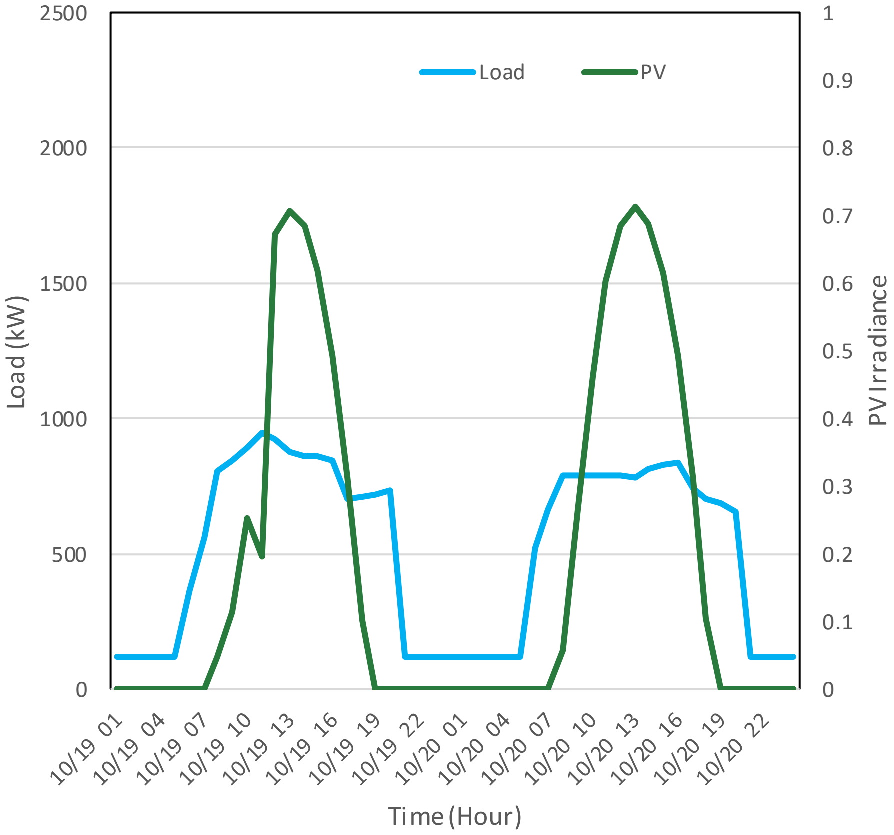
- Several cases resulted in benefit-cost ratios greater than one for project starts years after 2022 as illustrated in the graph below



Microgrid Design for PSPS Events

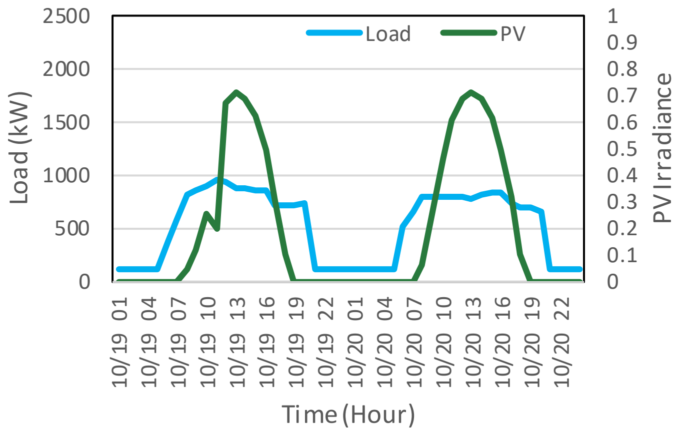
Microgrid Design - DER-VET Modeling Assumptions

- Identify potential Public Safety Power Shutoff (PSPS) planned events and duration in California
  - A load profile is chosen from Aug-Dec time period with the highest net energy demand
  - Load cannot be shed
- Solar PV assumptions and limitations
  - Corresponding Solar irradiance profile
  - PV profile from TMY profile
  - PV can be curtailed
- Battery ES assumptions:
  - Initial SOC at the start of outage event is 100%
  - Battery round trip efficiency – 91%
  - Hybrid solar plus storage installation – co-located at the dc side



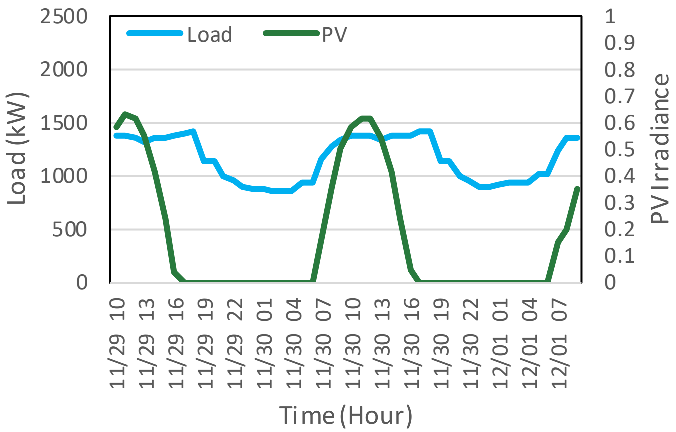
Load and PV Profile

LA – Sec School



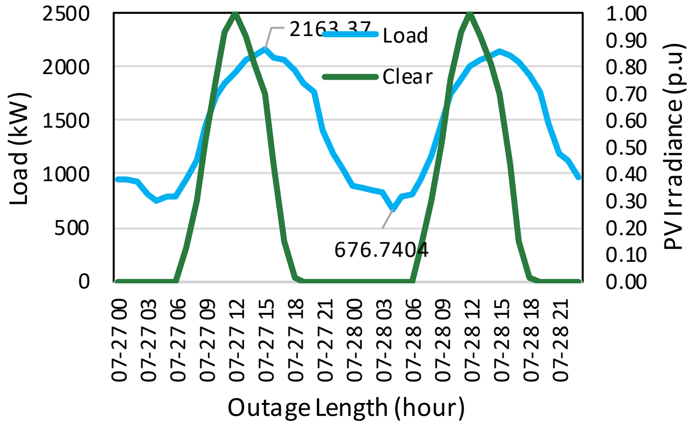
Peak load – 0.9 MW
24hr load requirement – 13MWh
36hr load requirement – 18MWh
48hr load requirement – 25MWh

LA - Hospital



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

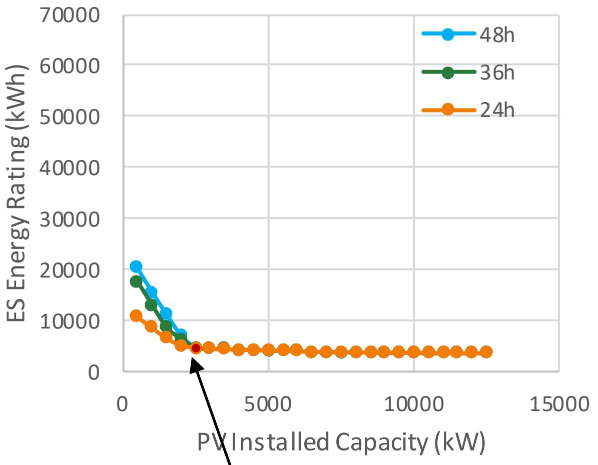
SCE Feeder



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

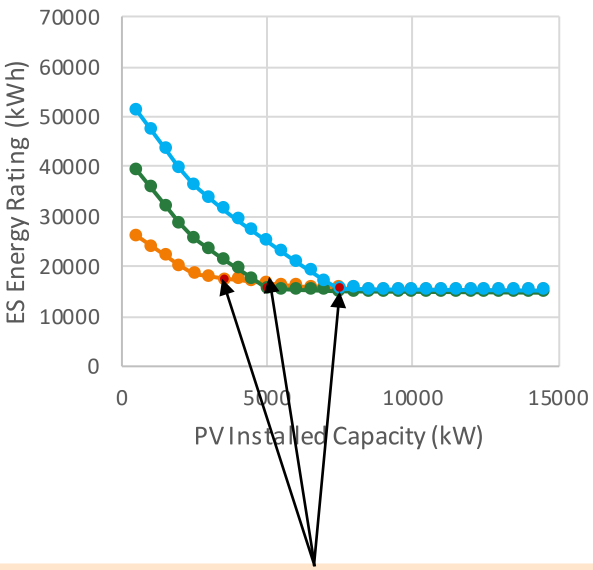
Microgrid Sizing Results

LA – Sec School



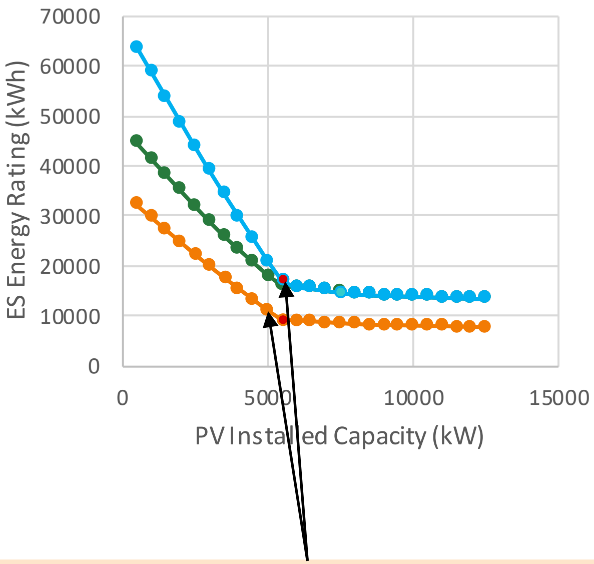
2.5MW PV +
0.735MW/4.9MWh ES

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

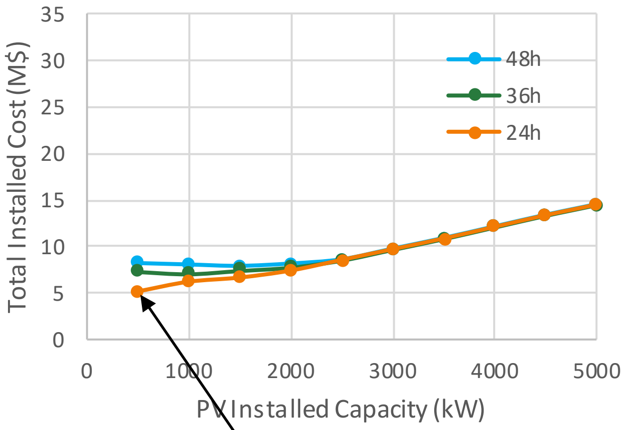


24h – 5.5MW PV+1.9MW/9.2MWh ES
36h– 5.5MW PV+1.9MW/17.2MWh ES
48h – 5.5MWPV +2 MW/17.2MWh ES

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.

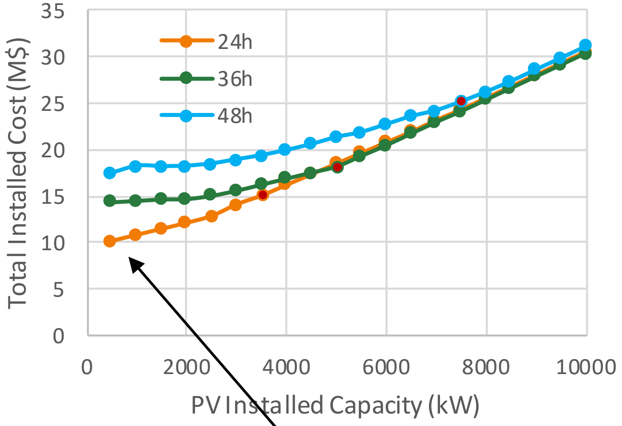
Microgrid Cost Summary

LA – Sec School



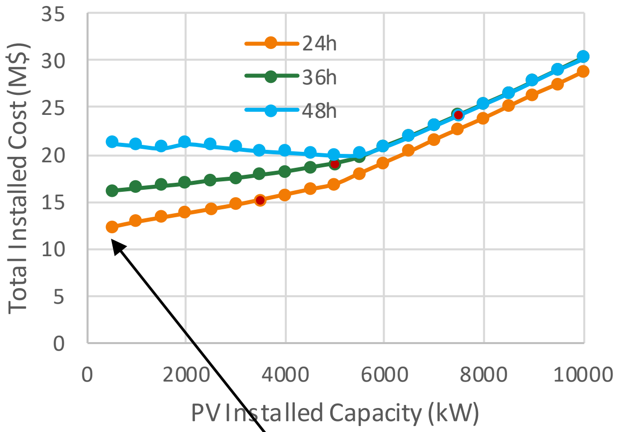
Min Cost of covering 24, 36 and 48hr outage – **5M$, 7M$ and 8M$**

LA - Hospital



Min Cost of covering 24, 36 and 48hr outage – **10M$, 14M$ and 17.5M$**

SCE Feeder



Min Cost of covering 24, 36 and 48hr outage – **12M$, 16M$ and 21.5M$**

Questions?

- Visit www.der-vet.com
  - Download the tool for free
  - Reference case examples
  - Help and documentation

- **NOTE:** Additional Detailed Case Studies in Appendix
  - T&D Upgrade Deferral
  - Military Installation Microgrid
  - Utility-Sited PSPS Microgrid
  - More details from case studies presented above

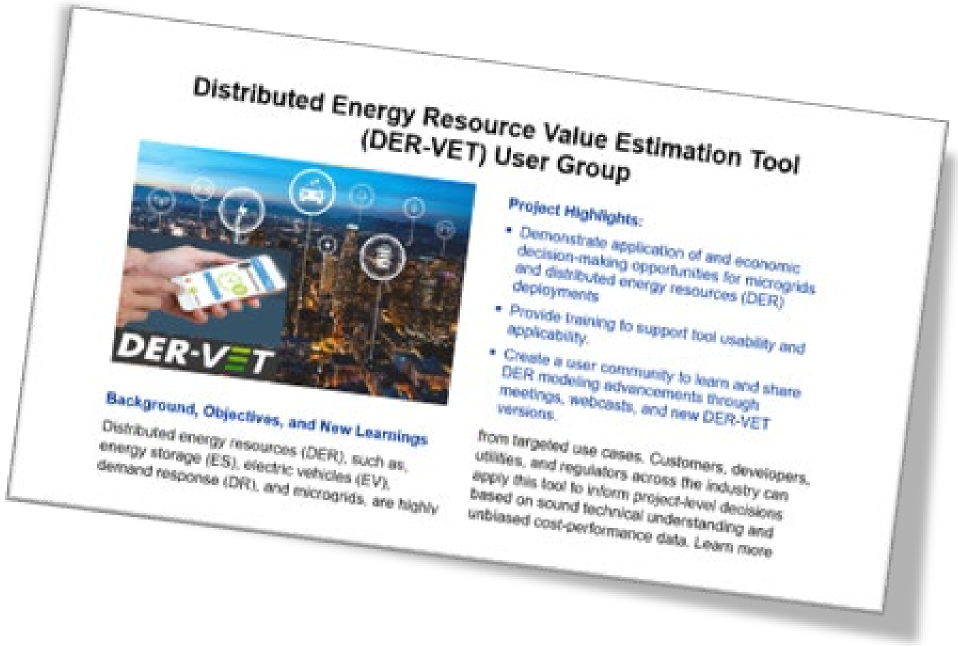
Together…Shaping the Future of Energy™

Additional DER-VET Background

DER-VET™ User Group

OBJECTIVES:

- Demonstrate application and economic decision-making opportunities to promote the applicability of microgrids and DER deployments
- Provide a forum to support tool usability, applicability, and user supported feature improvements
- Create a user community to learn and share experience and hare in training on DER-VET through meetings and webcasts


Distributed Energy Resource Value Estimation Tool (DER-VET) User Group

DER-VET

Project Highlights:
- Demonstrate application of and economic decision-making opportunities for microgrids and distributed energy resources (DER) deployments
- Provide training to support tool usability and applicability
- Create a user community to learn and share DER modeling advancements through meetings, webcasts, and new DER-VET versions

Background, Objectives, and New Learnings

Distributed energy resources (DER), such as energy storage (ES), electric vehicles (EV), demand response (DR), and microgrids, are highly

from targeted use cases. Customers, developers, utilities, and regulators across the industry can apply this tool to inform project-level decisions based on sound technical understanding and unbiased cost-performance data. Learn more

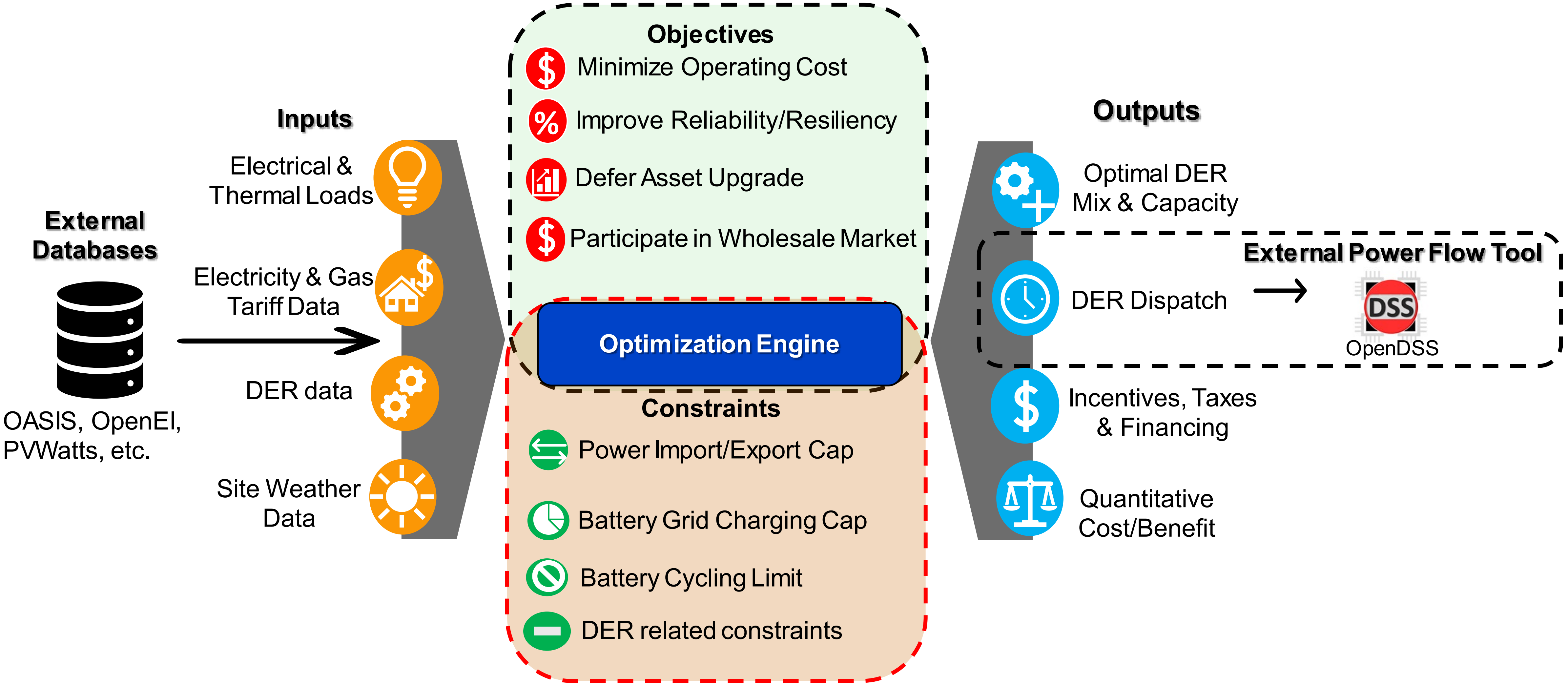
APPROACH:

- Access to advanced DER-VET modules, features, and datasets that promote tool usability and user experience
- Annual Meeting to provide updates on tool functionality, facilitate user experience sharing, and solicit inputs for tool development direction, new features, and updates
- Quarterly Webinars to share feedback of new feature development and case studies
- Personalized user training to facilitate for tool development and promote questions and answers

DETAILS	CONTACT
3 years **Funding** *Collaborators*: $45k **3002020769** Eligible for Self Directed Funds, Tailored Collaboration	**Ram Ravikumar** rravikumar@epri.com **Miles Evans** mevans@epri.com **Arindam Maitra** amaitra@epri.com **Giovanni Damato** gdamato@epri.com

Personalized DER-VET User Training to Promote Applicability

DER-VET Optimization Framework

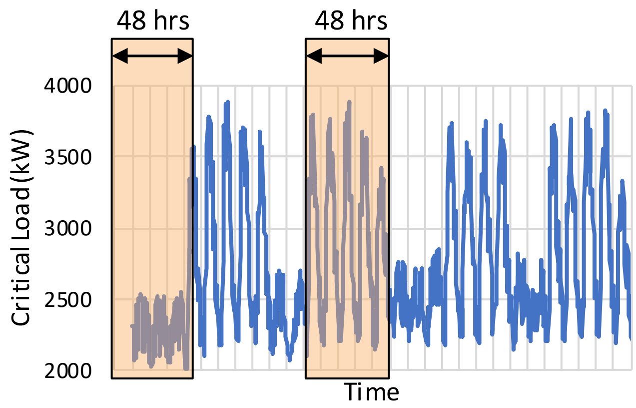


*DER-VET is CEC funded open-sources software tool. https://www.der-vet.com/

User-Defined Reliability Targets in DER-VET

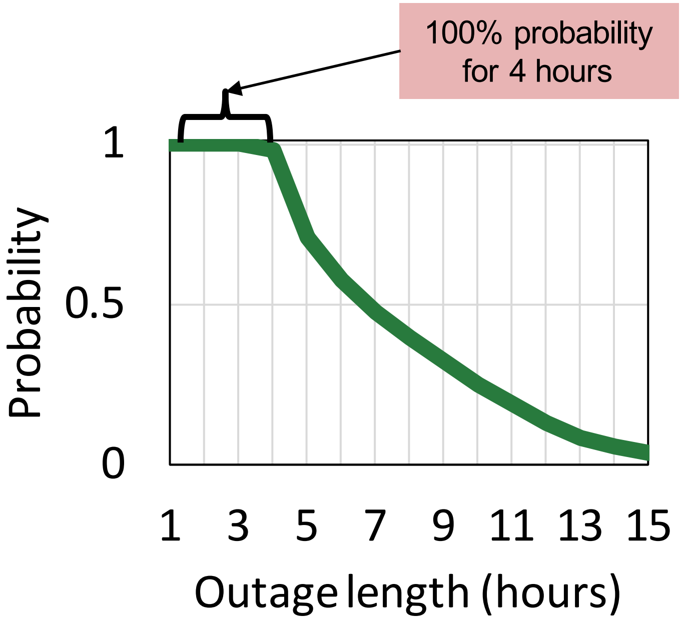
- **Planned Outages:**

  100% or <100% load coverage for target hours of **planned** outages



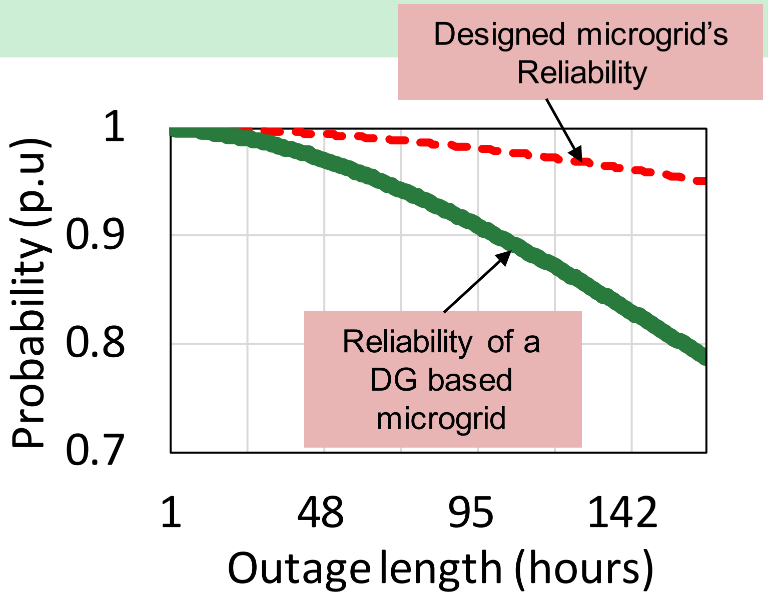
- **Un-planned Outages:**

  100% or <100% load coverage for target hours (ex. 4 hours) of any possible un-planned outages



- **Relational Definition:**

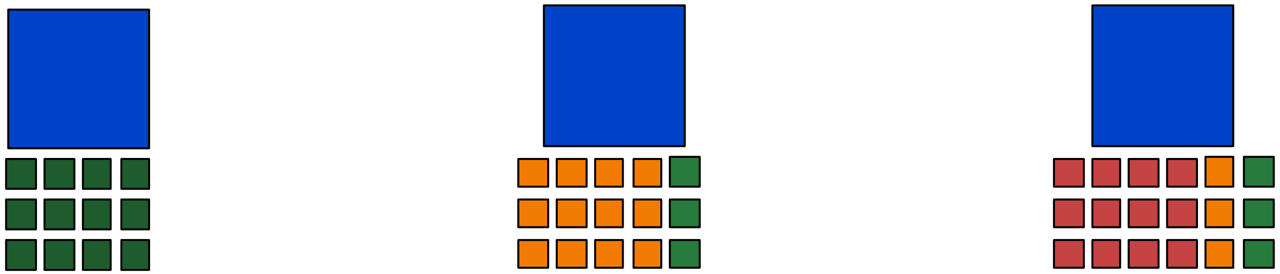
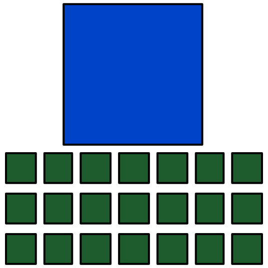
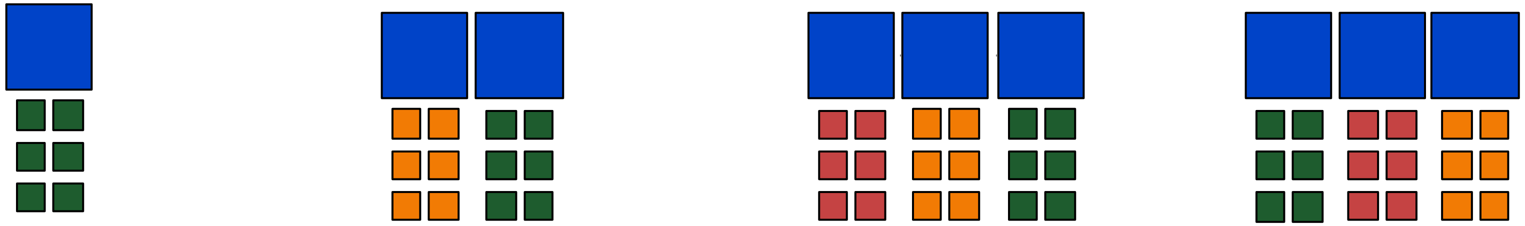
  Reliability target for every outage length



Microgrid is designed to have probabilistic reliability equal to or greater than the target

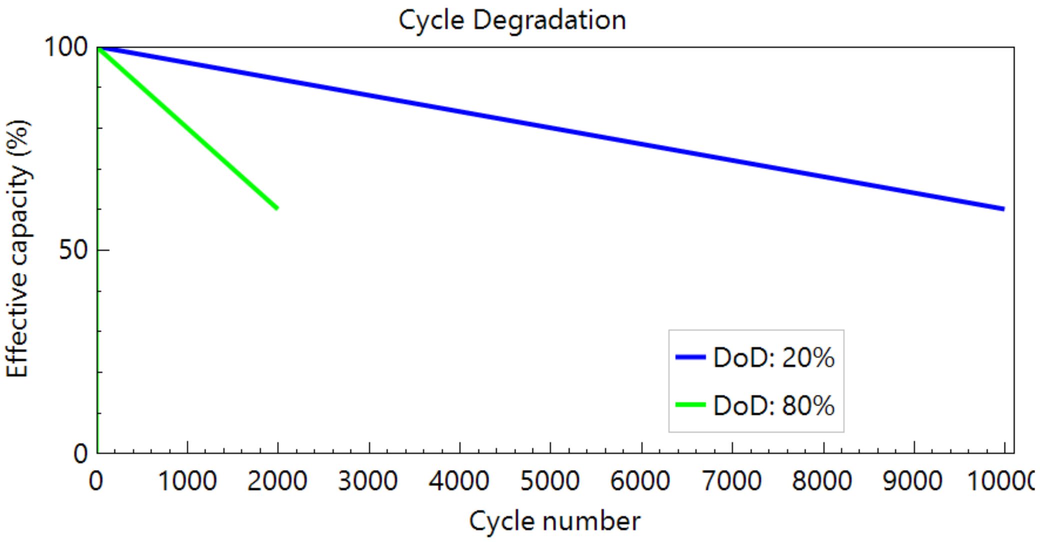
Energy Storage Implementation Strategies in DER-VET

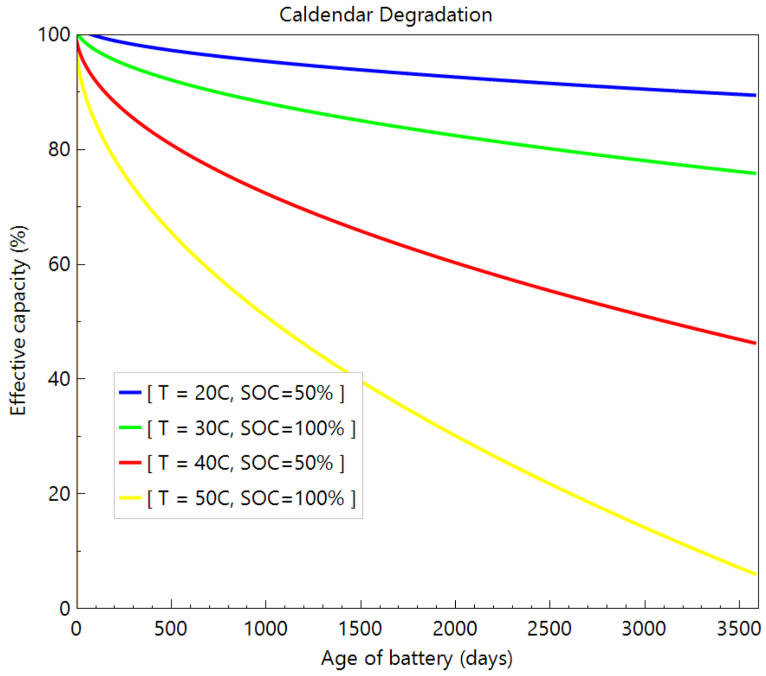
Time →

Augmentation	
Replacement	
Oversizing	
Modular Implementation	

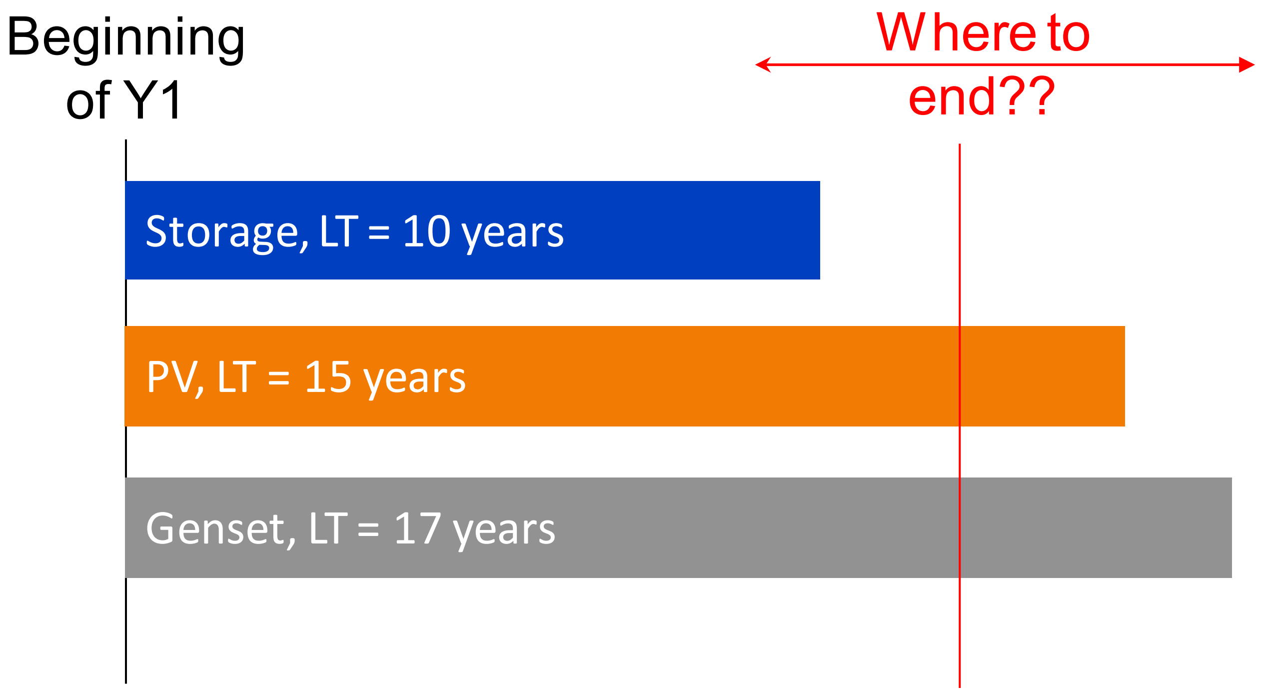
Degradation in DER-VET

- Only consider calendar and cycling degradation of energy capacity with no compounding stress factors
- Cycle life curve input and %/yr calendar degradation input
- Images from NREL's SAM tool (very similar degradation model)





CBA in DER-VET: Time Horizon Solution



- Analysis end time
  - Shortest lifetime of all assets
  - Longest lifetime of all assets
  - Something else user-defined
- Replacement
  - User can turn automated replacement on or off
- Remaining value/cost at end of analysis
  - Sunk cost (0$, do not consider)
  - Salvage value (linear decline over life or customized)
  - Decommissioning cost
- Annualize everything (ECC)

Slide Credit: Tanguy Hubert, EPRI

OpenDSS + DER-VET Tool Interaction

- Inputs to DER-VET:
  - From User
    - Customer load profile (8760)
    - Customer tariff
  - From OpenDSS*
    - Operational envelope (min/max power at POI OR min/max battery power, depending on if load is already included in OpenDSS model)
- Outputs from DER-VET
  - Optimal battery size
  - Customer electric bill savings

* https://www.epri.com/pages/sa/opendss

Validation through Case Studies

Case List	Goals (WHY)	Objectives (WHAT)	DER Options & Features (WHICH)	Outcome (HOW)
Case Study #1	Customer DER portfolio sized for Bill Reduction and customer resilience Check if the DER portfolio sized for bill reduction can also provide backup and improve customer resilience	Primary objective: Customer bill reduction. DER sized for this service Secondary objective: Evaluate reliability in terms of load coverage	Blue sky day: ES+PV (retail services) Outage days: ES+PV+DG (optional) User-defined critical load percentages to calculate reliability metrics	Metrics: 1. NPV comparisons (CBA), Payback period, Cost Normalization (e.g.: $/kW of DER installed capacity), Avoided costs per service 2. Critical load coverage comparisons ($/kW-yr) 3. Reliability performance and load coverage
Case Study #2	Energy storage-enabled microgrid designed with the similar or better reliability than the conventional diesel generator-based microgrid Check if net cost of operation is same/lesser than the conventional diesel generator-based microgrid	Primary objective: Reliability/Resilience Secondary objective: Customer bill reduction	Blue sky day: ES+PV (retail services) Outage days: ES+PV+DG User-defined Load coverage probability User-defined critical load percentages to calculate reliability metrics	Metrics: 1. Critical load coverage comparisons ($/kW-yr) 2. Reliability Performance based on targets and load coverage curve comparison 3. NPV comparisons (CBA), Payback period, Cost Normalization (e.g.: $/kW of DER installed capacity), Avoided costs per service
Case Study #3	Improve community resilience during crisis (hurricanes, wildfire, PSPS events) with community & customer PV and Storage assets	Primary objective: Community Resilience, Improve grid reliability Secondary objective: Market Participation	Blue sky day: ES+PV (market services) Outage days: ES+PV User-defined outage durations User-defined critical load percentages to calculate reliability metrics	Metrics: 1. Critical load coverage comparisons ($/kW-yr) 2. Reliability Performance based on targets and load coverage curve comparison 3. NPV comparisons (CBA), Payback period, Cost Normalization (e.g.: $/kW of DER installed capacity), Avoided costs per service

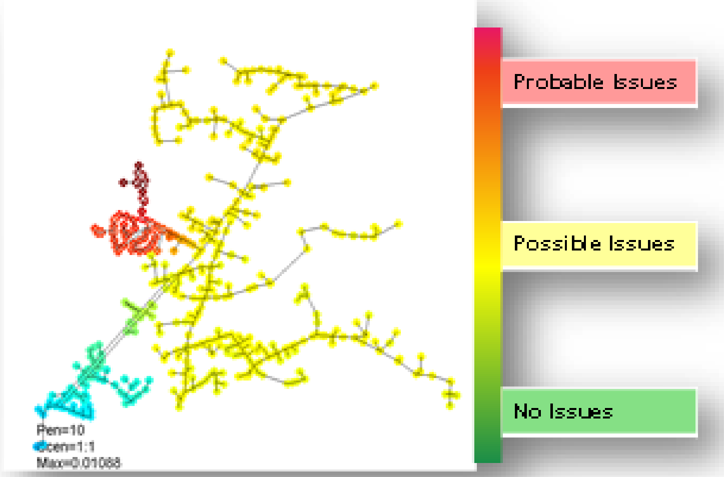
Validation through Case Studies (cont.)

Case List	Goals (WHY)	Objectives (WHAT)	DER Options & Features (WHICH)	Outcome (HOW)
Case Study #4	Customer DER + CHP portfolio sized for customer resilience + bill reduction	Primary objective: Customer bill reduction Secondary objective: Customer resilience	Blue sky day: Electric + Heating + Cooling CHP/CHP + other DER Outage days: CHP/CHP + other DER User-defined outage durations User-defined critical load percentages to calculate reliability metrics	Metrics: 1. NPV comparisons (CBA), Payback period, Cost Normalization (e.g.: $/kW of DER installed capacity), Avoided costs per service 2. Critical load coverage comparisons ($/kW-yr) 3. Reliability performance and load coverage
Case Study #5	Leverage EVs as a grid resource to maintain mobility and reliability	Primary objective: Customer Bill reduction. Secondary objective: Customer resilience	Blue sky day: ES+PV+EV (retail services) Outage days: ES+PV+EV User-defined outage durations User-defined critical load percentages to calculate reliability metrics	Metrics: 1. NPV comparisons (CBA), Payback period, Cost Normalization (e.g.: $/kW of DER installed capacity), Avoided costs per service 2. Critical load coverage comparisons ($/kW-yr) 3. Reliability performance and load coverage
Case Study #6	External Tool Integration: Assessing Non-Wires Solutions (NWS) impact on community feeder reliability. DER-VET integration with power flow tools (e.g. EPRI's OpenDSS)	Primary objective: Community feeder reliability improvements + capacity deferral (NWS) Secondary objective: Customer resilience	Blue sky day: ES+PV (grid services) Outage days: ES + PV User-defined feeder reliability improvement targets User-defined customer outage durations User-defined critical load percentages to calculate reliability metrics	Metrics: 1. Critical load coverage comparisons ($/kW-yr) 2. Reliability Performance based on targets and load coverage curve comparison 3. NPV comparisons (CBA), Payback period, Cost Normalization (e.g.: $/kW of DER installed capacity), Avoided costs per service

Transmission Solar + Energy Storage Case Study

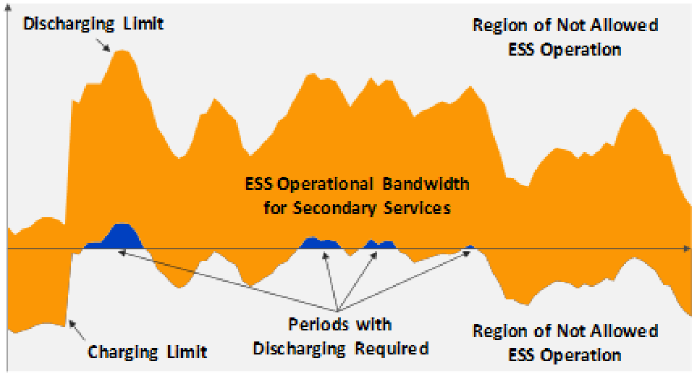
Site-Specific Energy Storage Analysis Framework

Dx and Tx Assessment



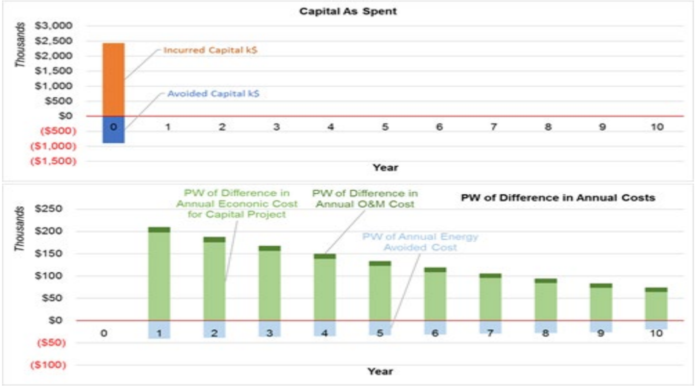
- Develop enhanced Dx and Tx planning criteria, methods, and tools
- Characterize Dx and Tx needs and solutions
- Apply energy storage non-wires solutions (NWS) screening criteria and methods

Alternative Evaluation



- Design energy storage NWS solution including sizing, siting, controls, etc.
- Assess energy storage Dx impacts
- Evaluate stacked benefits, state of charge management, degradation, etc.

Economic Evaluation



- How do energy storage costs & value compare to conventional solutions?
- What are the operating costs of the system?
- What revenues might the added energy storage provide?

Example: LADWP Transmission Project

Application	Description	Status
Market Service Participation Energy Arbitrage Frequency Regulation Spinning Reserves Resource Adequacy	Buy low, sell high Rapidly inject and remove power Dispatch power Real power reserve	**Project has been Contracted and in Execution**
Long-term resource planning and operational reliability	Meet long-term reliability needs with both high renewables and storage penetration in and out of LA Basin	In-Progress

LADWP Transmission Projects

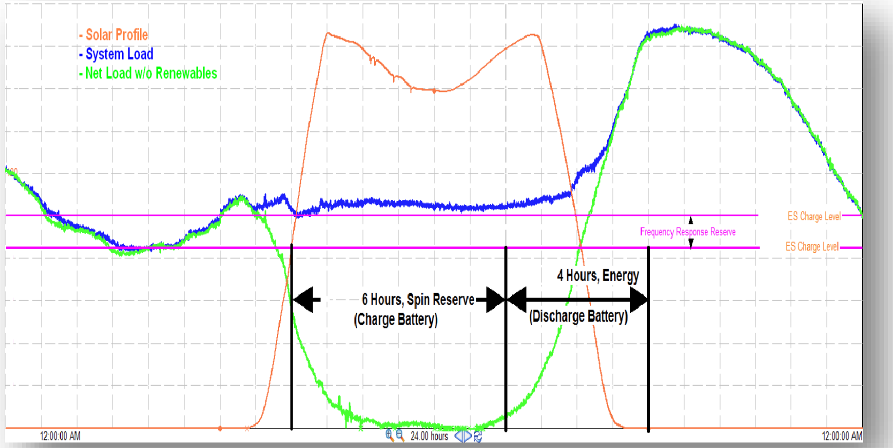
Application	Description	Status
Market Service Participation Energy Arbitrage Frequency Regulation Spinning Reserves Resource Adequacy	Buy low, sell high Rapidly inject and remove power Dispatch power Real power reserve	**Project has been Contracted and in Execution**
Long-term resource planning and operational reliability	Meet long-term reliability needs with both high renewables and storage penetration in and out of LA Basin	Concept Stage

LADWP Energy Storage Project #1

- Los Angeles Department of Water and Power (LADWP) was required to meet its California Senate Bill SB801 requirements

- The study considers a 100 MW, 4-hour battery energy storage system paired with a 200 MW solar PV facility to be procured through a Power Purchase Agreement (PPA) with a third-party developer who would be able to claim 30% Federal Investment Tax Credit incentive

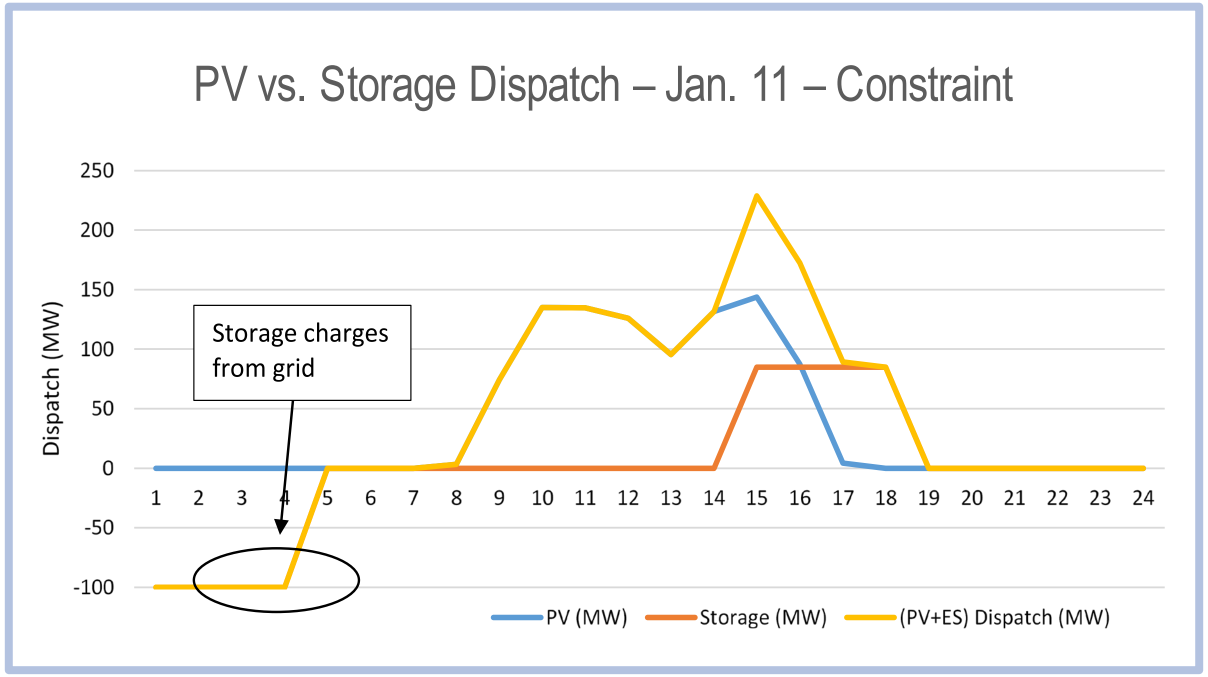
	Provide Energy Time Shift and Spinning Reserve	Restrict Charging from Grid	Restrict Charging from Grid and Discharge Min	Provide Frequency Response
Case #1	✓		✓	
Case #2	✓		✓	✓
Case #3	✓	✓		
Case #4	✓	✓		✓

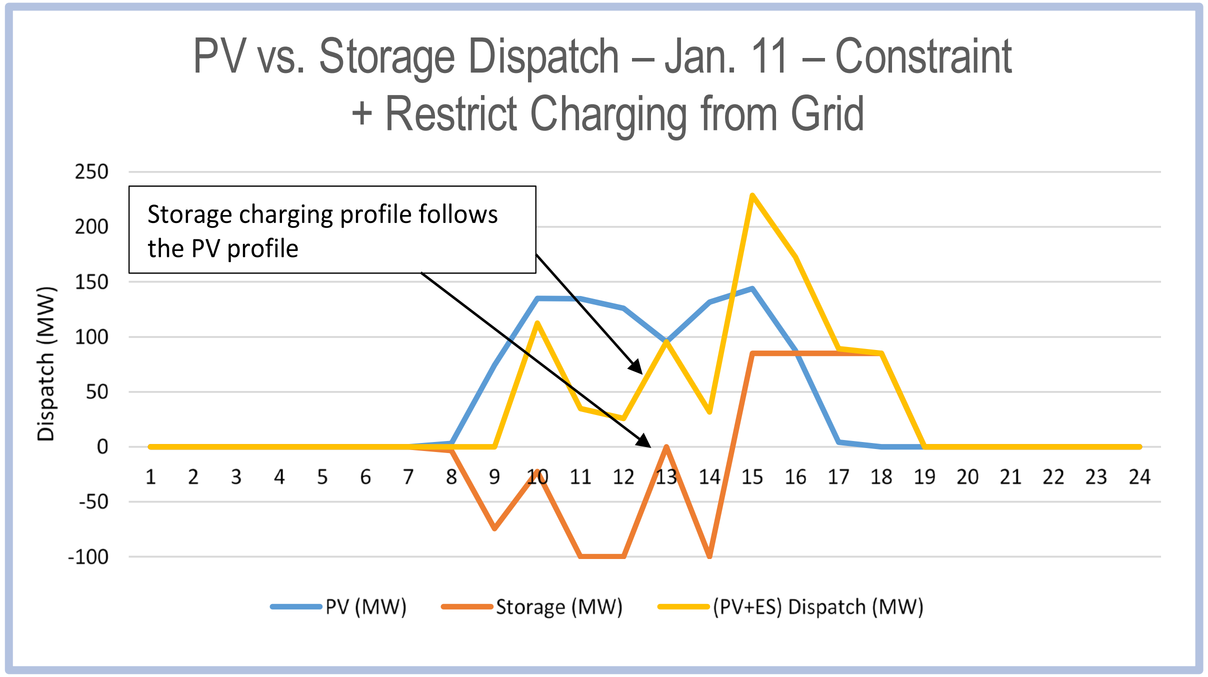


LADWP Full Report: *Integrating Energy Storage System with Photovoltaic Generation: Analysis within Los Angeles Department of Water and Power (LADWP) Service Territory to Meet SB801 Requirements at* http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002013007

LADWP Case Results - Dispatch

- Impact of grid charging constraints

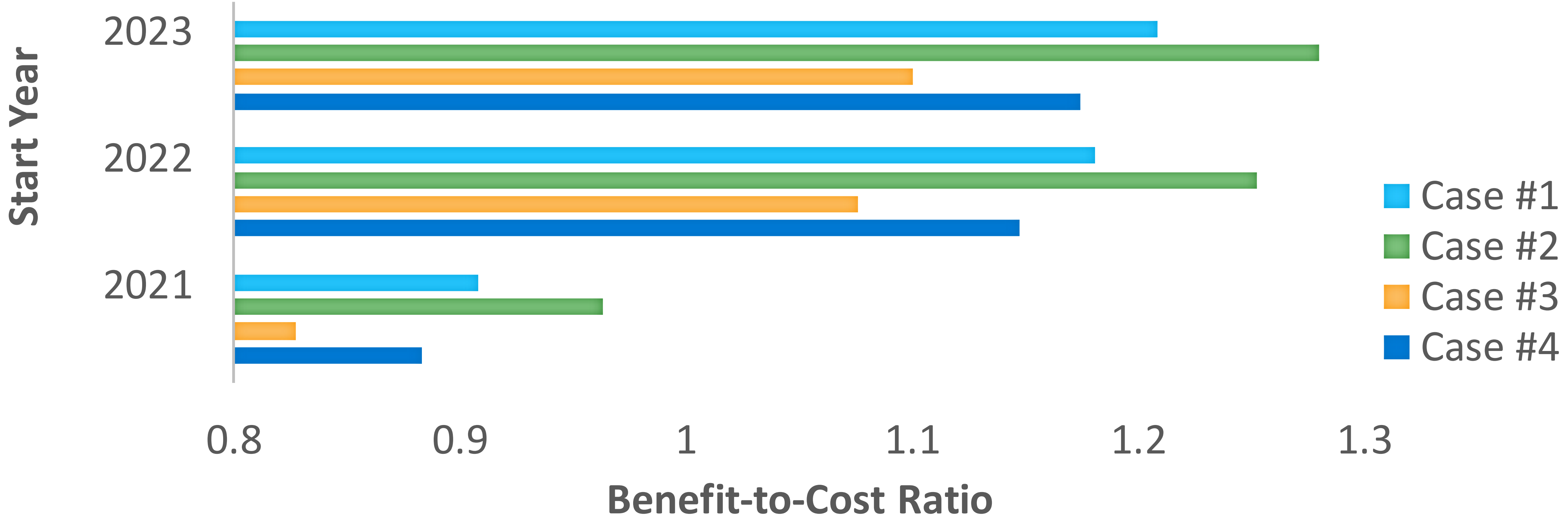




DER-VET (and StorageVET) Optimized Dispatch Outputs

LADWP Case Results - CBA

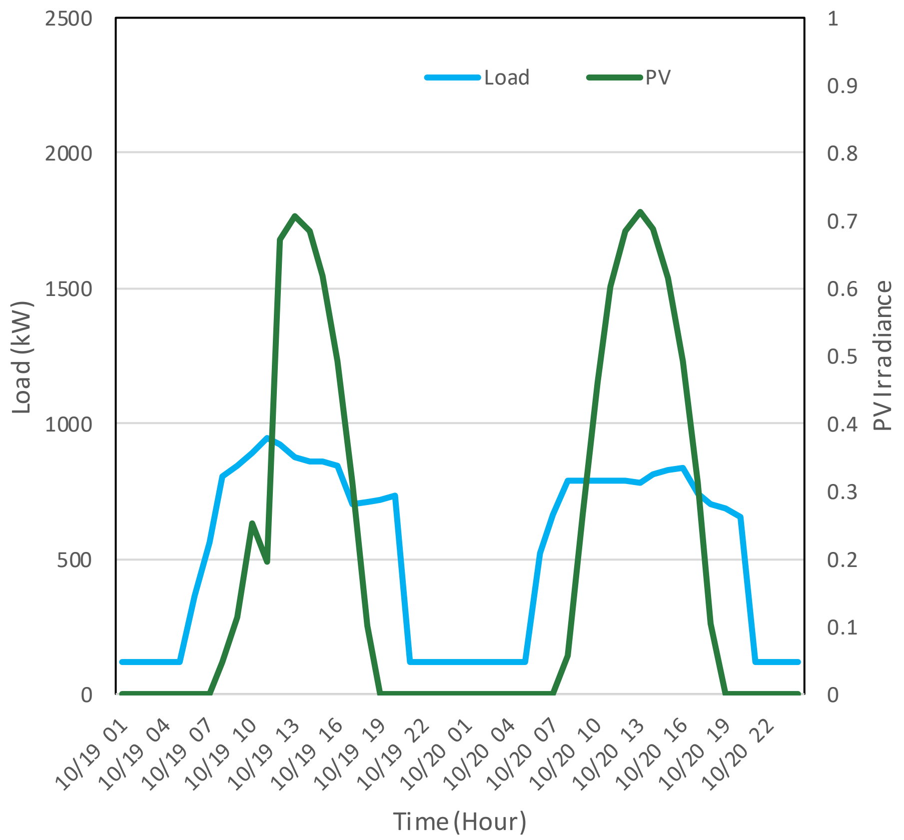
- Several cases resulted in benefit-cost ratios greater than one for project starts years after 2022 as illustrated in the graph below



Microgrid Design for PSPS Events

Microgrid Design - DER-VET Modeling Assumptions

- Identify potential Public Safety Power Shutoff (PSPS) planned events and duration in California
  - A load profile is chosen from Aug-Dec time period with the highest net energy demand
  - Load cannot be shed
- Solar PV assumptions and limitations
  - Corresponding Solar irradiance profile
  - PV profile from TMY profile
  - PV can be curtailed
- Battery ES assumptions:
  - Initial SOC at the start of outage event is 100%
  - Battery round trip efficiency – 91%
  - Hybrid solar plus storage installation – co-located at the dc side

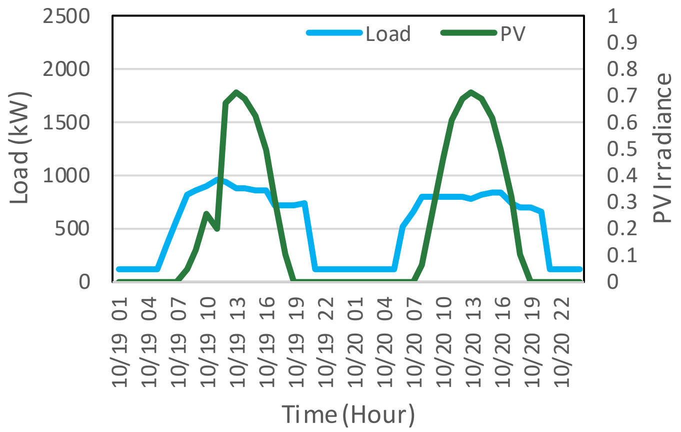


Candidate Critical Load Facilities

Critical Load Facility	Peak Load	Energy Requirement for 48h Outage (Without PV)
SCE – Feeder with 137 customers (98% commercial)	2.2 MW	68.6 MWh
LA – Hospital	1.4 MW	55.3 MWh
LA – Sec School	0.9 MW	24.97MWh

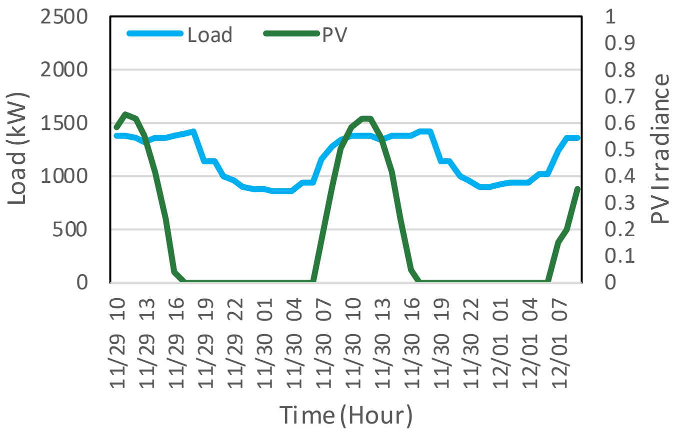
Load and PV Profile

LA – Sec School



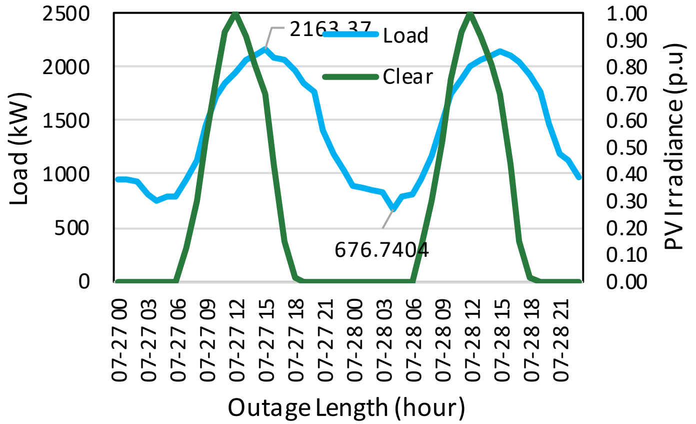
Peak load – 0.9 MW
24hr load requirement – 13MWh
36hr load requirement – 18MWh
48hr load requirement – 25MWh

LA - Hospital



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

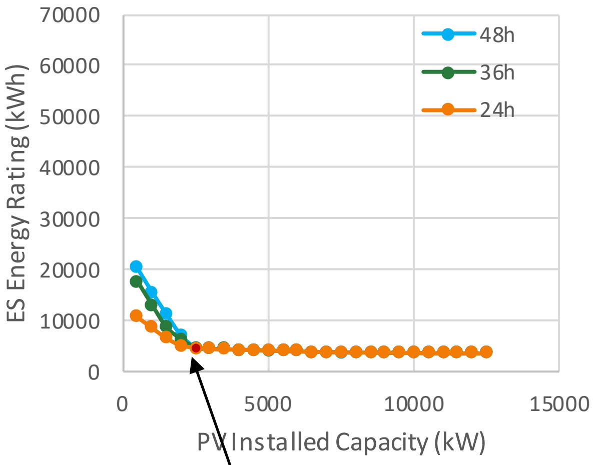
SCE Feeder



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

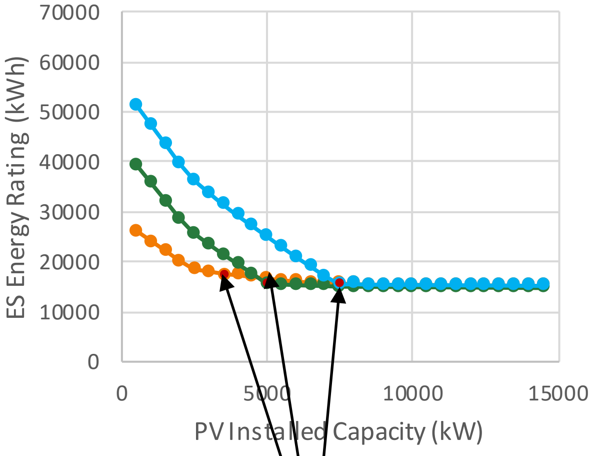
Microgrid Sizing Results

LA – Sec School



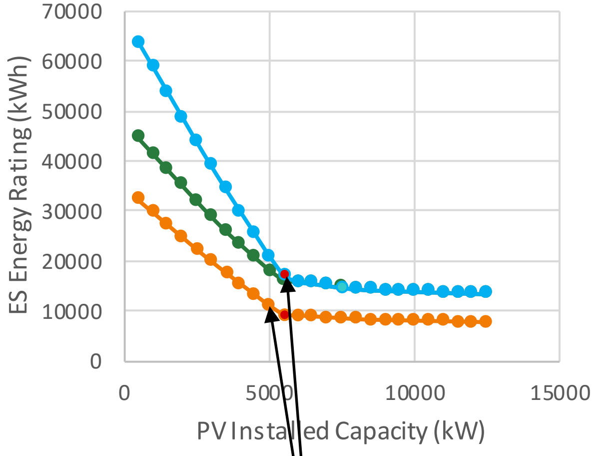
2.5MW PV +
0.735MW/4.9MWh ES

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

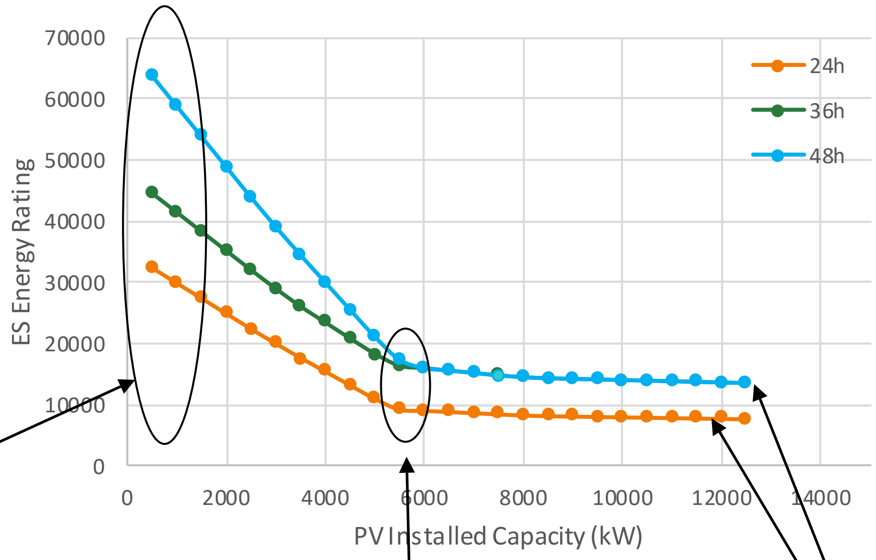


24h – 5.5MW PV+1.9MW/9.2MWh ES
36h– 5.5MW PV+1.9MW/17.2MWh ES
48h – 5.5MWPV +2 MW/17.2MWh ES

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.

Outage Length Variation – SCE case-study

- Microgrid designs results for 24, 36 and 48h outage lengths



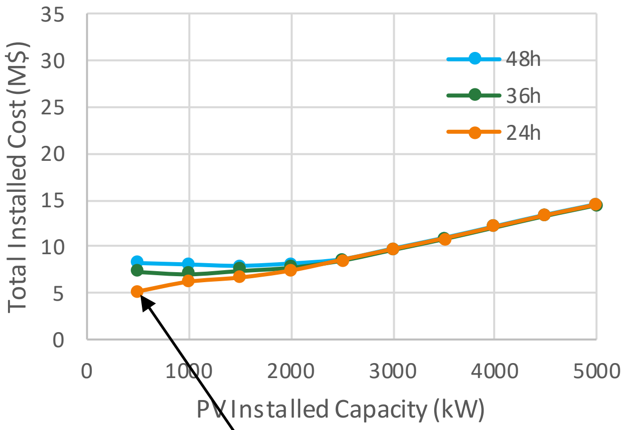
There is a linear relationship for low levels of installed PV capacity

In this case-study, the knee point happens for PV size of 5.5 MW in all three cases

It is non-linear for high PV generation. The microgrid size depends on the load shape and PV generation coincidence

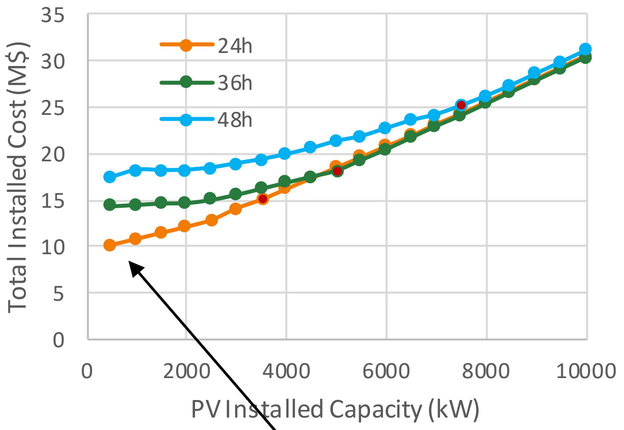
Microgrid Cost Summary

LA – Sec School



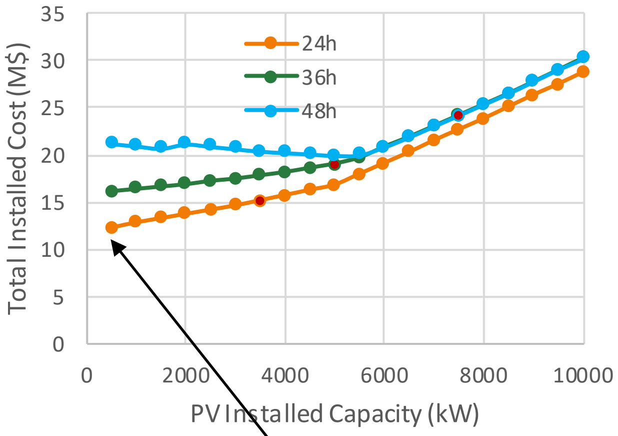
Min Cost of covering 24, 36 and 48hr outage – **5M$, 7M$ and 8M$**

LA - Hospital



Min Cost of covering 24, 36 and 48hr outage – **10M$, 14M$ and 17.5M$**

SCE Feeder



Min Cost of covering 24, 36 and 48hr outage – **12M$, 16M$ and 21.5M$**

T&D Upgrade Deferral Case Study

Screening of Three Energy Storage Sites*

	Feeder 1	Feeder 2	Substation		
			Feeder 3	Feeder 4	Transformer (Feeding 3 & 4)
Overloaded Asset Necessitating Action	379A underground cable limit 8% Overloaded few hours/year	379A underground cable limit 6% Overloaded few hours/year	400A switch 12% Overloaded few hours/year (Next limit: 491A Voltage Regulator)	295A overhead cable limit Not yet overloaded	15.45 MVA limit Not yet overloaded, could be soon
Traditional Upgrade Option and Cost	Reconfigure some load to adjacent feeder, also reconductoring underground portion of feeder head cables to double ampacity. $1.1 Million	Extend adjacent feeder and transfer some loads off of feeder $0.1 Million	Build a new substation $5.9 Million		
Projected Load Growth Rate	$0.5\ \%/year$	$0.5\ \%/year$	$1\ \%/year$		
Additional Data Provided by For Screening	• 2017 hourly feeder head currents (for each phase), total MW, and total MVAR • 2008-2029 recorded/predicted yearly feeder head peak load values	• 2017 hourly feeder head currents (for each phase), total MW, and total MVAR • 2008-2029 recorded/predicted yearly feeder head peak load values	• 2017 hourly feeder head currents (for each phase) • 2004-2029 recorded/predicted yearly feeder head peak load values		

* The three sites were identified by distribution planners.

Screening Analysis Results - Choosing a Feeder for Detailed Analysis

	Feeder 1	Feeder 2	Substation		
			Feeder 3	Feeder 4	Transformer (Feeding 3 & 4)
Energy Storage Requirements in Year 10 to Defer Capacity Investment	2 MW 4.72 MWh 2.4 Hour	1.47 MW 9.07 MWh 6.1 Hours	0.17 MW 0.17 MWh 1 Hour	0 MW 0 MWh 0 Hours	1.22 MW 3.4 MWh 2.8 Hours
Distribution Upgrade Cost	Reconfigure feeder and loads **$1.1 Million**	Reconfigure feeder and loads **$0.1 Million**	Build new substation **$5.9 Million**		
Estimate for Storage Installed Cost* (assuming $900/kWh**)	**~$4.2 Million**	**~$8.1 Million**	**~$3.1 Million**		

Total storage required for

Winner!

Substation transformer bank is the best candidate for detailed energy storage analysis due to the relatively high cost of the new substation transformer bank as compared to the cost of the energy storage asset.

* The energy storage cost estimates here do not include the value of storage secondary services, which will improve the overall economics of the storage project. The valuation of stacked secondary services is a part of the detailed storage analysis.

** Source: Energy Storage Cost Analysis: Executive Summary of 2017 Methods and Results, EPRI, Palo Alto, CA: 2017. EPRI 3002012046.

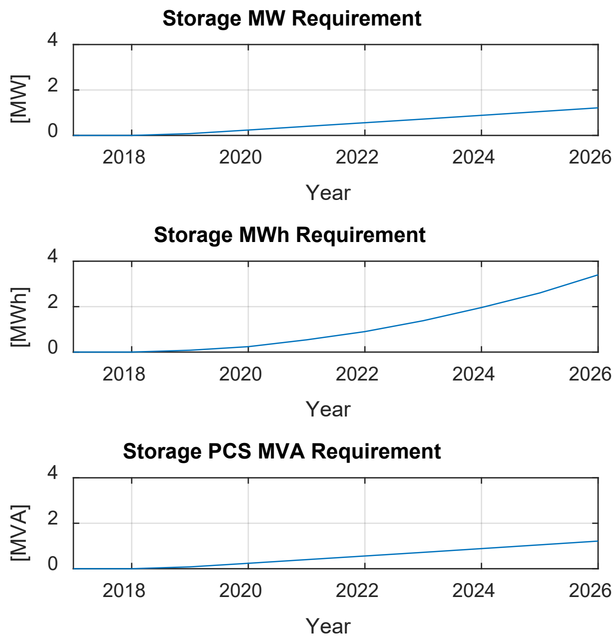
Screening Analysis Results – Storage Requirements

Capacity Limits (Before Any Distribution Upgrades)

- Feeder 3 operational capacity is originally limited to 400A by a substation switch. This switch will be upgraded increasing the feeder capacity to 491 Amps limited by feederhead voltage regulator
- Substation transformer bank capacity is 15,451 kVA

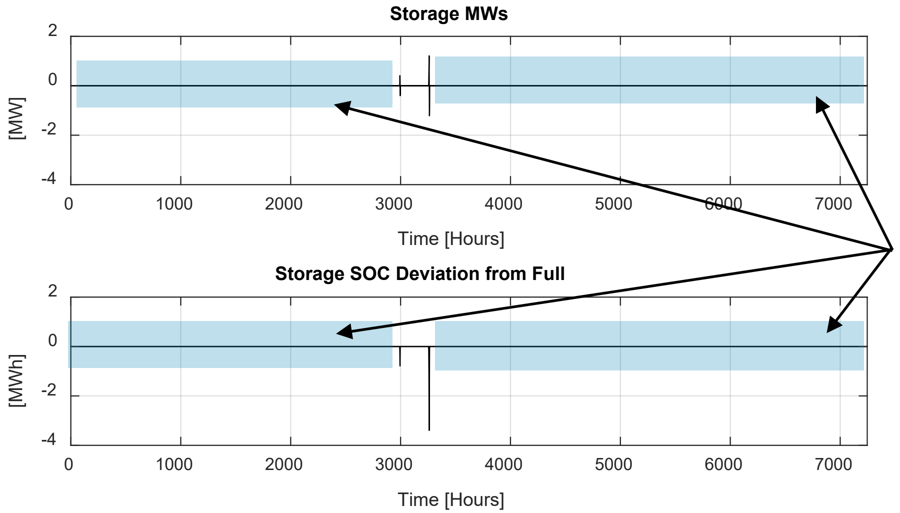
Storage Capacity Requirement in Year 10

- *1.22 MW / 3.4 MWh (2.8 hrs)*
- The capacity is needed seldom leaving room for stacked secondary services



Storage Capacity Requirements

	MW	MWh	MVA*
2017	0	0	0
2018	0	0	0
2019	0.08	0.08	0.08
2020	0.24	0.24	0.24
2021	0.4	0.54	0.4
2022	0.56	0.9	0.56
2023	0.72	1.38	0.72
2024	0.89	1.96	0.89
2025	1.05	2.6	1.05
2026	1.22	3.4	1.22



Stacked-service opportunities

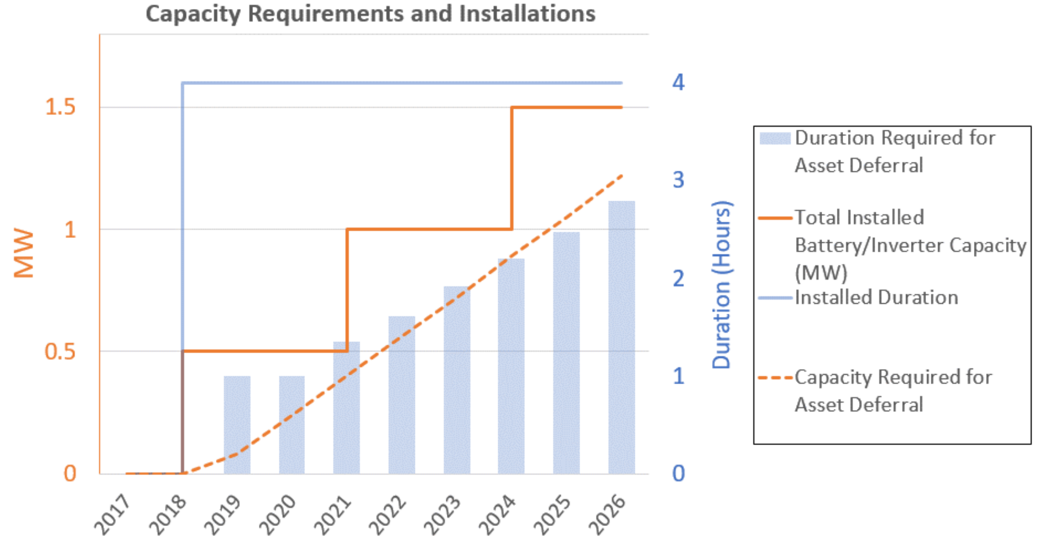
Stacked secondary services: Storage is not utilized for its primary asset deferral objective for much of the year. What additional services could it provide when available?

* No inverter oversizing was considered for volt/var or other secondary services.

Screening Analysis Results – Storage Scenarios

Consider two energy storage scenarios for stacked-service and cost-benefit analysis

- Scenarios 1: Install full energy storage capacity (Year 10 requirement 1.22 MW / 3.4 MWh / 2.8 hrs) in Year 1
  - Advantage: More storage capacity immediately available for secondary services
  - Disadvantage: High initial capital investment
- Scenario 2: Increase energy storage capacity *modularly* as the capacity need increases
  - Advantages:
    - Take advantage of lower storage costs in the future
    - Defer some of the initial investment
    - Hedge against uncertainty: If the projected load growth does not materialize, no unnecessary energy storage investments are made
  - Disadvantage: Limited storage capacity initially available for secondary services
- Several energy storage vendors, e.g., Tesla Powerpack, offer such modular solutions
  - For example, assuming 50kW – 4 hour modular storage packs (e.g., Tesla Powerpack), 30 Powerpacks would be required in Year 10 (total capacity of 1.5 MVA – 6 MWh – 4 hours)*



	Added Battery (Inverter)	Total Installed Capacity	Total Installed Powerpacks (Inverters)
2018	0.5 MW (0.5 MVA)	0.5 MW – 4 Hours (0.5 MVA)	10 Powerpacks (1 Inverter)
2021	0.5 MW (0.5 MVA)	1 MW – 4 Hours (1 MVA)	20 Powerpacks (2 Inverters)
2024	0.5 MW (0.5 MVA)	1.5 MW – 4 Hours (1.5 MVA)	30 Powerpacks (3 Inverters)

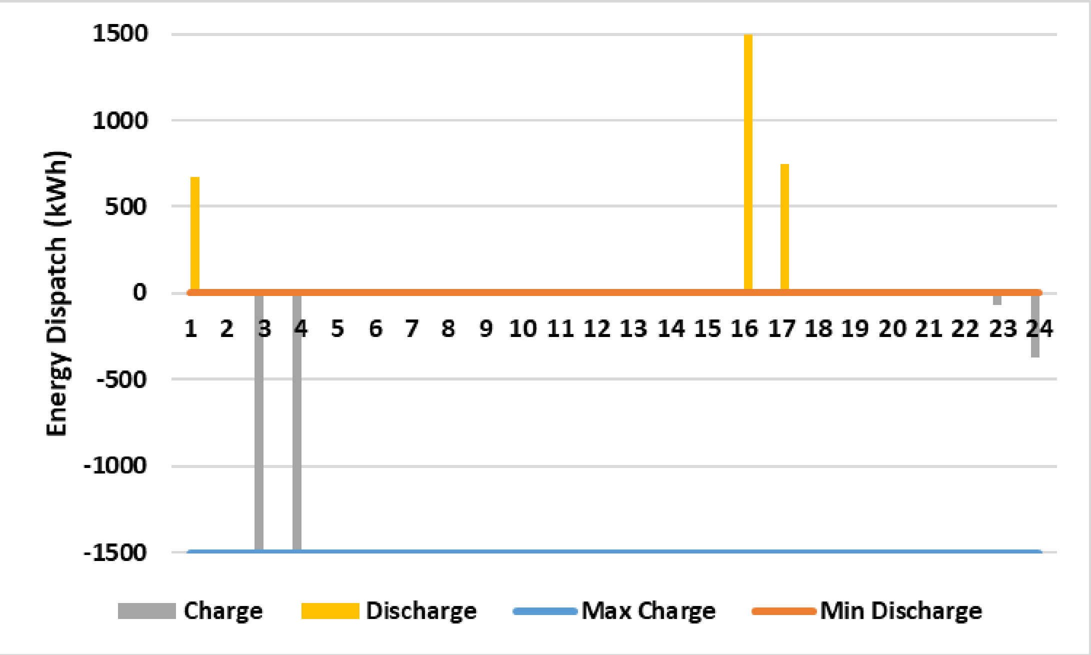
* Less capacity may be needed if the load grows slower than anticipated.

Secondary Non-Distribution Services Overview

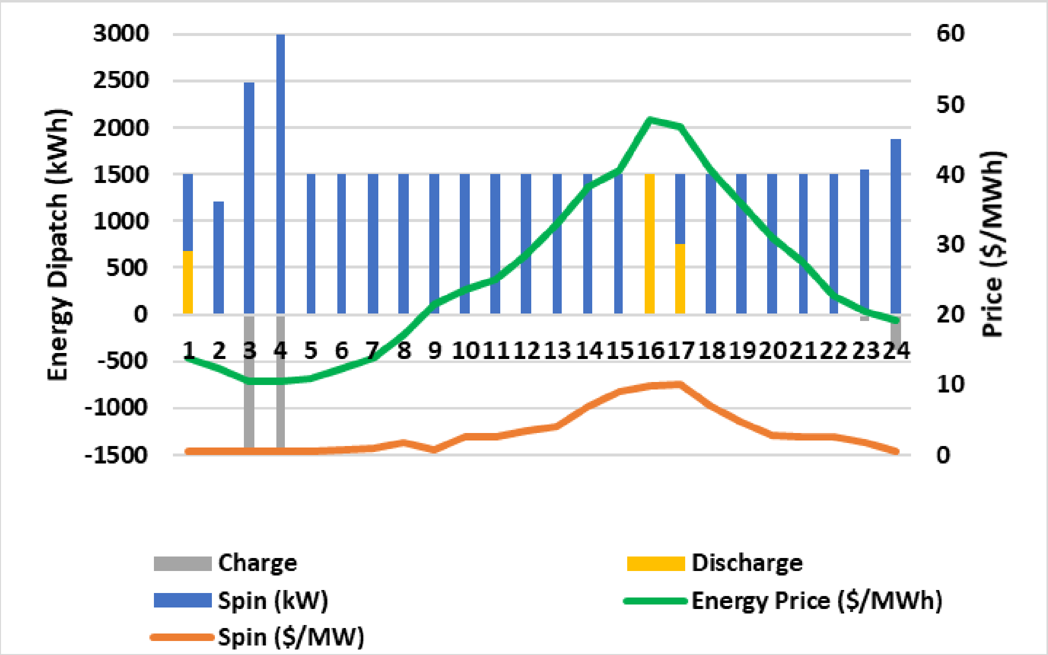
	Scenario B	Scenario C
Energy Storage Size	1.5 MW, 3.75 MWh	3 **X** (0.5 MW, 1.25 MWh)
Year(s) Deployed	2018	2018, 2021, 2024
Analysis Timeframe	10 years	10 years
ES RT Efficiency	85%	85%

Service	Price
Day Ahead Energy Price	Local LMPs from 2017
Day Ahead Ancillary Services	Market Clearing Prices from 2017
Services Modeled	Day Ahead Energy Arbitrage Spinning & Non Spinning Reserves

Storage Activity on an Unconstrained Day (2019)



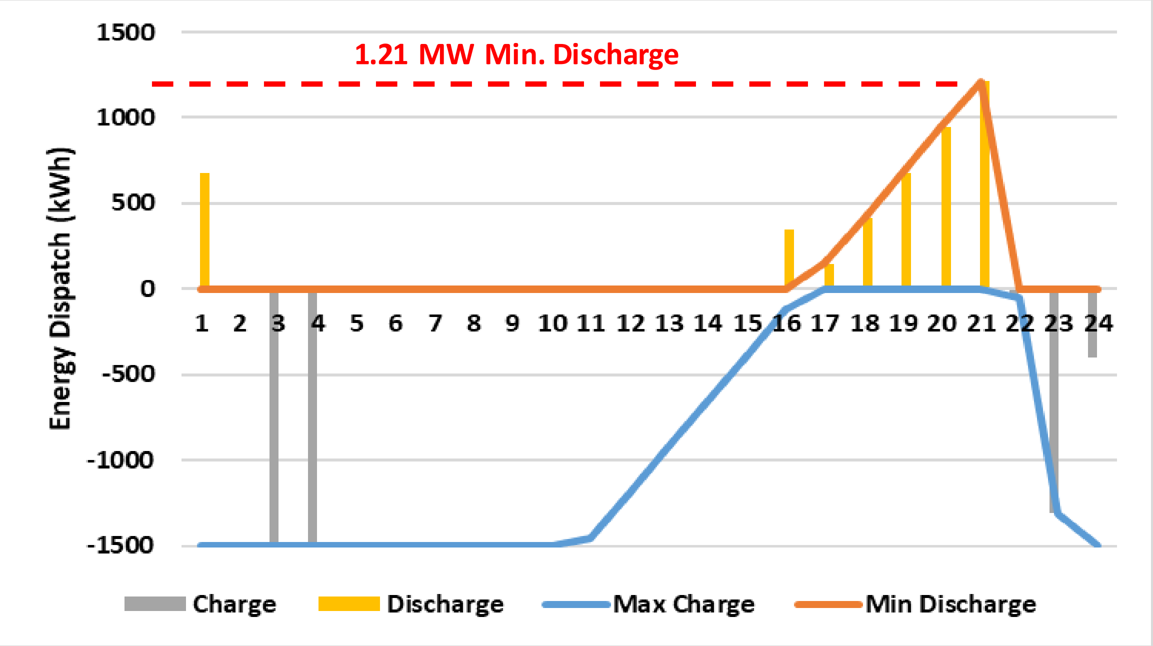
Constraints



ESS Activity

Energy storage activity driven by price on an unconstrained day

Storage Activity on a Constrained Day (2026)



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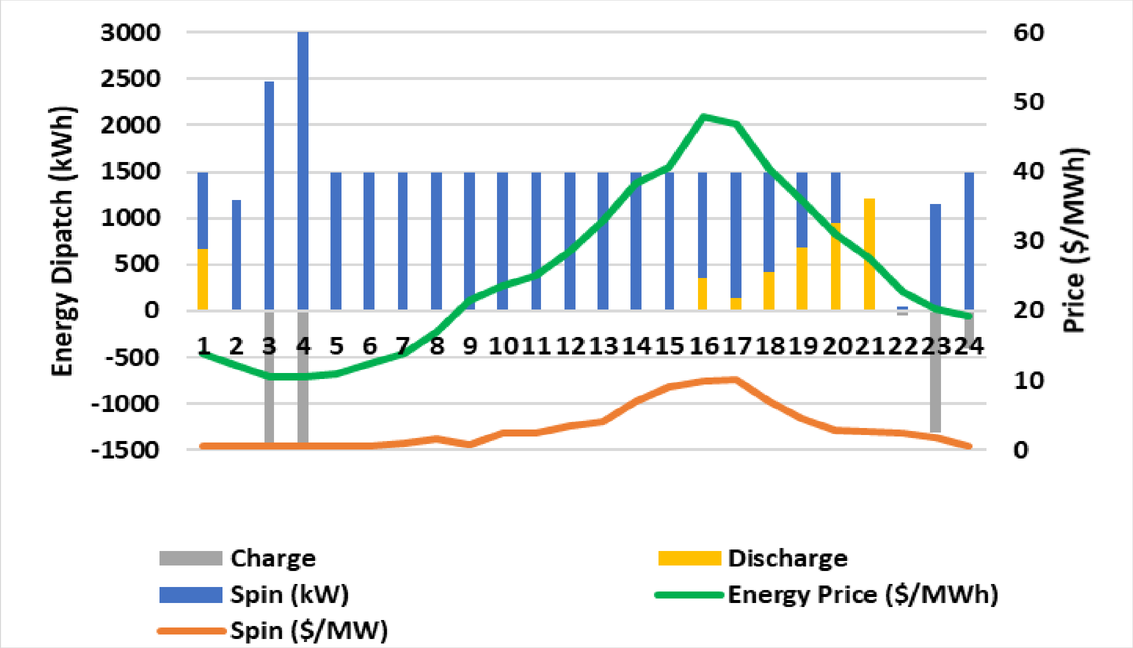
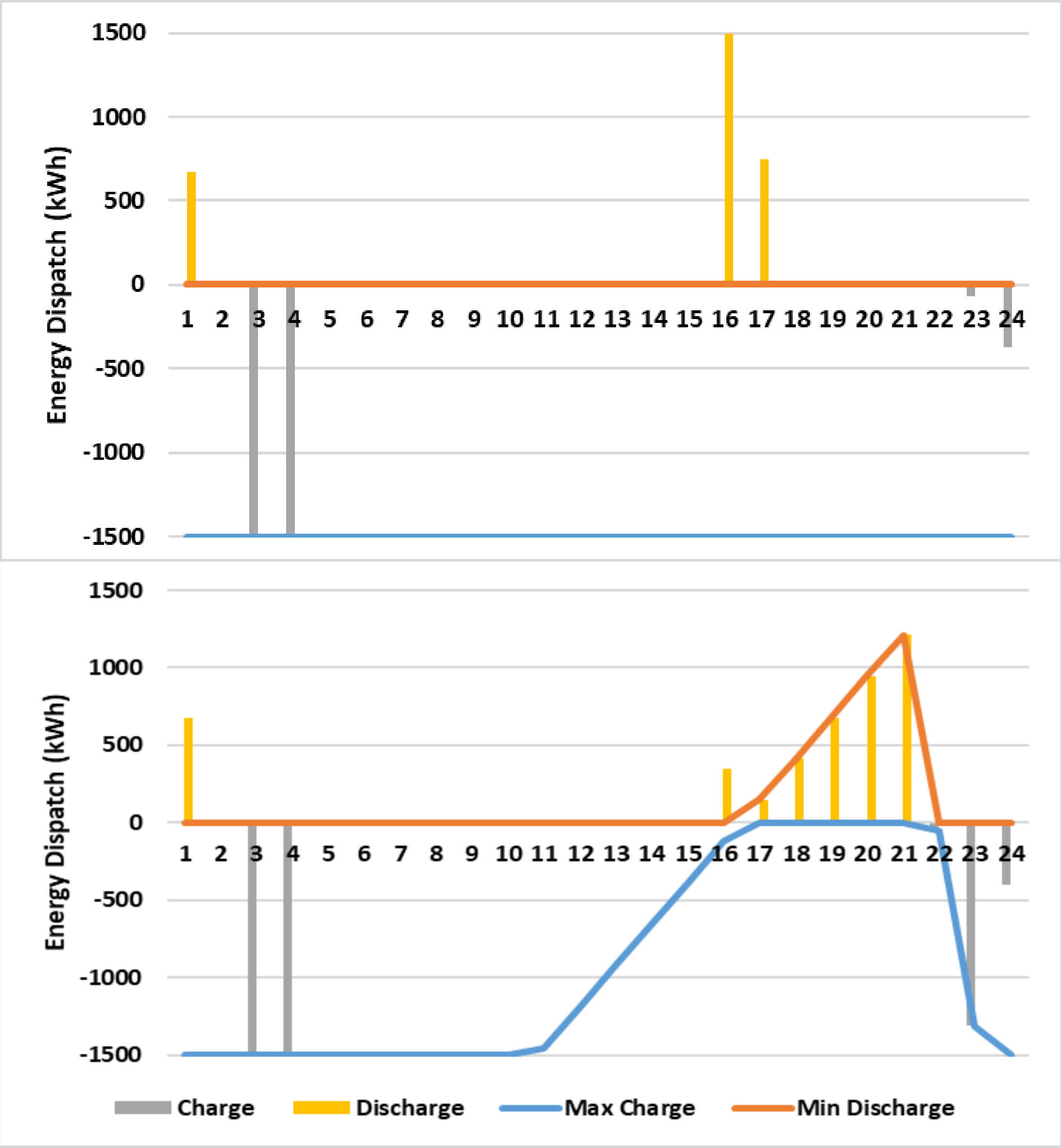
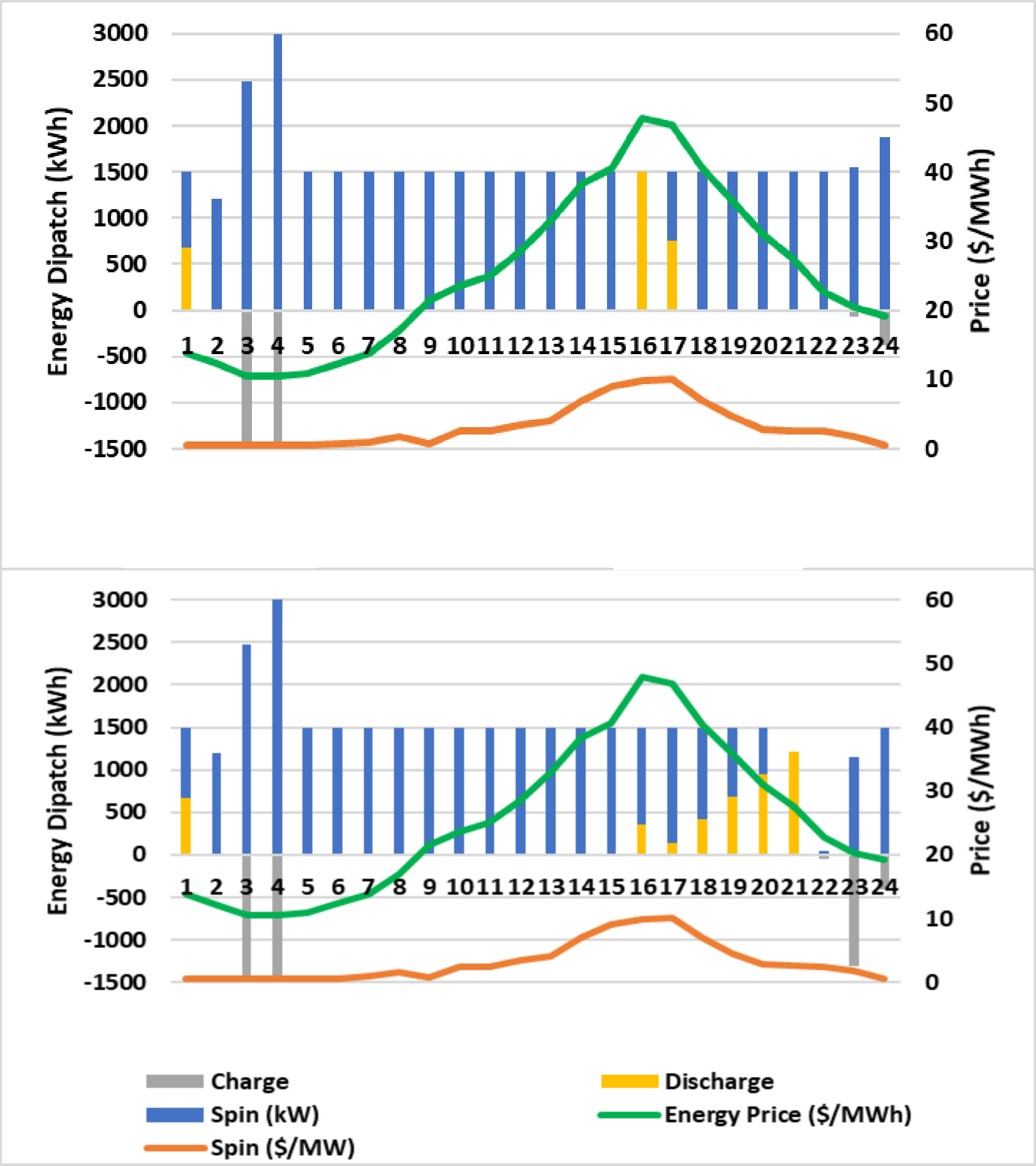


ESS Activity

Energy storage activity driven by distribution requirements on a constrained day

Storage Activity Unconstrained vs. Constrained Day





Cost-Benefit Analysis: Financial Parameters Assumed

MN - 2019 Electric Multi-year

Parameter	Value
Debt/Equity Ratio	~50%
Interest Rate	~5%
ROE	~10%
Discount Rate	~7%
Inflation Rate	2.70%
Federal Income Tax Rate	21%
State Income Tax Rate	9.80%
Property Tax Rate	1.19%

Allowed return on LTD

Assumed after-tax WACC

Assumed weighted

Cost Assumptions for Measures Considered

2. Storage

All-in Storage System Cost	2017 ($2017)	2022 E ($2017)	Annual Esc. Rate	Annual Esc. Rate incl. inflation	Useful Life
4 hrs	$2,070/kW	$1,360/kW	-8.06%		
2.5 hrs*	$1,473/kW	$980/kW	-7.83%	-5.34%	10 yrs
2 hrs	$1,274/kW	$853/kW	-7.71%		
O&M**	$10/kW-yr	$11/kW-yr		2.07%	N/A

**Costs linearly interpolated from 2hrs and 4hrs configurations*

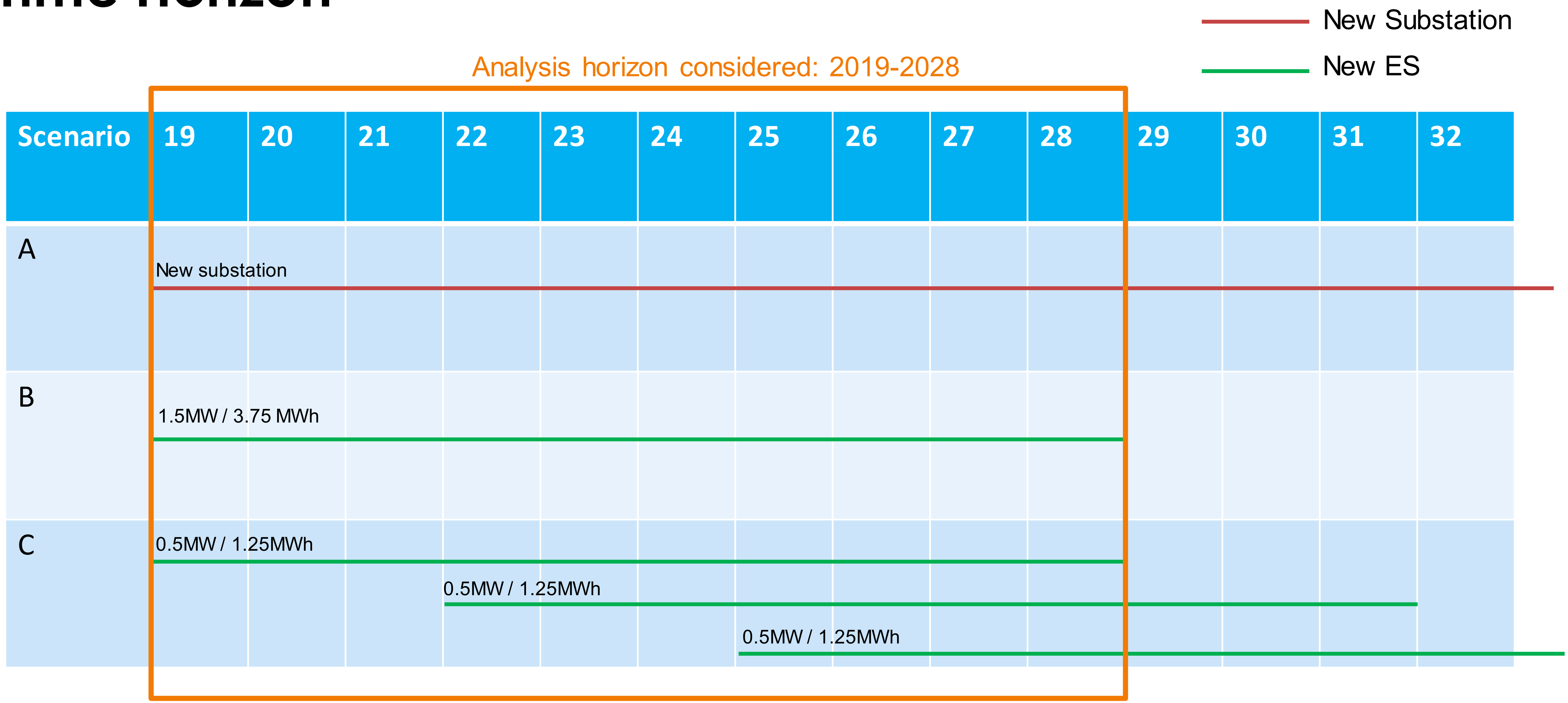
***O&M costs are highly project specific and can vary widely, from $8 to $37/kW-yr.*

All-in Storage System Cost ($)	2017 ($2017)	2022 E ($2017)	Annual Esc. Rate incl. inflation	Useful Life	Calculated Economic Carrying Cost (ECC)*
1.5 MW / 2.5 Hrs	2,209,500	1,469,625	-5.34%	10yrs	19.54%
0.5 MW / 2.5 Hrs	736,500	489,875	-5.34%	10yrs	19.54%
O&M**	$10/kW-yr	$11/kW-yr	2.70%	N/A	N/A

**ECC calculated assuming financial parameters shown above*

***O&M costs are highly project specific and can vary widely, from $8 to $37/kW-yr.*

Time Horizon



Note that years on this slide refers to <u>in-service</u> years, while years on previous slide refers to <u>construction</u> years.

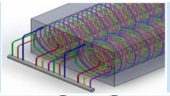
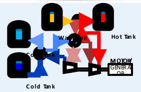
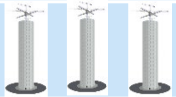
CBA Results

Scenario / $2017	A (avoided)	CAPEX	OPEX	MKT REV	NPV
B-	3,460,026	3,062,132	115,429	352,466	**634,931**
B - market only	*3,460,026*	*3,062,132*	*115,429*	*352,528*	***634,993***
C-	3,460,026	1,845,991	77,209	228,716	**1,765,542**
C- market only	*3,460,026*	*1,845,991*	*77,209*	*228,776*	***1,765,602***

1. All scenarios considered yield positive economic returns. This is true even when not considering market revenues.
2. Scenario C –three smaller ES installed sequentially– yields better returns than a larger ES.
   - Note: For ES #2 and #3, some costs are still to be recovered after 2028
3. Operation constraints for primary service only marginally reduce market revenues.

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

- Modeling Inputs
  - Round-Trip Efficiency (RTE) (Total AC power generated / total AC energy consumed)
  - Capital Costs (Anticipated costs for power [$/kW] & energy [$/kWh])
  - Operating Costs (Dwell energy losses, maintenance, and augmentation)
  - Startup Energy (Energy consumed during startup)

DER-VET Base Case and Sensitivities

Base

- All technologies were run using the original pricing curves in each region for the 6-, 8-, and 10-hour duration cases (Li-ion batteries were also run at their prevalent 4-hour duration case)

Sensitivities

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

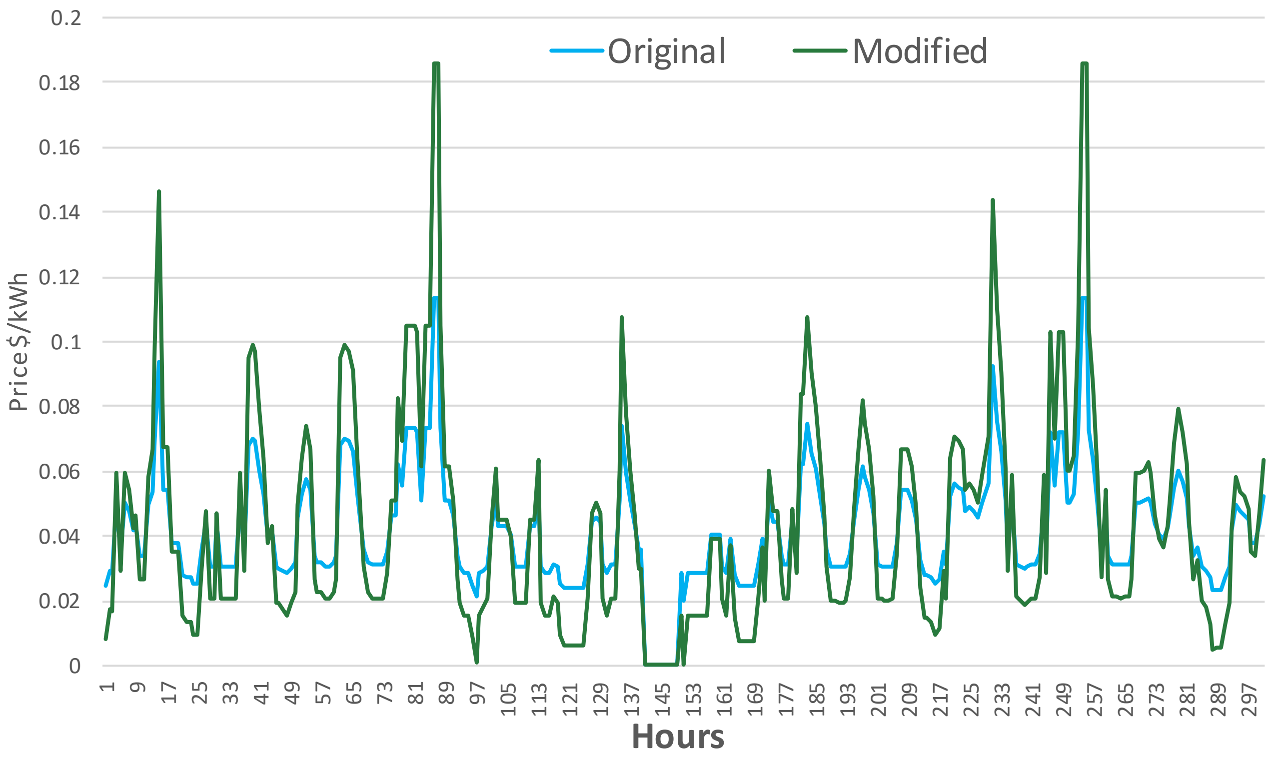
18 Cases per Technology per Hours of Duration

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

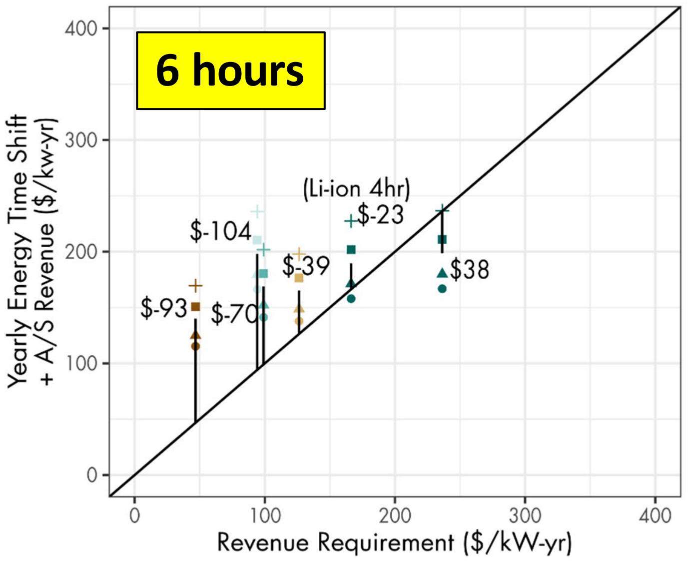
Significant number of DER-VET cases: 1728 total

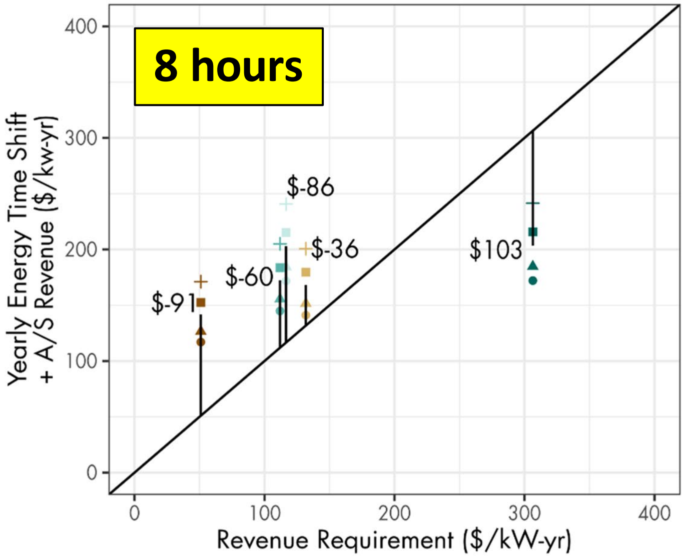
Energy Pricing Sensitivity

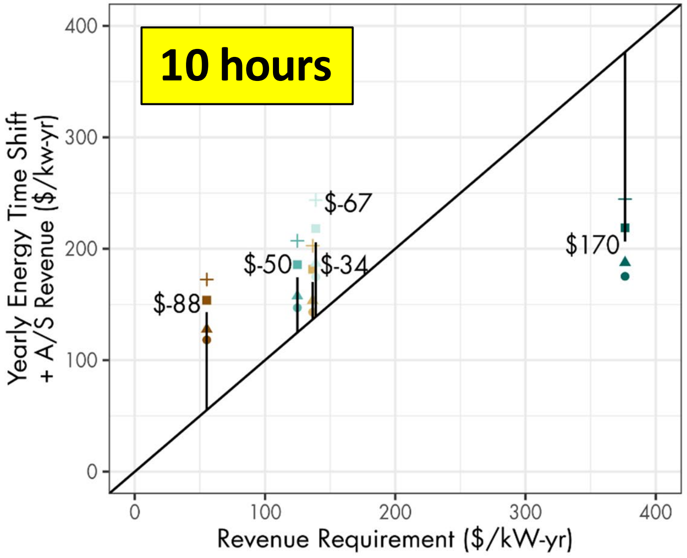
- Original
  - Predicted based on expected energy mix and demand profiles
- Modified
  - Original prices amplified 2x from overall annual average
  - When negative values occur, these are reset to zero
  - All pricing data offset to achieve equivalent average values vs. original average prices



DER-VET Results: Tech Duration vs. Revenue Requirements







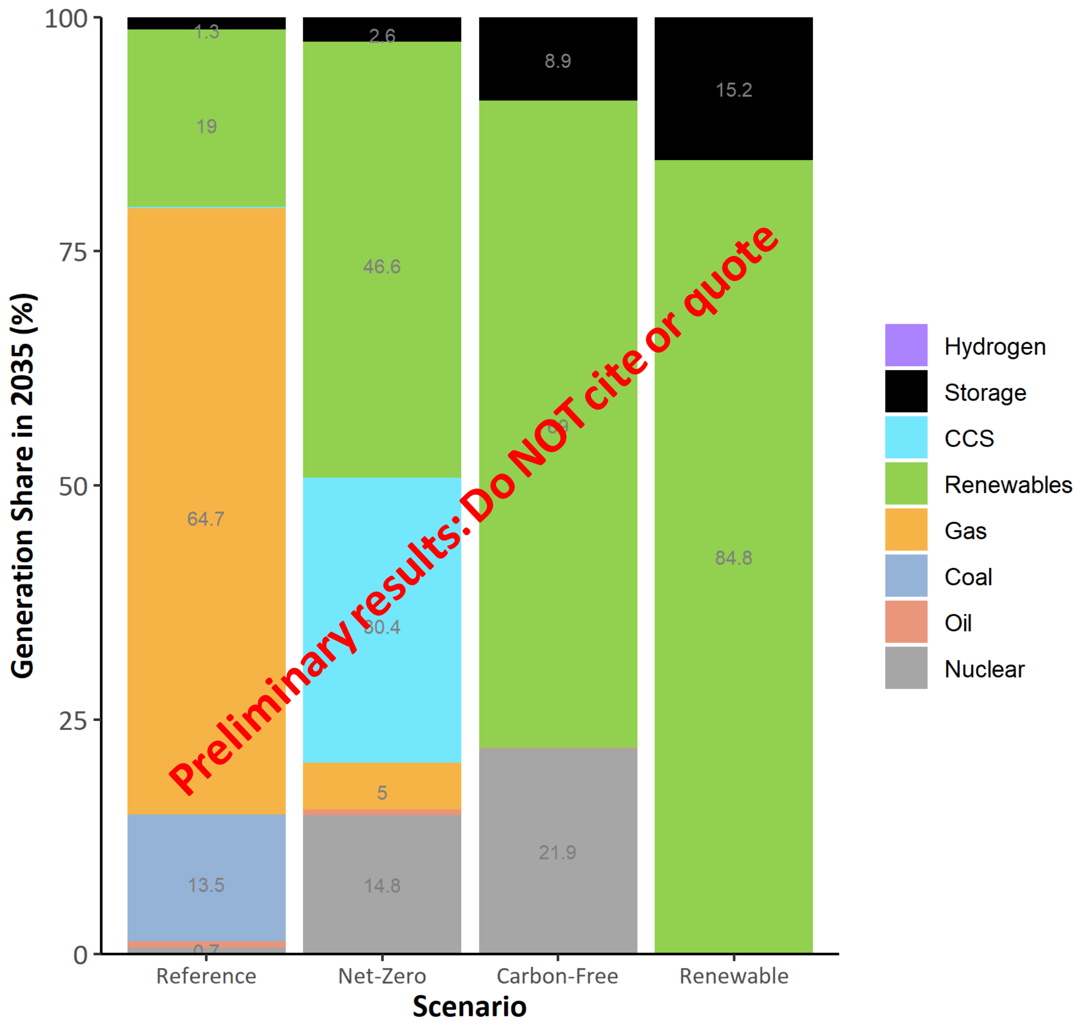
Revenue Requirement ($/kW-yr)

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

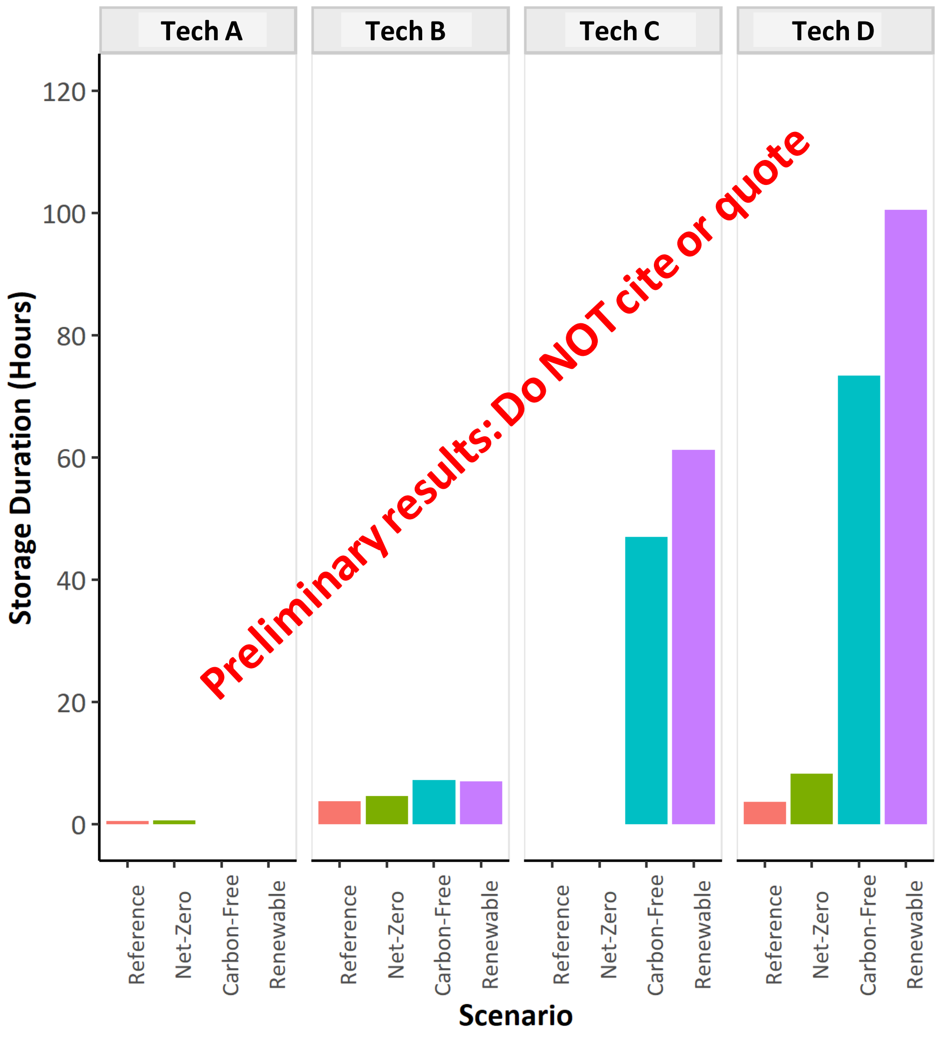
Technology cost forecast is a key driver for LDES analysis

LDES Deployment Driven by Future Macro-Economic Scenarios

GENERATION MIX



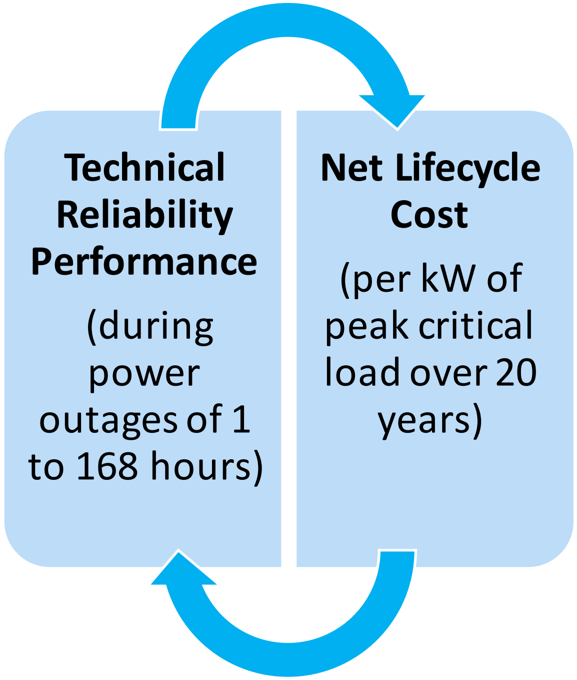
STORAGE DURATION



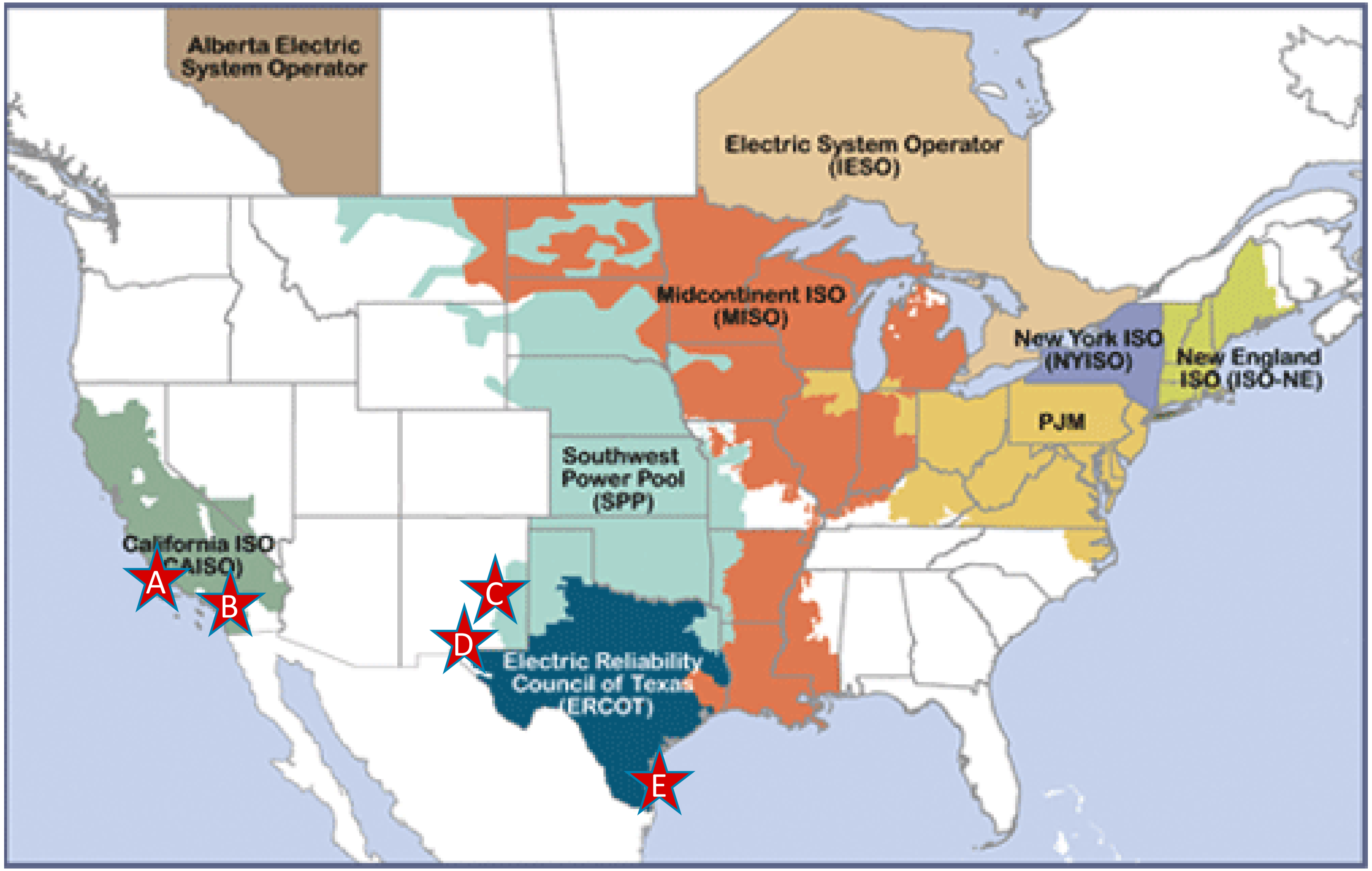
Military Installation Microgrids

PROBLEM STATEMENT (WHY?)

1. Design an ES enabled microgrid with the similar or better **reliability** than the traditional DG based baseline microgrid
2. Check if net cost of operation of the ES enabled microgrid is same/lesser than the traditional diesel generator-based baseline microgrid



SITES ANALYZED



<u>Sites Considered</u>:

A. Naval Base Ventura County

B. March ARB

C. Holloman Air Force Base (AFB)

D. Fort Bliss

E. NAS Corpus Christi

Installations Modeled are a Cross-Section of:

- *Geographies*
- *Energy Market Areas*
- *Sizes*
- *Mission Activities*
- *Military Services*

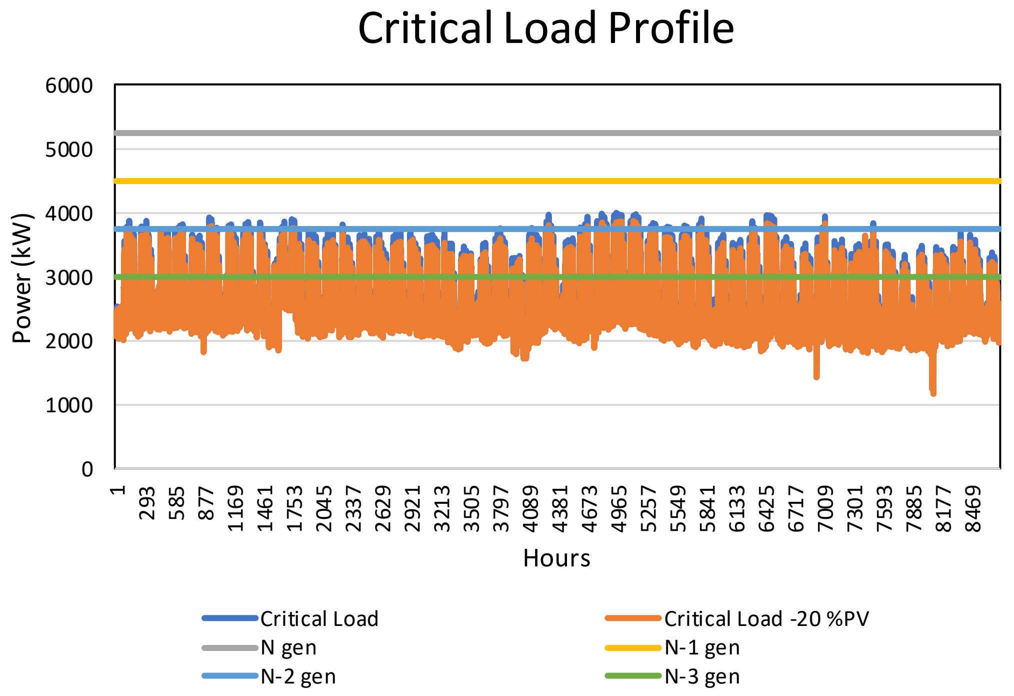
INPUT DATA FOR THE ANALYSIS

Three Types of Variables

Military Installation Conditions	Secondary Services	Energy Storage Technologies
- Critical Load Size & Shape - Solar and DG Assets - Other Conditions	- Utility Retail Tariff Structure - Wholesale Market Prices - Regulatory Rules in different service territories	- Lithium-Ion

EXAMPLE MILITARY INSTALLATION CONDITONS

- Peak load: 14 MW
- Peak critical load: 4 MW
- 7 diesel generators available:
  - 750 kW each
  - 50,000 gallons of diesel available
- PV Nameplate rating: 830 kW
  - Hourly PV irradiance resolution



Secondary Services

BILL REDUCTION

- Energy charge reduction
- Demand charge reduction
- Demand response

WHOLESALE MARKET

- Energy arbitrage
- Frequency regulation
- Spinning reserves and non-spinning reserves

STORAGE TECHNOLOGY CONSIDERED

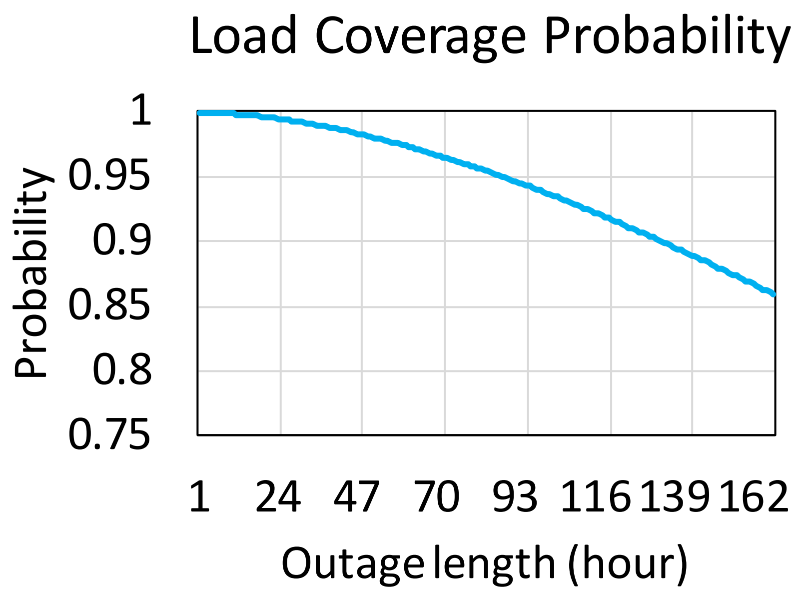
- Li-Ion battery (Mature technology)
- Round Trip Efficiency: 91%
- Battery Replaced every 7 years over the 20-year analysis horizon
- CAPEX cost derived from EPRI's 2019 cost study*
- O&M Cost: $10/kW-yr

**Energy Storage Cost Assessments. Solar Plus Storage Cost Assessment and Design Considerations: Executive Summary*

Also considered Flow Battery technology, but that data was proprietary

BASELINE ANANLYSIS – PERFORMANCE METRICS

- Reliability Analysis - Critical load coverage probability as a function of outage length (hours)



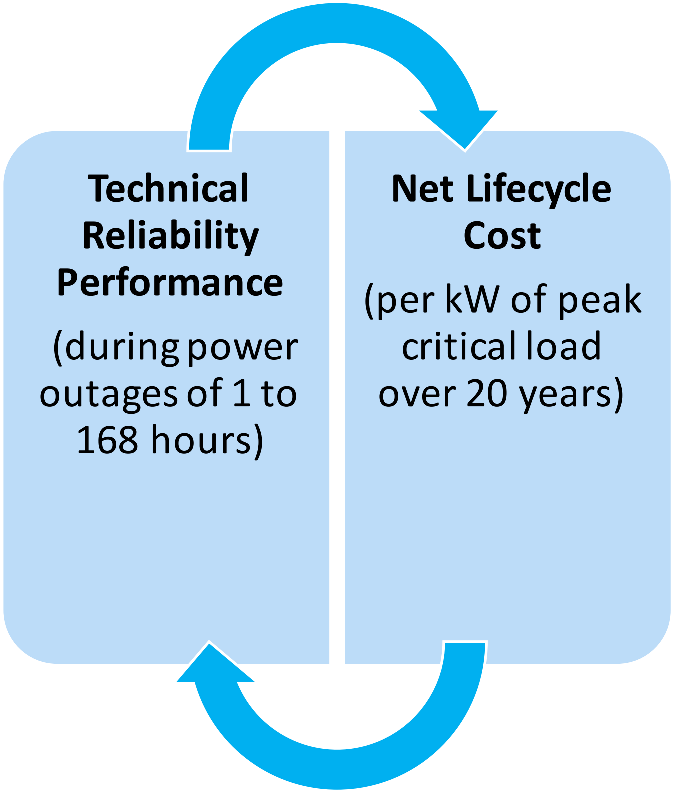
Baseline Microgrid configuration:
DG – 7x750kW+ PV – 830 kW

Duration	Probability (%)
24 hours	99.46%
168 hours	85.94%

- Cost Benefit Analysis

Cost Benefit Analysis Components	Metrics
Baseline NPV (20 Yr) (Cost)(Millions of $)	$108.95
Baseline Critical Load Coverage ($/kW-yr)	$135.50

Energy Storage Enabled Microgrid Design



Compared to Modeled Baseline Microgrid at each Installation with no Storage, N+1 Back-Up Diesel Generators, solar PV, and UPS

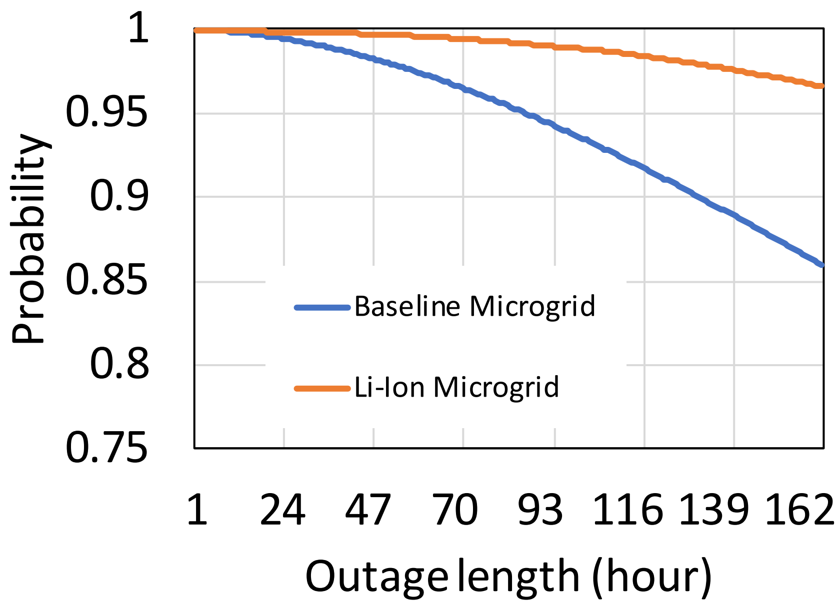
Final Microgrid Design Output

	Baseline Microgrid Configuration	Li-ion ES Microgrid Configuration
Power and Duration	**-**	**4375kW 4hr**
SOC Reservation (Reliability)	-	5.16%
# Gensets	7 x 750 kW	5 x 750kW
Secondary Services	-	Bill reduction

Note:

1. Baseline and ES-enable design included PV
2. The final microgrid design with ES replaced two generators from the baseline microgrid

Microgrid - Reliability Performance

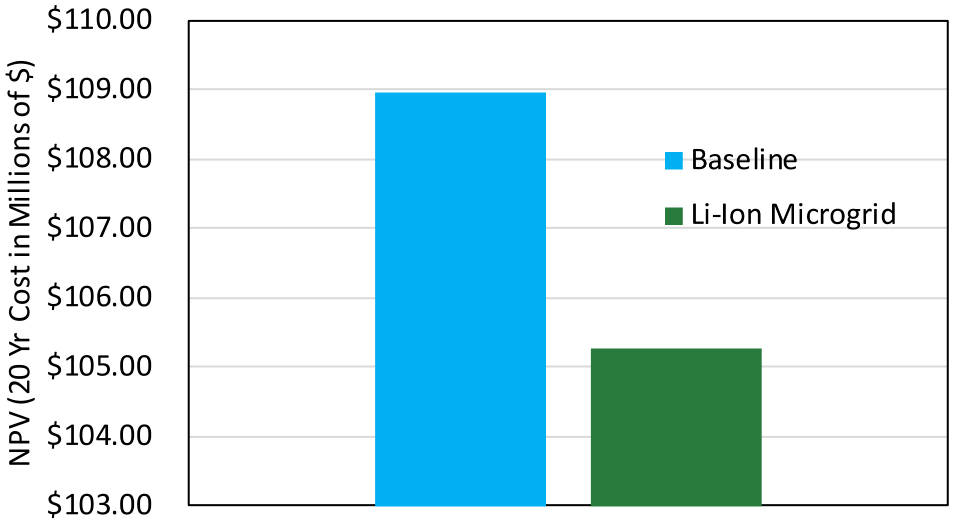


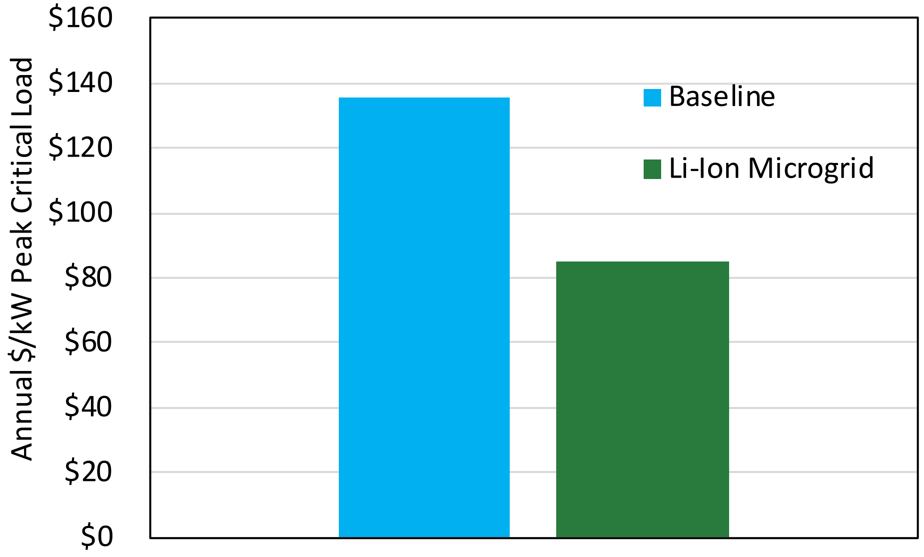
Duration	Probability (%)	
	Baseline	Li-Ion ES
24 hours	99.46%	99.85%
168 hours	85.94%	96.6%

Both the designed microgrid has better reliability performance than the baseline microgrid

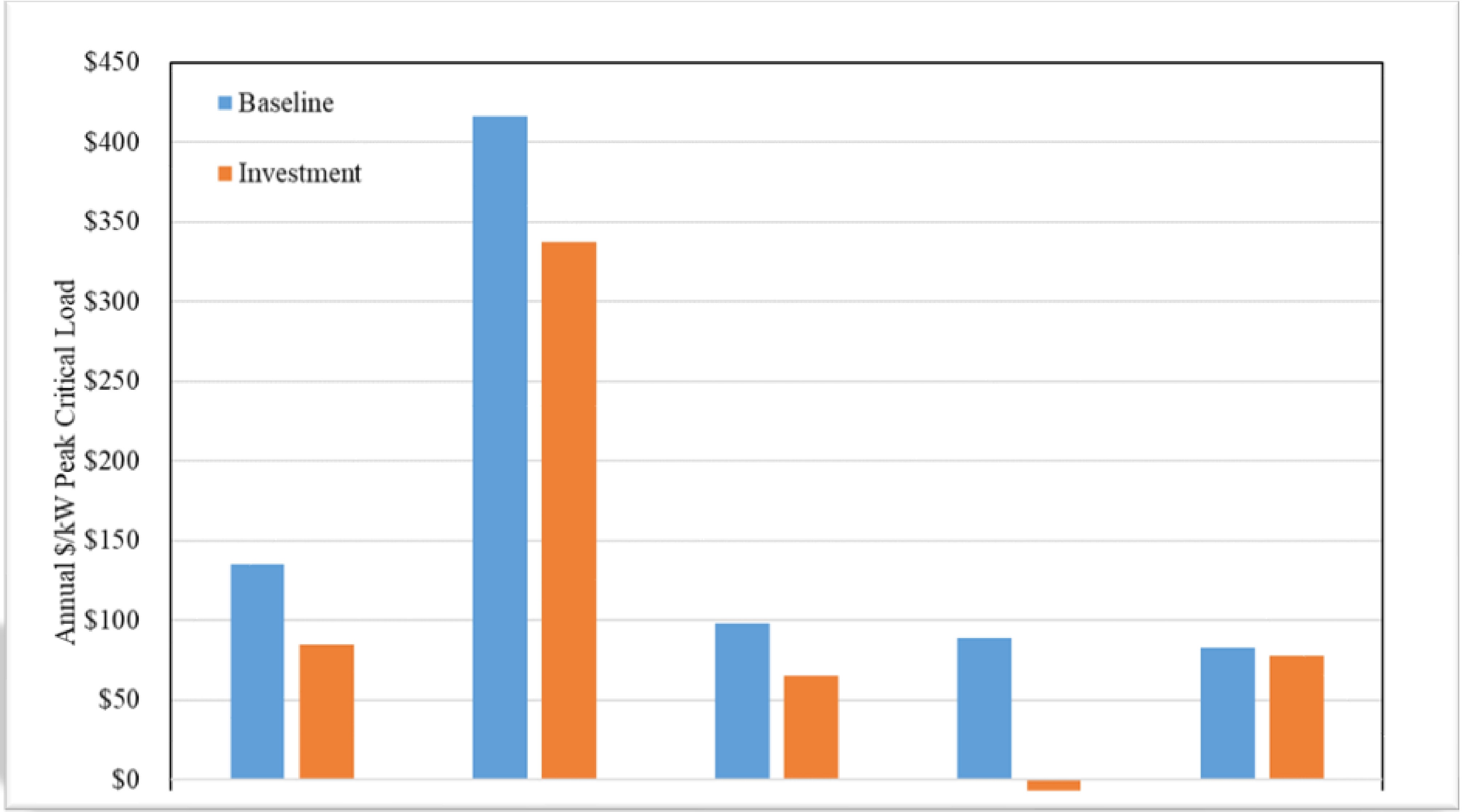
Li-Ion Storage Microgrid – Economic Performance

Cost Benefit Analysis Components	
Battery Size	4375 kW, 4 hr
CAPEX Cost ($/kWh)	$445/kWh
O&M Cost ($/kW-yr)	$10/kW-year
Baseline NPV (20 Yr) (Cost)(Millions of $)	**$108.95**
Investment Case NPV (20 Yr) (Cost)(Millions of $)	**$105.27**
% NPV Improvement	**3.38%**
Baseline Critical Load Coverage ($/kW-yr)	**$135.50**
Storage-Enabled Critical Load Coverage ($/kW-yr)	**$85.20**
% Critical Coverage Improvement	**37.12%**
# Generators Retired	2
Profitable Secondary Service	Retail Bill Reduction
Total Sec. Service Revenue ($)	$8,785,963
Avoided Costs due to Demand Charge Reduction	$4,850,519
Avoided Costs due to Energy Cost Reduction	$3,935,444





Economic Metric Li-Ion Microgrid – All Sites



Microgrid Design for PSPS Events (Study for SCE)

Introduction

Problems (Why?)

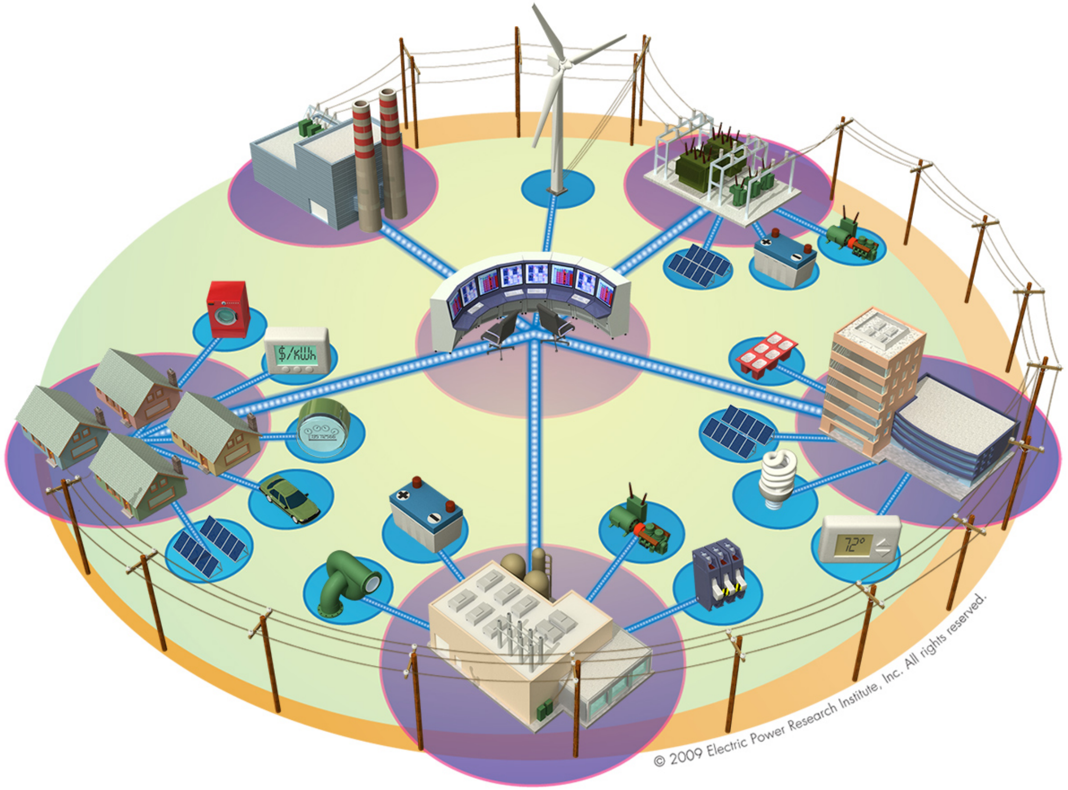
- **Customer interruption** during prolonged outages (PSPS, scheduled maintenance)
- California State push to meet **Clean Energy Targets** and **GHG Emission Reduction** targets

Solution

- Solar plus Storage Microgrids to build **Resilient Communities**

Design (How?)

- Microgrid Design – **Solar plus storage** using **DER-VET** to maximize **resiliency** and **cost-efficiency**



*DER-VET is a CEC funded open-source software tool

*PSPS: Public Safety Power Shutoff

Solar plus Storage Microgrid Design Overview

DER Technology Mix

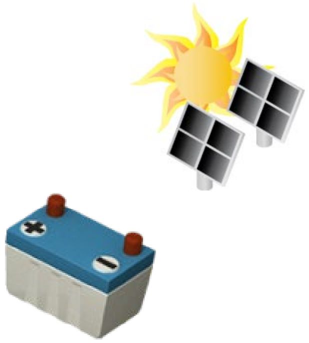
- Solar PV
- Energy Storage

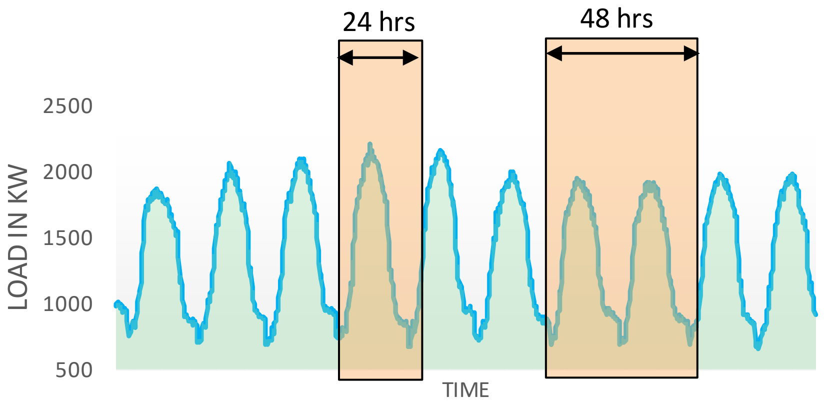
DER Sizing & Operation

- **Primary Objective**: Customer Reliability/Resiliency for planned outage
- **Secondary Objective**: Maximize economic benefits from Wholesale market participation

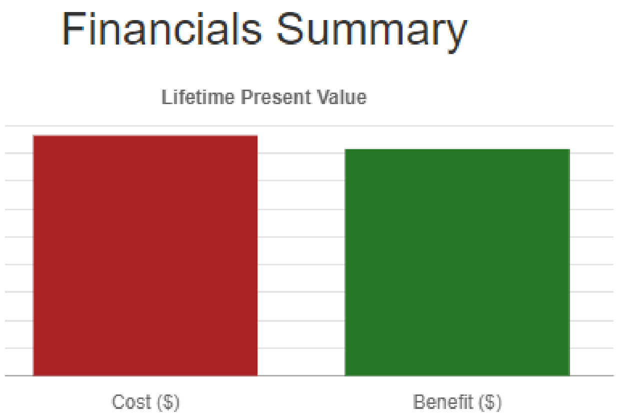
Cost Benefit Consideration

- DER ownership model: FTM utility owned
- Lifetime of assets and replacement
- Analysis time horizon
- CBA Metrics: Total project NPV





Outage Horizon



Microgrid Candidate Selection Scenario

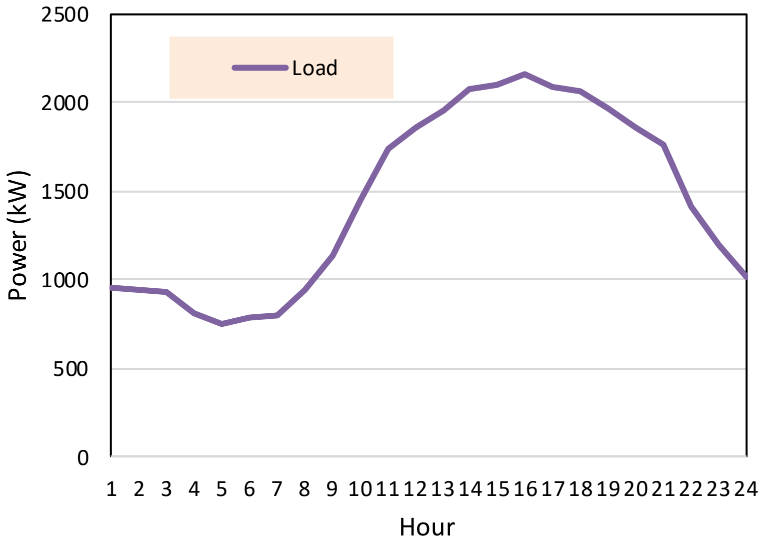
1. High frequency PSPS circuits (based on 2018 and 2019 data)
2. Candidate that can safely remain energized during PSPS events
3. Screen out candidate with planned mitigation solutions
4. Prioritize candidates based on key criteria (low income, no. of PSPS, critical and/or disadvantaged customers, etc.)

Study conducted on one of SCE's feeders:

- Peak demand approx. = 2.2 MW
- No. of customers = 137 customers
- Customer type = 98% commercial and industrial circuit

Microgrid Design - DER-VET Input

- Identify potential planned outages and duration
  - Load profile to identify microgrid demand
- Solar PV assumptions and limitations
  - Solar irradiance profile and dependability percentages – (0, 27 %, 42%, 100%)
  - PV limited by land availability – Size varied between 0.5 MW - 30 MW (carport, ground mount)
  - PV can be curtailed
- Battery ES assumptions:
  - Initial SOC at the start of outage event is 90%
  - Battery round trip efficiency – 91%
  - Hybrid solar plus storage installation – co-located at the dc side
  - No duration constraint

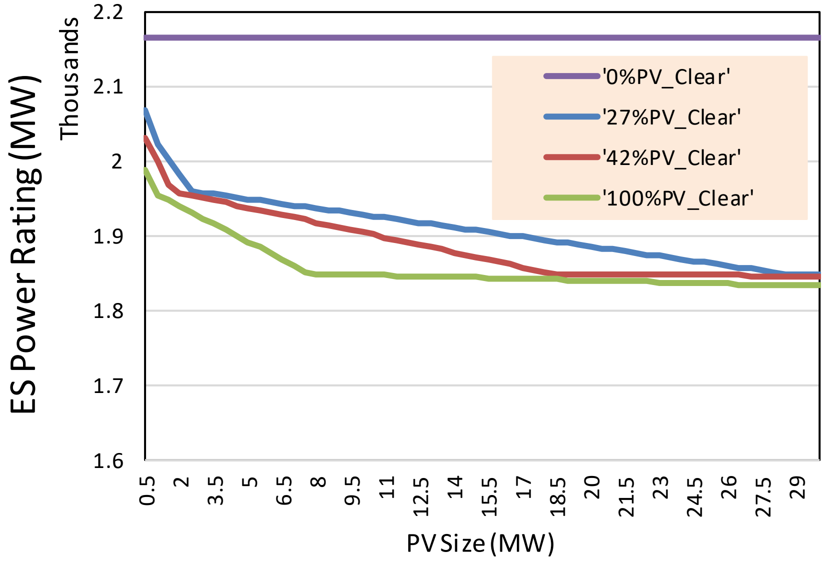


24 Hr Load Profile

24 Hour Outage DER Sizing

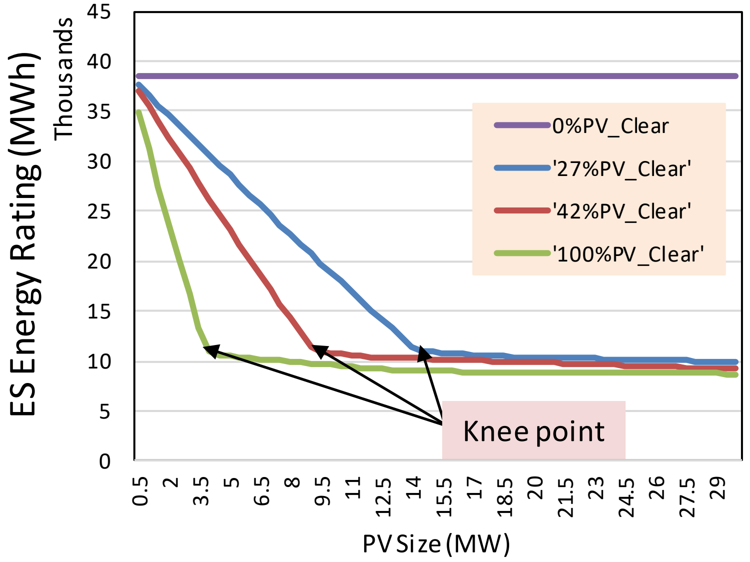
Optimal Microgrid Design – 24-hour Outage

ES Power Rating



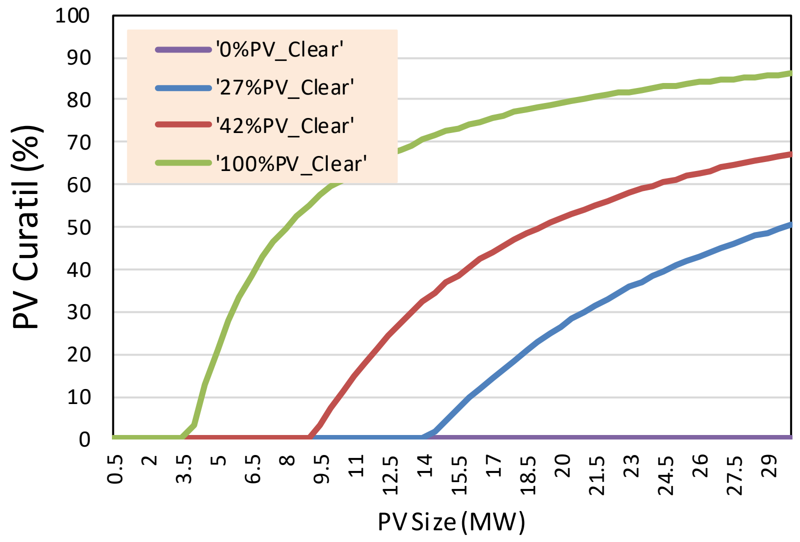
Min power rating for the storage = Peak Load (~2.2 MW)

ES Energy Rating



Energy rating of the battery decreases with increase in installed PV capacity until the knee point

PV Curtailment



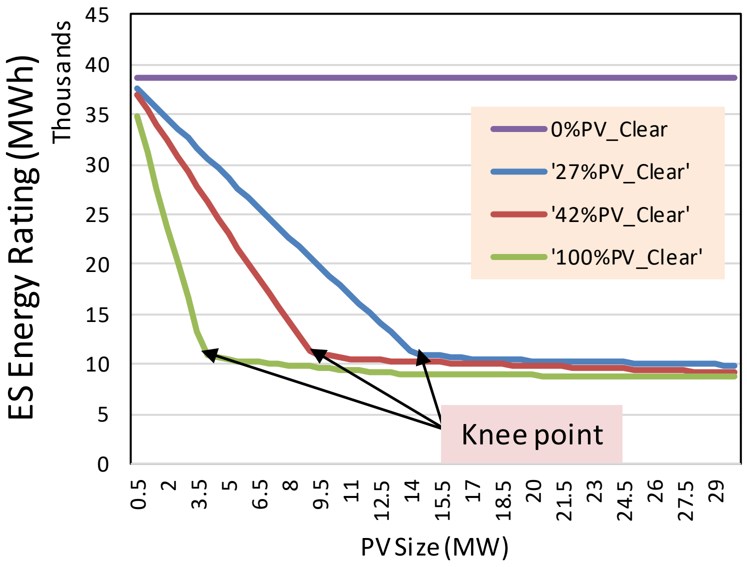
PV curtailment happens at and after the knee point

PV curtail % = [Sum of curtailed PV energy at each time step / Sum of total PV energy at each time step]

PV Curtailment and the 'Knee Point'

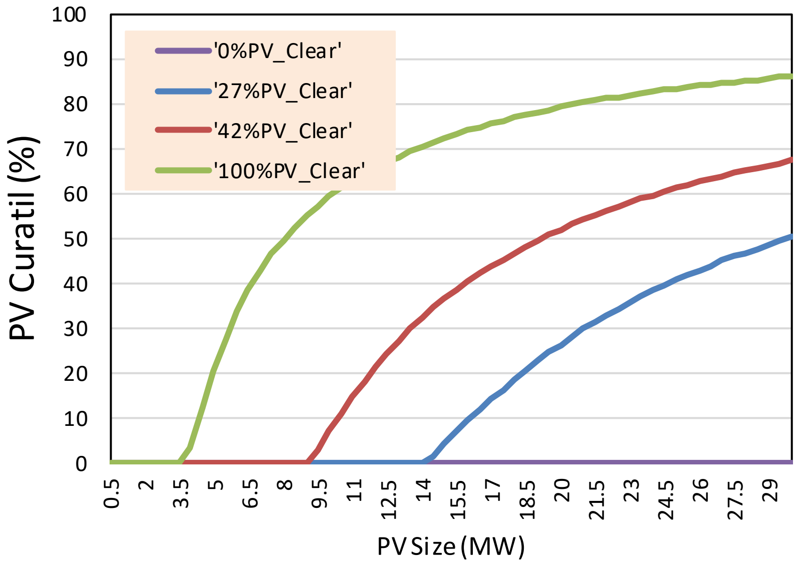
- There is direct correlation between PV curtailment and Knee point
  - PV curtailment happens at and after the knee point

ES Energy Rating



Knee point for 42% PV case is 9MW

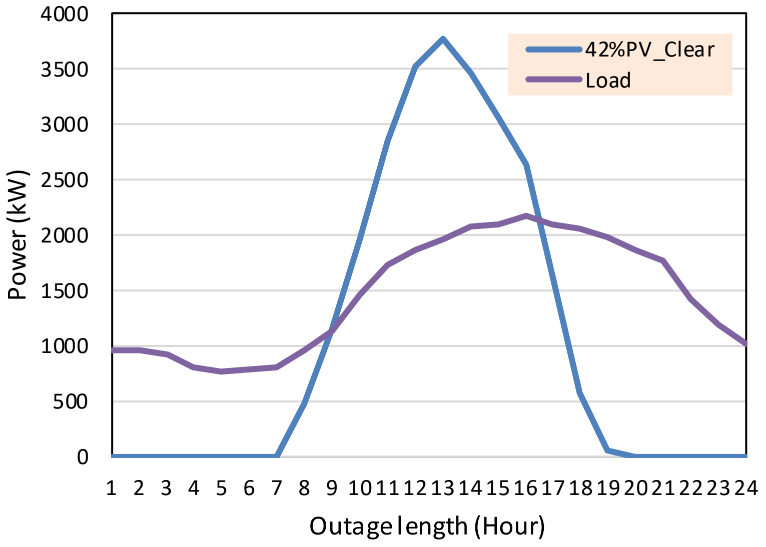
PV Curtailment



PV curtail % = [Sum of curtailed PV energy at each time step / Sum of total PV energy at each time step]

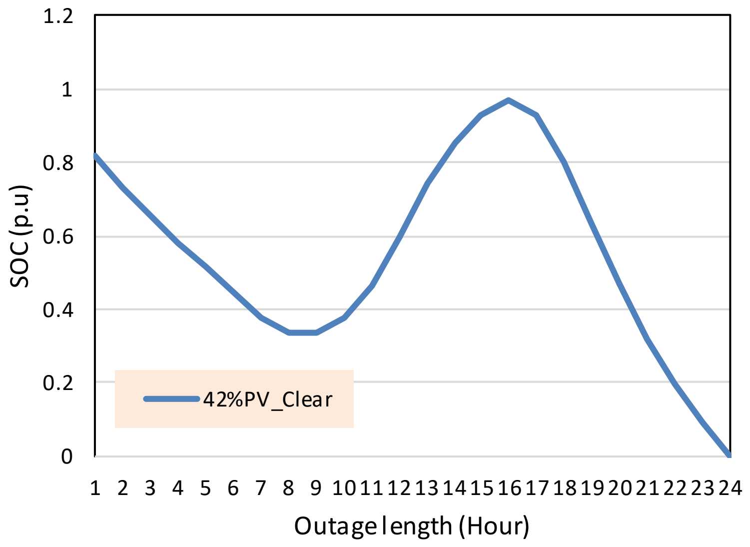
Outage Simulation – Solar (9 MW) + Storage (2.2MW/11.5MWh)

Load and PV Profile



Min ES size:
Power= 2.2 MW
Energy= 11.5 MWh

SOC Profile



- SOC is not 100%, so there is no PV curtailment in this case
- Excess PV generation is charged in ES and so there we can see an increase in battery SOC %

Cost-Benefit Analysis - Assumptions

- Benefit Services and Modeling Approach

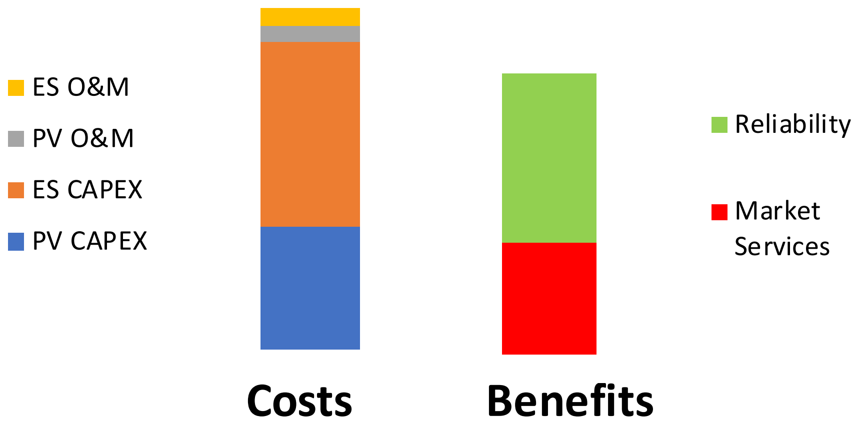
Benefit Services	Modeling Assumption
Reliability*: 100% Load coverage for Planned Outages (3 events X 24 hrs)	Reserve 100% Energy Storage Capacity for 24 hrs
Wholesale Market Participation	Co-optimized for - Energy arbitrage - Frequency Regulation

*Reliability: Value of service calculated based on customer minutes of interruption (CMI) and customer type (residential, commercial, industrial)

- EPRI Financial Assumptions

Design Parameters	Value
Discount Rate	10%
Inflation Rate	2%
Economic Carrying Cost (PV)	10.64%
Economic Carrying Cost (ES)	15.11%*

*Considers Federal Income Tax Credit (ITC) for solar plus storage assets

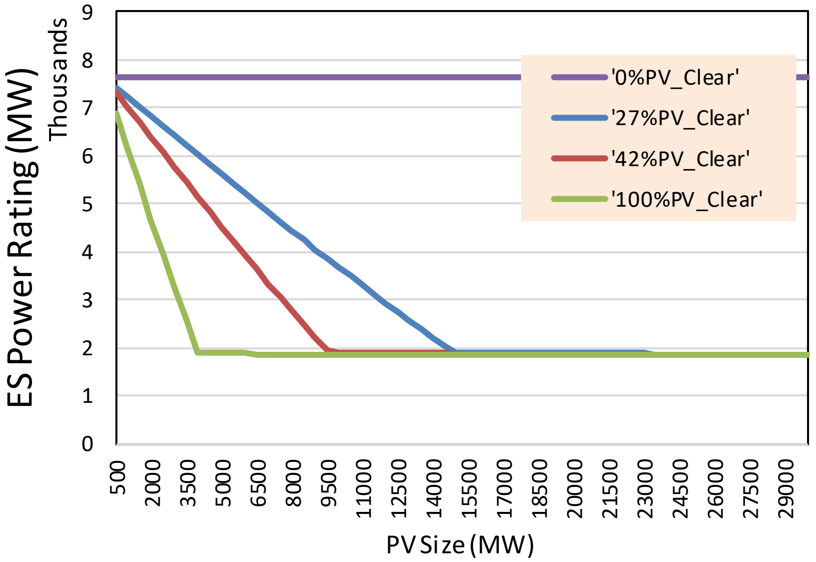


For illustration propose only (not in scale)

48 Hour Outage DER Sizing

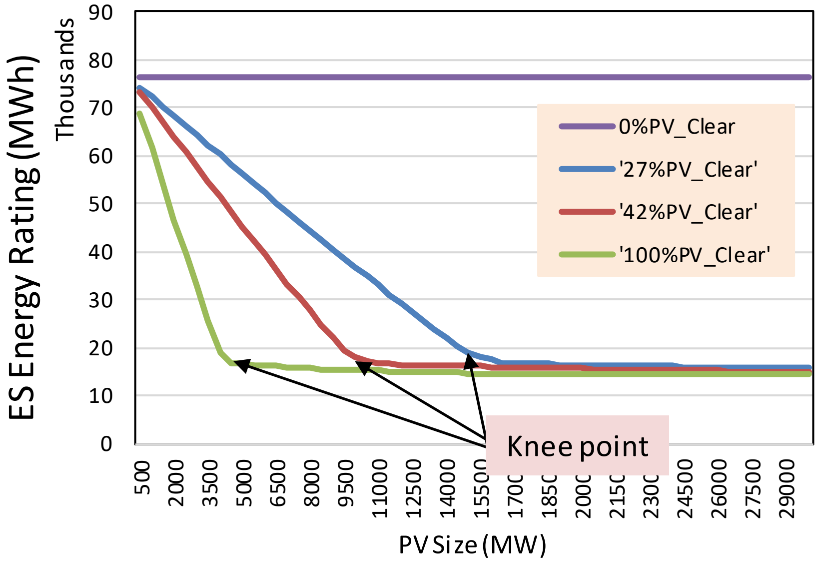
Min ES Size – Allowing PV Curtail – 48 hr Outage

ES Power Rating



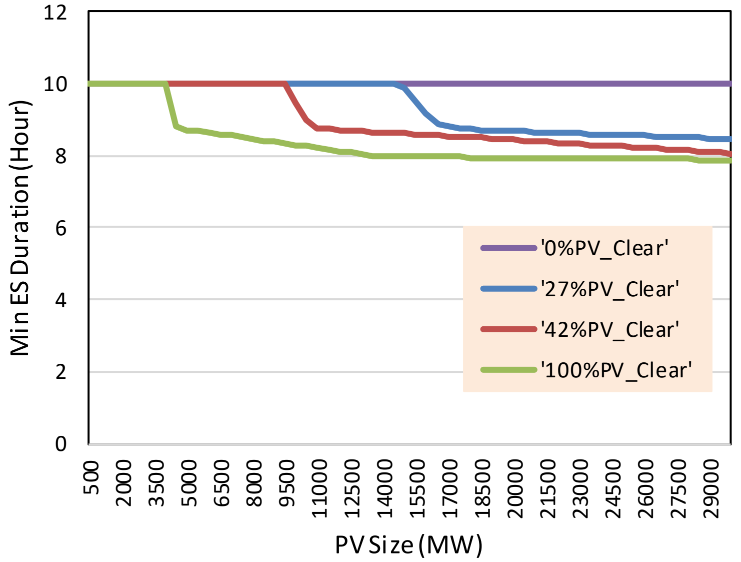
Min power rating for the storage is about 2 MW (~peak load). Similar to the 24 hr outage case

ES Energy Rating



Energy rating follows the same trend as in prev case. The knee points are slightly different from the previous case

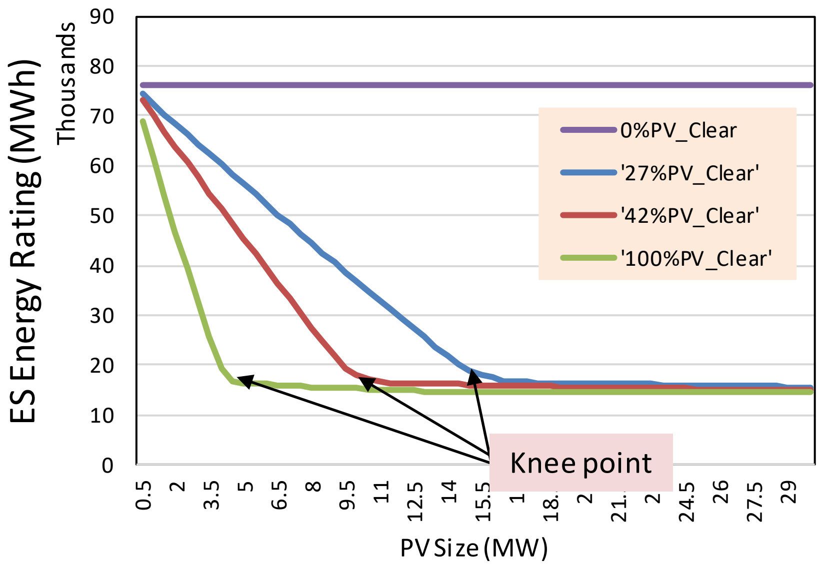
ES Duration



ES duration trend is also similar to 24 hour outage

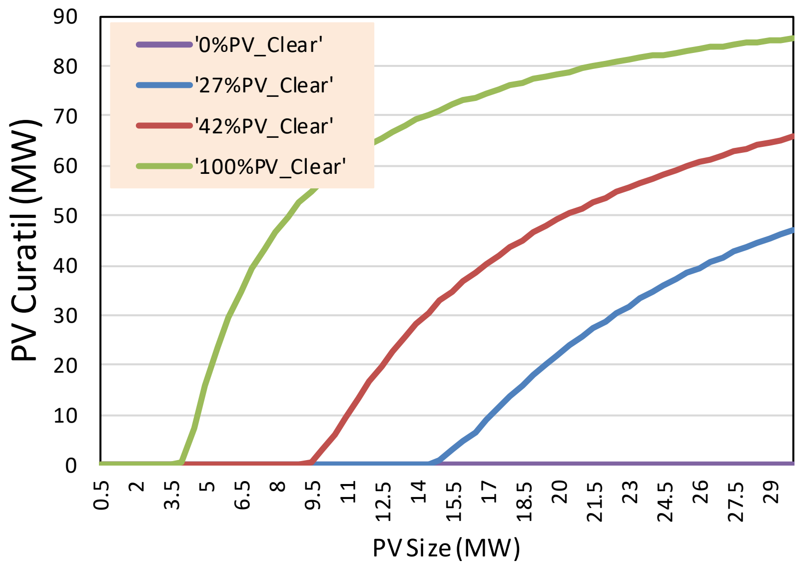
Min ES Size – Allowing PV Curtail – 48 hr Outage

ES Energy Rating



Knee point for 42% PV case is 10 MW

PV Curtailment



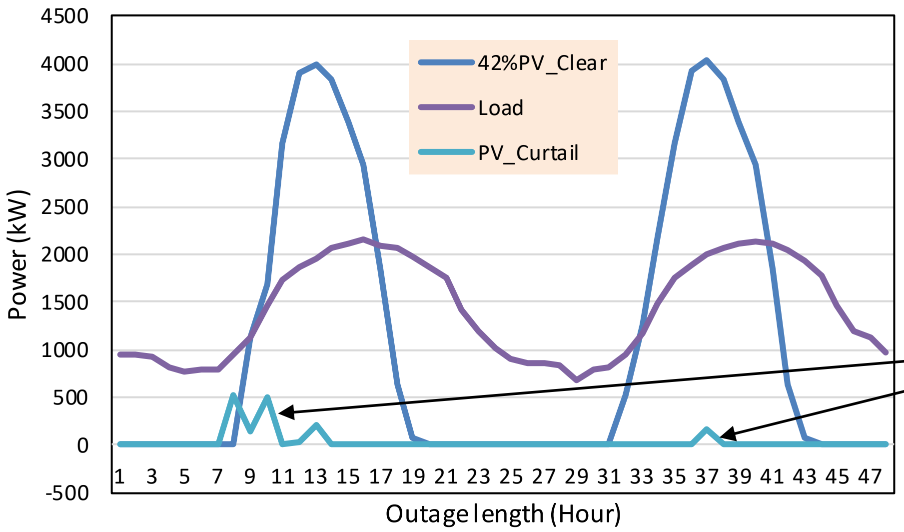
PV curtailment happens at or after the knee point

PV curtail % = [Sum of curtailed PV energy at each time step / Sum of total PV energy at each time step]

Timeseries Plots for 42% PV Case's Knee Point – 10 MW PV

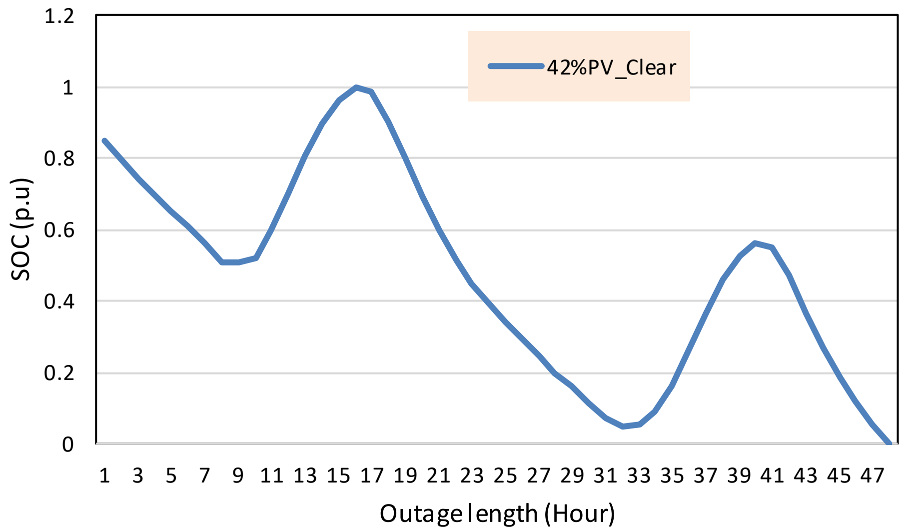
Min ES size:
Power=2.03 MW
Energy=17.81 MWh

Load and PV Profile



There is some curtailment because excess generation is more than the Battery power rating of 2.03MW

SOC Profile



Microgrid Design Summary

- Solar plus storage microgrid design using DER-VET
  - Ensured **100% load coverage** during outage events and planned maintenance
  - Demonstrated ability to determine a minimum size system to **meet 24 hour** microgrid demand
  - Detailed cost-benefit analysis to estimate the net present value of the designed microgrid
- SCE issued RFP in Q1 for potential microgrids deployment in 2020
  - Decided to **not pursue** the proposed projects based on **costs, technology**
  - Following the Q1 RFP, **SCE started reevaluating possibilities**, applying lessons learned, and developed site selection & evaluation criteria for potential **2021/22** microgrid deployment

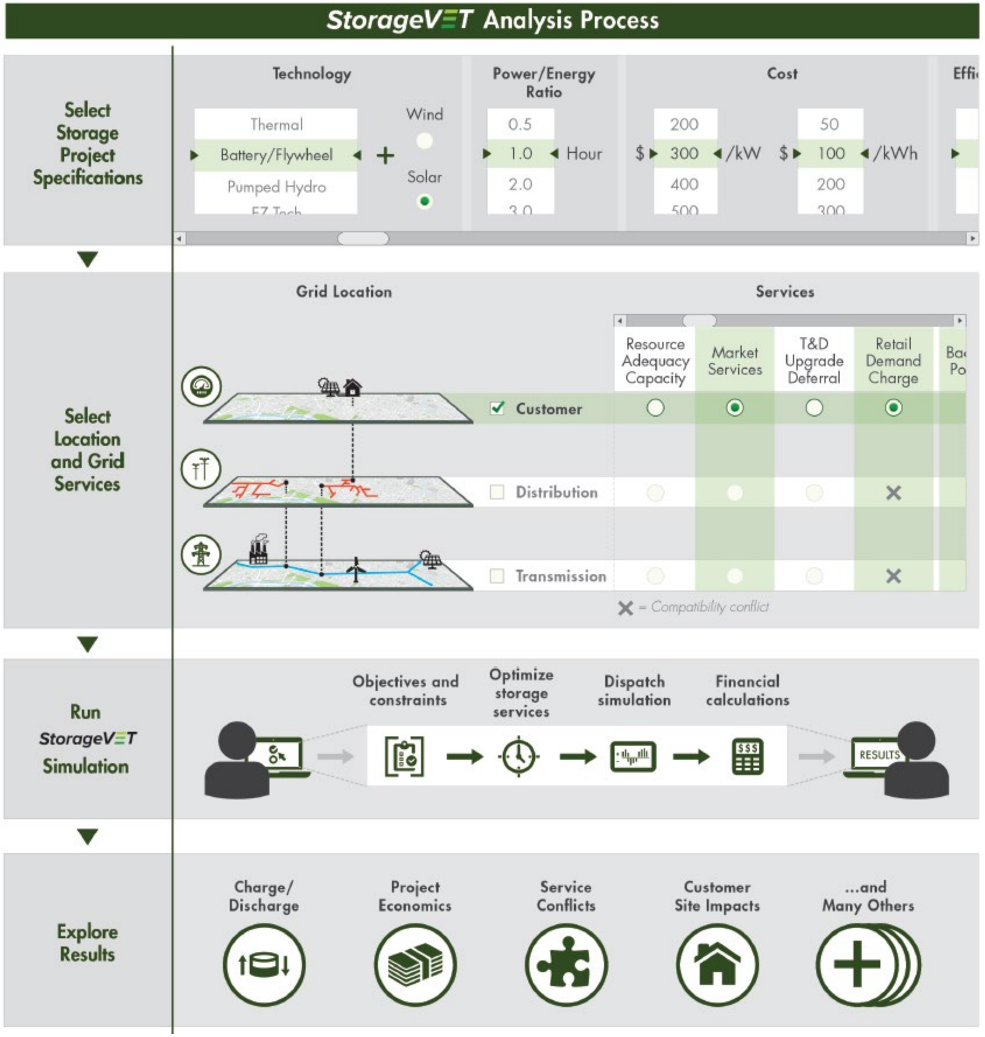
SCE's EPIC Front-of-The-Meter (FTM) Microgrid Projects

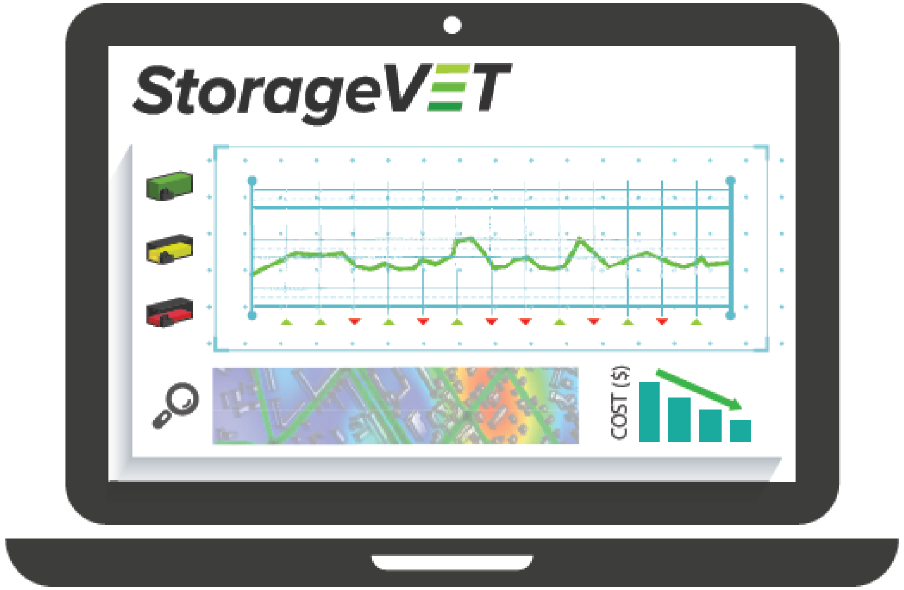
- Control and Protection for Microgrids and Virtual Power Plants
  - Development of hardware-in-the-loop (HIL) microgrid test-bed and demonstration of control & protection schemes
  - Platform to **design & integrate** microgrids into SCE **planning & operational processes**
- Smart City Demonstration
  - Partner with City to deploy **FTM microgrid** supporting **critical facilities**
  - **Customer** and **utility-owned DERs** to operate FTM microgrid (100% inverter-based)
  - Interface between Microgrid Control System and Grid Management System for improved **visibility and operation** (island and resynchronize)
- Service and Distribution Centers of the Future
  - Integrated electric fleet center field demonstration with **managed EV charging** and DERs
  - Use of a FTM energy storage to support **load management** and **resiliency**

StorageVET® Background

StorageVET® in Action

StorageVET® is a free, open source energy storage project valuation tool informing decision-makers across the electric grid





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