The Economic Potential for Energy Storage in Nevada

PRESENTED TO

Nevada Governor's Office of Energy
Public Utilities Commission of Nevada

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Disclaimer

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Agenda

Study Purpose and Scope

Approach to Estimating Storage Costs and Benefits

Evaluation of Key Storage Value Drivers

Aggregate System-Wide Benefits of Storage

Behind-the-Meter Applications

Comparison to Other Storage Potential Studies

Study Conclusions

Study Purpose and Scope

Study Purpose: "Provide information to be used by the Public Utilities Commission of Nevada (PUCN) in determining whether procurement targets for energy storage systems should be set in Nevada pursuant to Senate Bill (SB) 204 (2017), and at what level"

Scope:

- Evaluate benefits of storage across several uses
- Identify storage use cases, including behind-the-meter at customer sites, on the distribution system, and on the transmission system
- Evaluate the global storage industry landscape, including trends in costs
- Estimate cost-effective storage potential for Nevada for 2020 and 2030

Approach to Estimating Storage Costs and Benefits

Approach and Key Value Drivers Evaluated

We utilize Brattle's bSTORE model to evaluate the key drivers of storage value change as increasing amounts of storage is added to Nevada.

We quantify four key value drivers:

- **Production Cost Savings:** Changes in NV Energy's cost of providing energy and ancillary services
- **Avoided Capacity Investments:** Reduction in generation capacity needed to meet peak load
- **Deferred T&D Investment:** Value of deploying storage to defer upcoming T&D investments
- **Avoided Distribution Outages:** Reductions in load shedding by locating storage on certain distribution feeders

Our approach accounts for likely limitations in the ability to "stack"these values

- **Location limitations:** We assumed that storage can be deployed at certain distribution grid locations either to defer T&D investment or avoid distribution outages, but we have conservatively assumed that both value cannot be captured simultaneously
- **Operational constraints:** Discharging storage to provide one service (e.g. to defer T&D investment), limits its ability to provide other services

Summary of Analytical Approach

Analysis Inputs

Develop Simulation Inputs
- Nevada power system data
- WECC power system data
- Storage technical assumptions

Develop Storage Cost Estimates

bSTORE

Identify Key Value Drivers
- Reduction in production costs
- Avoided generation capacity
- T&D investment deferral
- Customer outage reduction

Simulate Storage With bSTORE
- Simulate 2020 and 2030
- 200 MW and 1,000 MW storage at highest-value NV locations

Quantify Ratepayer Benefits
- Compare customer costs with storage to Base Case without

Compare Ratepayer Benefits to Storage Cost

Analytical Results

Evaluate Additional Value
- Reduced emissions
- Reduced renewable curtailment
- Provision of voltage support
- Reduced T&D losses

Identify Cost-Effective Levels of Storage in 2020 and 2030

Approach

Data Sources

We model Nevada consistent with NV Energy's 2018 IRP and rest of WECC consistent with 2026 TEPPC database (adjusting for 2020 and 2030).

Data Element	Source(s)
Transmission Topology	2026 TEPPC Common Case (as updated in 2017 CAISO TPP)
NV and WECC Generator List	NV Energy's 2018 IRP, 2026 TEPPC Common Case, SNL
NV and WECC Generator Characteristics	NV Energy's 2018 IRP, 2026 TEPPC Common Case
Fuel Prices	NV Energy's 2018 IRP, 2026 TEPPC Common Case, EIA
NV and WECC Demand	NV Energy's 2018 IRP, 2026 TEPPC Common Case, SNL
NV and WECC Reserve Requirements	NV Energy's 2018 IRP, 2026 TEPPC Common Case
NV and WECC RPS Requirements	NV Energy's 2018 IRP, Database of State Incentives for Renewables & Efficiency (DSIRE)
T&D Deferral Analysis	NV Energy's Transmission and Distribution Capital Expenditure Data
Distribution Reliability Analysis	NV Energy's Distribution Outage Data

Storage Technology Assumptions

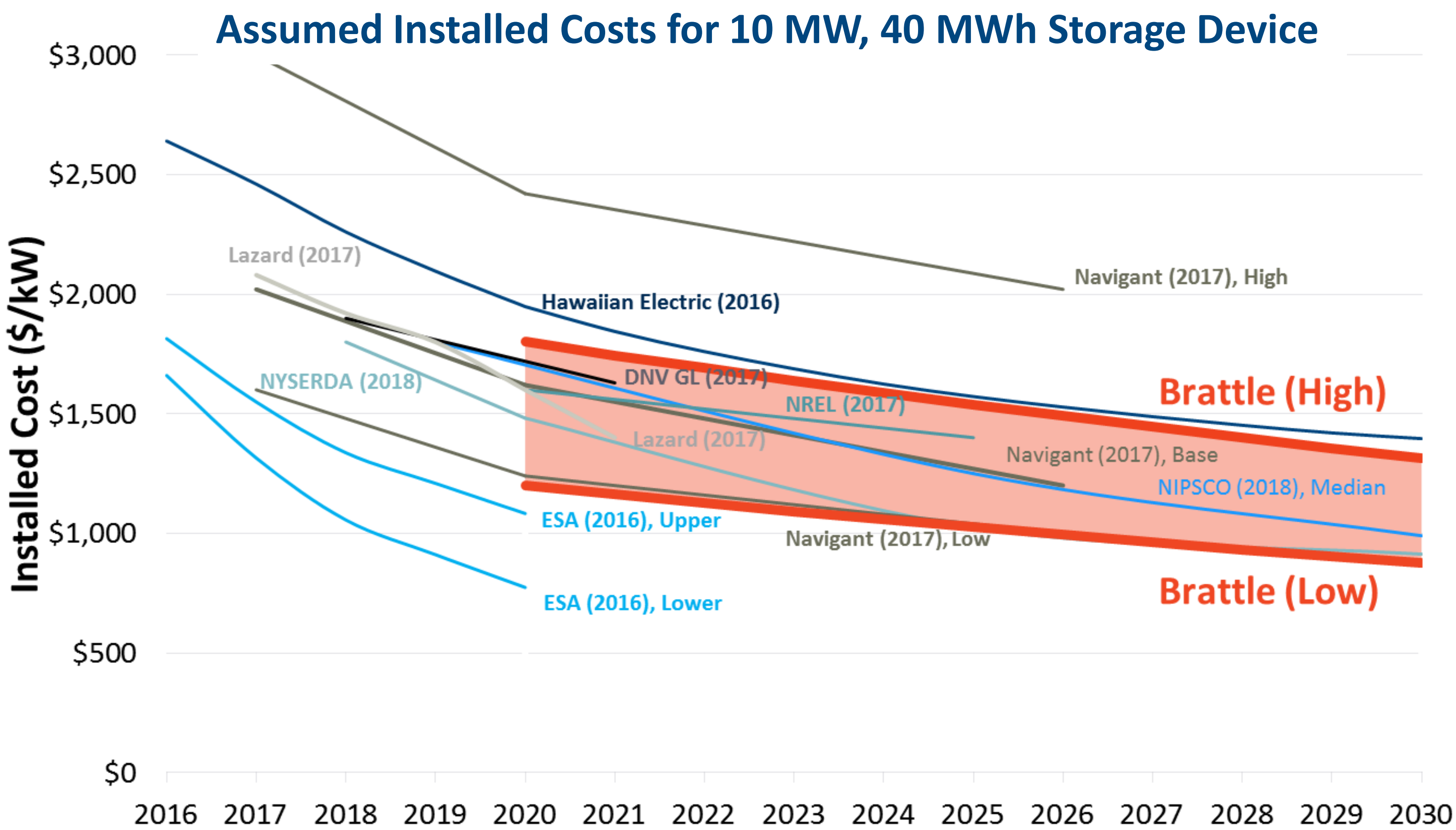
Although our analysis approach is technology agnostic, we simulate batteries with operational characteristics that resemble Li-Ion chemistry.

- **Configuration and siting**
  - Stand-alone storage, not co-located with solar PV or other generator
  - Distribution and transmission connected
  - Sited in front-of-meter (behind-the-meter use case evaluated separately)
- **Size of individual storage devices:** 5 to 10 MW
- **MWh:MW ratio:** 4:1
  - Four hour discharge capability at full output
  - Consistent with types of storage systems procured in many recent solicitations
- **Round-trip efficiency:** 85%
- **Lifespan:** 15 years

Notes: Assumptions developed with input from the PUCN and PNNL. Our fixed-cost and cost-levelization assumptions include the costs of replacing worn-out battery cells during the 15-year period. We do not assume degradation over time, consistent with the assumption that worn-out battery cells will be replaced throughout the 15-year period.

Storage Installed Cost Trends

We analyze a range of installed costs for 4-hour storage in 2020 and 2030 to reflect uncertainty we see in current cost projections.



Sources and Notes: Literature review of Navigant (2017), Hawaiian Electric Companies (2016), NREL (2017), NIPSCO (2018), DNV GL (2017), NYSERDA (2018a), ESA (2016), and Lazard (2017). Installed cost estimates for a 4-hour storage system. All values in nominal dollars.

Levelization of Storage Costs

We assume levelized installed costs of $136-204/kW-yr in 2020 and $99-149/kW-yr in 2030 for 4-hour storage device.

Financial Assumptions

Financial Assumption		Value
Fixed O&M	*% of Installed*	1%
Developer After-Tax WACC	*%*	7%
Battery Asset Life	*yrs*	15
Balance of Plant Asset Life	*yrs*	15
Total Income Tax Rate	*%*	21%
Depreciation Schedule		15-yr MACRS
Annual Inflation Rate	*%*	2%

Levelized and Installed Cost Assumptions For 10 MW (40 MWh) Storage Device

	Assumed Installed Costs		Implied Levelized Costs
	$/kW Installed	*$/kWh Installed*	*$/kW-year*
Assumed Costs			
2020 Low	$1,200	$300	$136
2020 High	$1,800	$450	$204
2030 Low	$876	$219	$99
2030 High	$1,314	$328	$149

Note:
Cost and financing assumptions indicative of new development costs in Nevada. All values in nominal dollars

Cost Effectiveness Framework

We utilize the RIM test to evaluate cost-effectiveness of energy storage, including the value of avoided customer outages.

The Ratepayer Impact Measure (RIM) test provides an indication of how average retail rates will change as the result of a new utility initiative

- Includes all reductions in resource costs (*e.g.*, reductions in fuel and capacity costs)
- Includes savings associated with procuring services more cheaply (*e.g.*, ancillary services)

We also include as a benefit the ratepayer value of avoided distribution outages

- Not traditionally included in RIM test (does not result a cost incurred by the utility), but reflects a benefit to ratepayers who experience fewer outages
- We separately report cost-effective storage levels excluding customer outage value

We quantify, but do not include as ratepayer benefits, the societal cost impacts associated with changes in carbon and other emissions

Evaluation of Key Value Drivers

Evaluation of Key Value Drivers

Reduction in Production Costs

Approach

We use a production cost model – Power System Optimizer (PSO) – to estimate cost of meeting Nevada's energy and ancillary service needs.

- We simulate entirety of WECC, with focus on Nevada
- To account for changes in Nevada production costs, purchases, and sales, we calculated adjusted production costs (APC) for the Nevada footprint
- We simulate 3 scenarios: base case (no storage), 200 MW, and 1,000 MW of storage

Calculating Nevada Adjusted Production Costs (APC)

Nevada Adjusted Production Costs = **Production Costs**
+ Cost of Purchases
– Revenue from Sales

Production Costs = Cost of Nevada owned generation

- Generation costs include fuel, emissions, variable operating, and startup costs

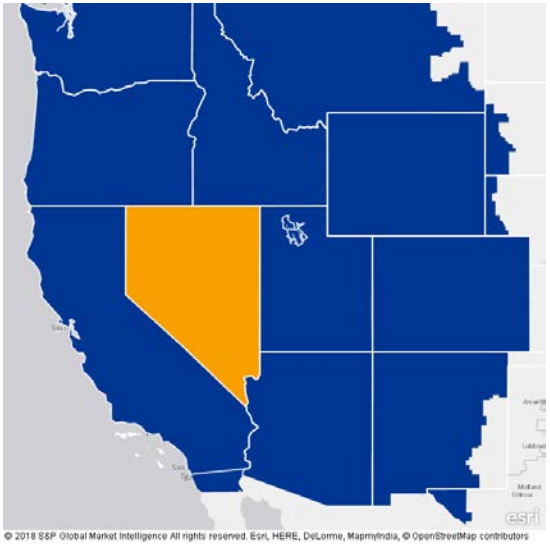
Cost of Purchases = Deficit in generation × Price Hub

- Purchases priced at the Malin and Mead hubs for Northern and Southern Nevada, respectively.

Revenues from Sales = Surplus in generation × Price Hub

- Sales priced at the Malin and Mead hubs for Northern and Southern Nevada, respectively.

WECC Footprint



Source: SNL

Evaluation of Key Value Drivers

Reduction in Production Costs

Findings

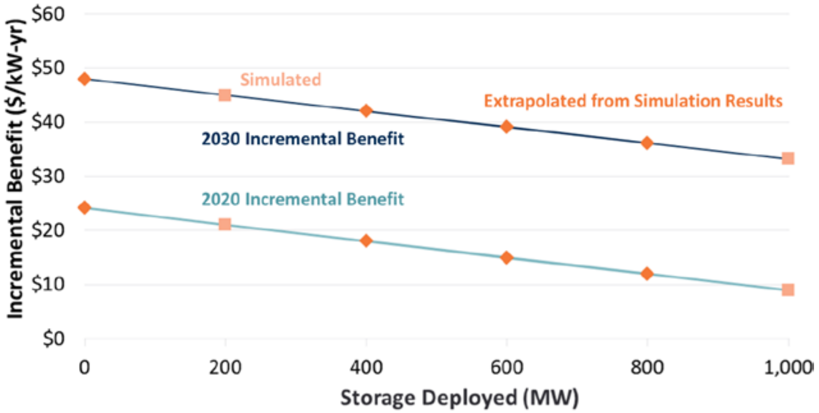
We find APC savings of $4.5 to $16.5 million in 2020 (200 MW vs. 1,000 MW storage deployed), and $9.3 to $40.6 million in 2030.

- Savings due three factors:
  - Reduced costs of operating NV generators
  - Reduced imports during high priced hours
  - Increased revenues from sales
- Savings account for the value of storage providing ancillary services
- Incremental savings (savings due to adding 1 additional MW of storage) fall as more storage is added and highest-value opportunities saturate

2020 Adjusted Production Cost Savings
(in nominal $million/year)

	Production Cost			Savings (Storage Case minus Base Case)	
	Base	200 MW	1,000 MW	200 MW	1,000 MW
Production Cost	$421	$420	$423	($1.1)	$2.2
Cost of Market Purchases	$132	$129	$124	($3.1)	($7.9)
Revenues from Sales	($46)	($46)	($57)	($0.4)	($10.8)
Total	**$507**	**$502**	**$490**	**($4.5)**	**($16.5)**

Estimated Incremental Benefit from APC Savings



Sources and Notes:
All values in nominal dollars. The total APC savings from simulations with 200 MW and 1,000 MW were used to estimate a relationship between storage deployed and total savings, from which we can estimate the relationship between storage deployed and incremental APC savings.

Avoided Generation Capacity

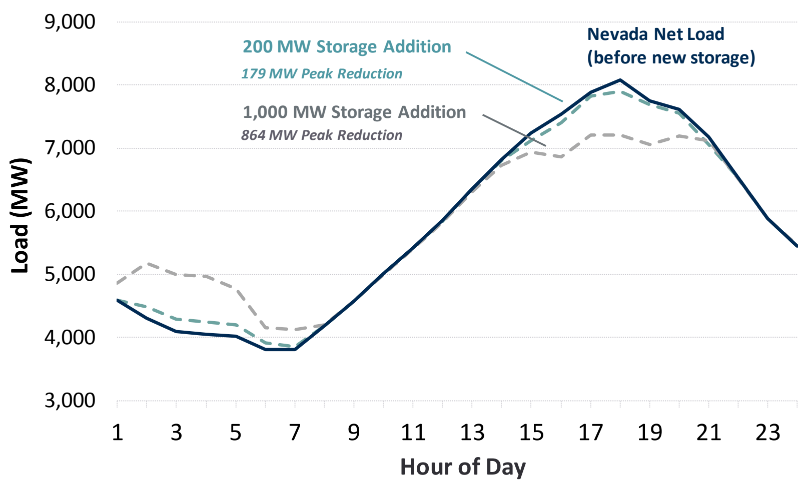
We find storage can effectively offset the need for additional peaking capacity in both 2020 and 2030, across all levels of deployment evaluated.

- If discharging during system peak load hours (net of renewable generation), storage offsets the need for other capacity
- Net peak load reductions valued at the market price for capacity assumed in 2018 NV Energy IRP
- We find 4-hour storage can effectively offset the need for new generation capacity
  - Net load peaks concentrated in July and August
  - Net load peaks are relatively short duration, due to high PV generation in summer months
  - 1 MW of storage equivalent to 0.86 MW of capacity for simulated deployment of 1,000 MW

2020 and 2030 Net Peak Reduction due to 200 MW and 1,000 MW of Storage

	MW	*%*
200 MW	179	90%
1,000 MW	864	86%

Nevada Net Load Peak Day Reduction (July 27, 2020)



Transmission & Distribution Investment Deferral

Approach

We used NV Energy capital expenditure data to identify high-value T&D deferral opportunities and evaluate how storage could defer investments.

- NV Energy provided cost data and descriptions for 260 capital projects from 2014-2027
- We estimate the subset that could be deferred by storage
  - We identified 35 projects (14% of total) are potentially deferrable by storage
  - Primarily transformer upgrades needed to support local load growth
  - We estimate the value of deferring each investment by 15 years
- We make several assumptions to approximate how much storage may be require to defer an investment
  - **Initial Peak Load:** based on NV Energy's project descriptions
  - **Rate of Load Growth:** Assumed 2%
  - **Hourly Load Shape:** Based on average residential or C&I load shapes
- We size the storage to 15 year load growth

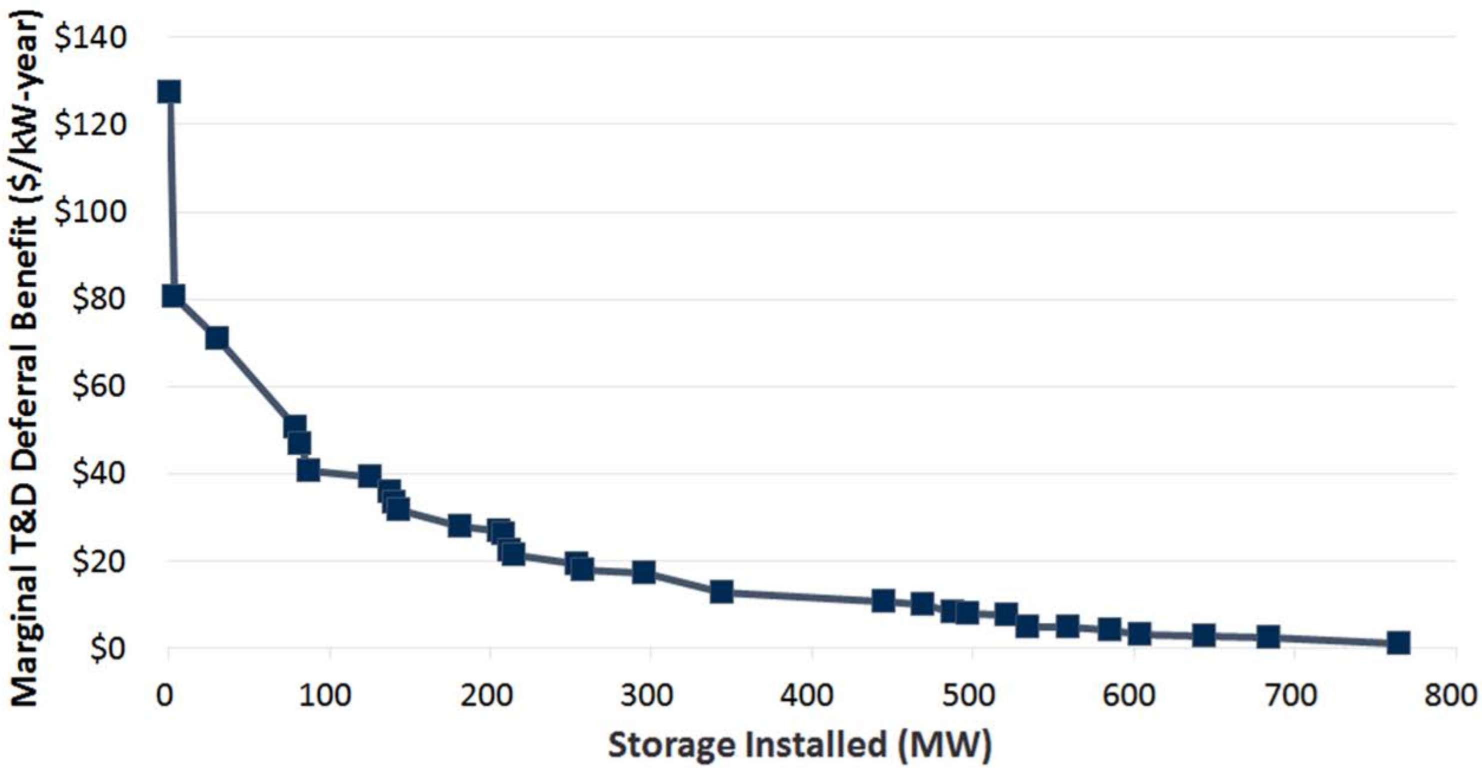
* Average of NPC and SPPC After Tax Weighted Average Cost of Capital (ATWAAC) per NV Energy 2018 IRP, weighted by each system's contribution to total peak load.

Transmission & Distribution Investment Deferral

Findings

We identify a small number of high-value opportunities to defer specific T&D investments.

Marginal T&D Deferral Benefit of Storage for Individual T&D Projects ($/kW-year)



Notes:

Points reflect individual projects from NV Energy's 2018 transmission and distribution capital expenditure outlook identified as deferrable by storage. Although NV Energy's outlook is over a 10-year span, we annualize the size and value of opportunities. We order projects by $/kW-year value, and plot to estimate the marginal benefit for storage from T&D investment deferral. Values in nominal dollars.

Customer Outage Reduction Value

Approach

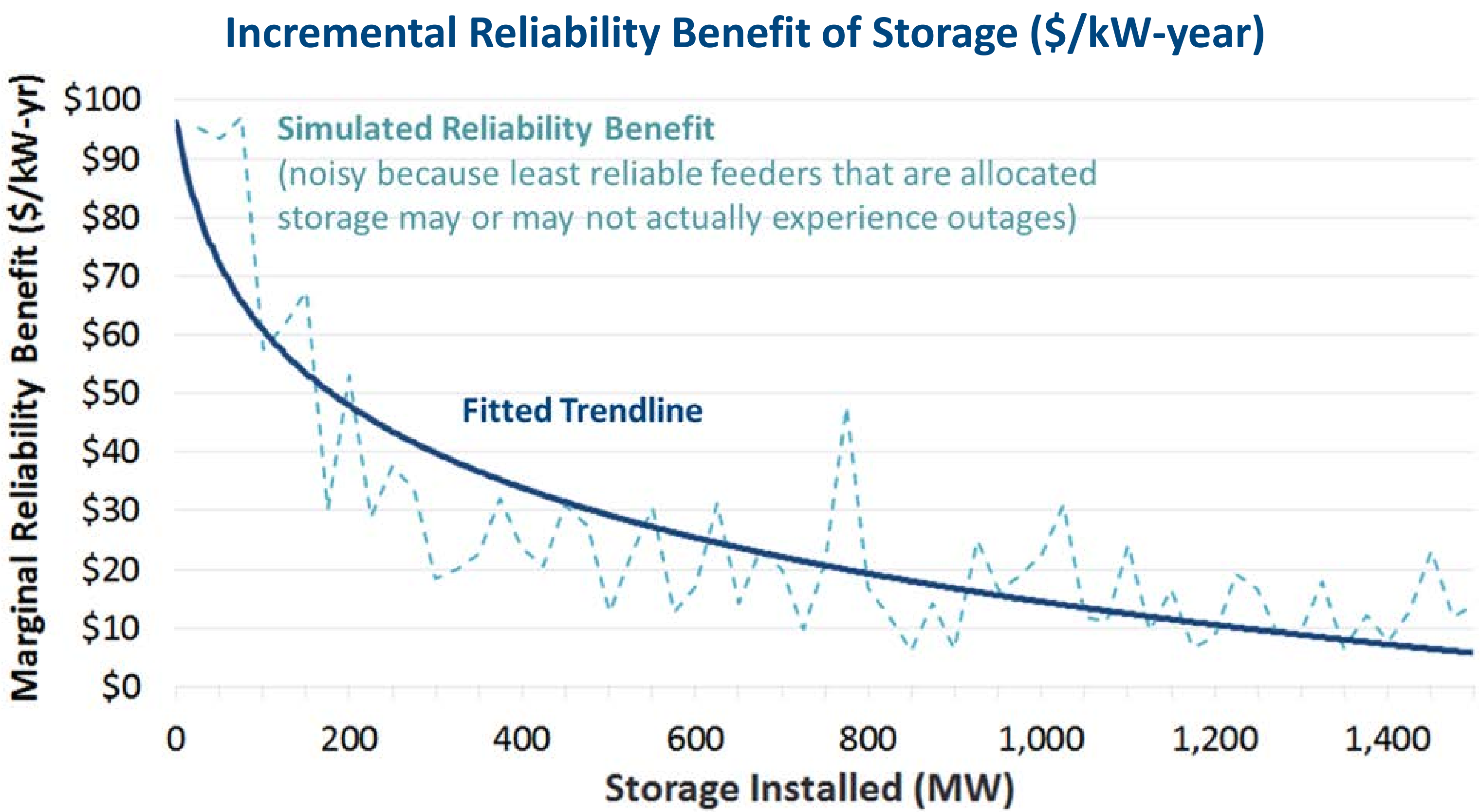
We evaluate the reliability value to customers of deploying storage on specific feeders that historical experience relatively high levels of outages.

- NV Energy provided data on 43,000 distribution-level outages for 2014-2018
- We evaluate customer outage reduction benefits of siting storage at least-reliable feeders
  - We simulate storage deployed at each identified feeder, sized at average feeder peak load
  - Account for both the duration (hours) and magnitude (MWh) of each outage
  - Account for unpredictability of outages
  - Assume customers value improved reliability at $12,500/MWh value of lost load (VOLL)
- Analysis assumes feeders can be “islanded” in event of an outage
  - Requires grid modernization investments, e.g. microgrids, automated distribution switching
  - We separately report cost-effective storage levels if grid modernization efforts not made and customer outage value cannot be captured

Customer Outage Reduction Value

Findings

The marginal benefit from avoided distribution outages declines as storage is added to the least-reliable feeders.

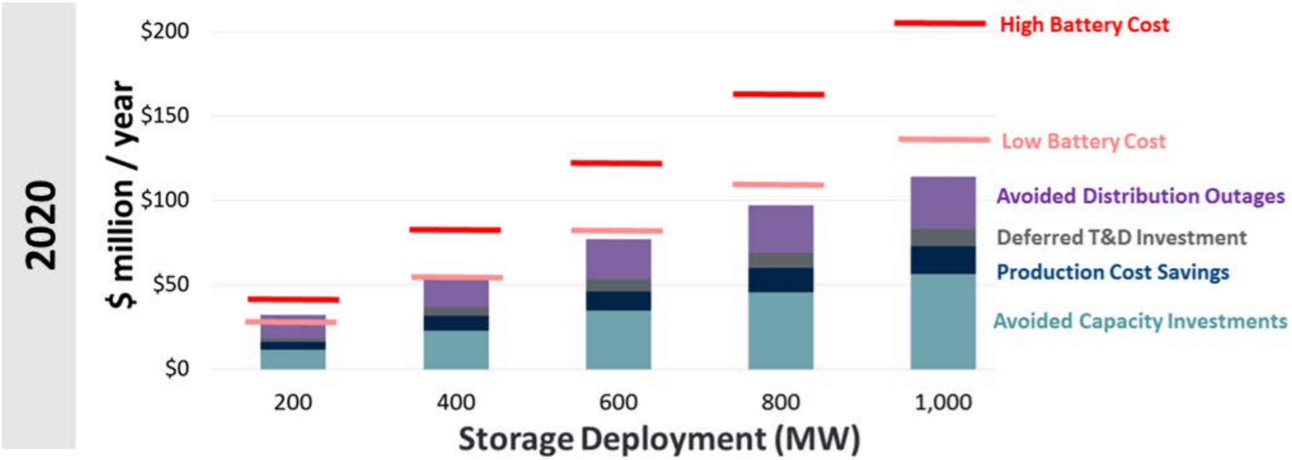


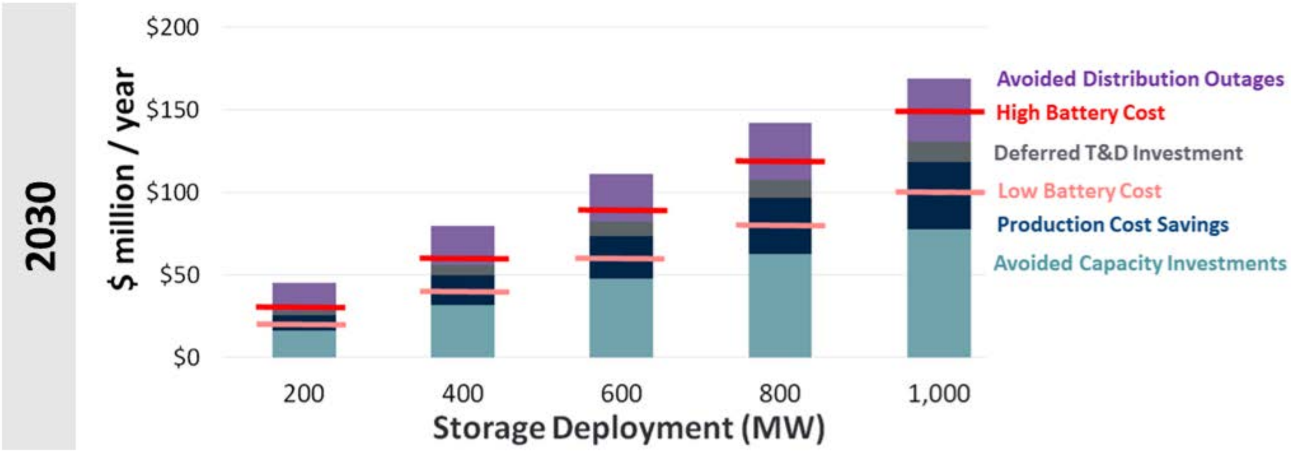
Note:
All values in nominal dollars.

Aggregate System-Wide Benefits of Storage

Total System Benefits and Costs of Storage at Various Deployment Levels

In 2020, storage benefits are less than costs if more than 200 MW deployed. In 2030, benefits exceed costs beyond 1,000 MW.

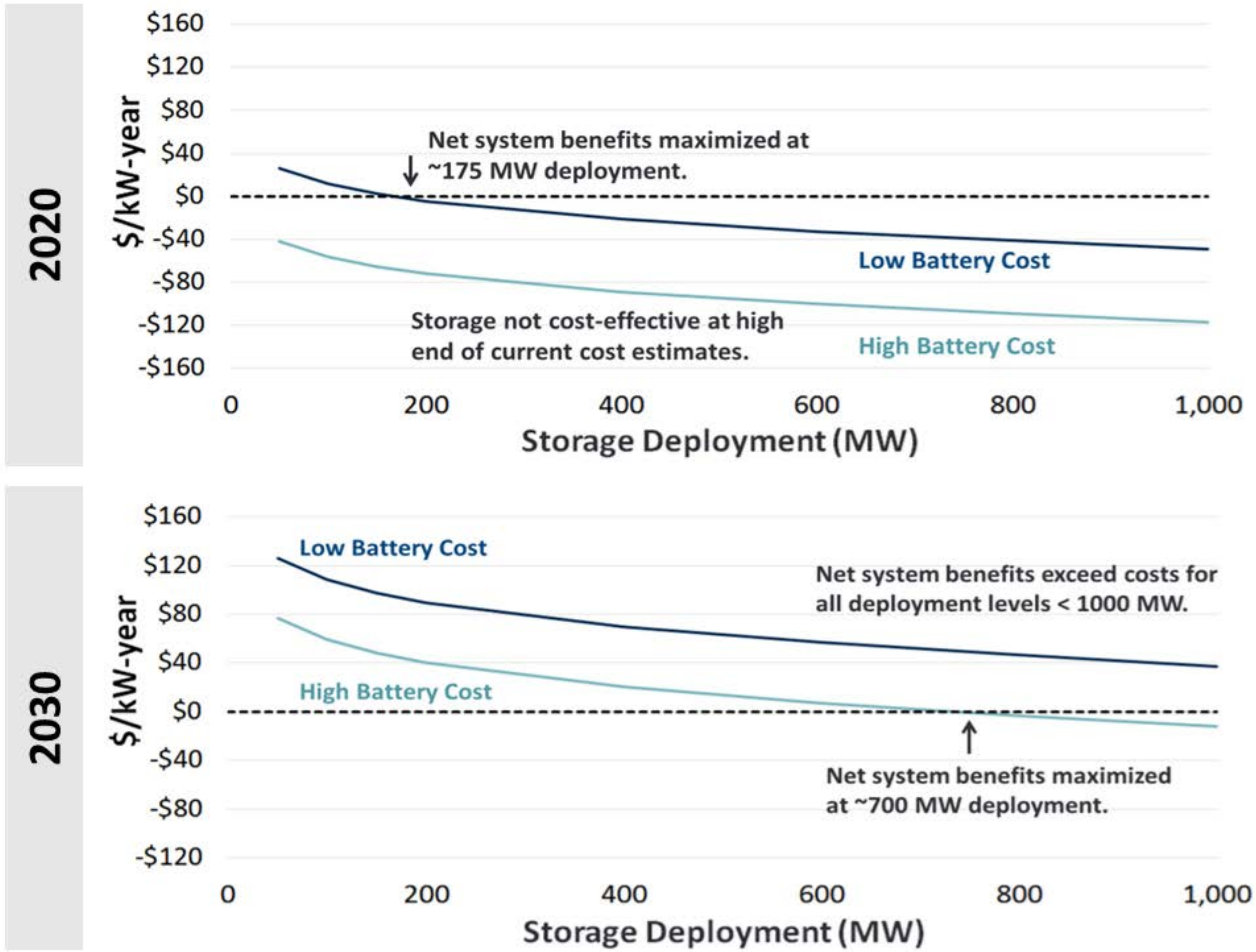




Note: All values are in nominal dollars

Incremental Net Benefits of Storage Deployment in Nevada

2020 cost-effective storage levels are up to 175 MW, depending on storage costs. In 2030, cost-effective levels are greater than 700 MW.



Note: All values are in nominal dollars

Renewable Integration and Emission Benefits

Storage reduces WECC-wide emissions in both 2020 and 2030. Storage also reduces Nevada solar curtailments in 2030.

Reduction in Nevada Renewable Generation Curtailments, 2030

	GWh			[Change] - [Base]	
	Base	200 MW	1,000 MW	200 MW	1,000 MW
Nevada					
Total Solar Generation	6,630	6,633	6,659	3	29
Solar Curtailment	57	54	28	-3	-29
Percent Change in Curtailment				-5%	-51%

- In 2020, minimal curtailments with or without storage
- In 2030, 1,000 MW of storage significantly reduces curtailments

Impact on WECC-Wide Emissions

	Change in Emissions (tons)		Change in Emissions (%)	
	200 MW	1,000 MW	200 MW	1,000 MW
2020 Cases				
CO2	-46,974	-131,998	-0.02%	-0.06%
NOX	135	117	0.06%	0.05%
SO2	161	351	0.12%	0.26%
2030 Cases				
CO2	-63,162	-234,955	-0.03%	-0.10%
NOX	-79	-455	-0.03%	-0.17%
SO2	8	-480	0.00%	-0.26%

- Storage reduces WECC-wide CO_2 emissions in all cases
- Societal savings of $2.6 to $7.2 million in 2020 and $5.0 to $18.5 million in 2030*

* Emission reductions valued consistent with U.S. Government Interagency Working Group on the Social Cost of Carbon. Baseline 2020 value of $54/ton and 2030 value of $79/ton (3% discount rate scenario). See report for results under 5% and 2.5% discount rate scenarios.

Sensitivities

Storage is likely to be cost effective by 2030 across a variety of tested sensitivity cases.

Sensitivity	Cost-Effective Storage Level 2020	Cost-Effective Storage Level 2030
Base Case	Up to 175 MW	>700 MW
Zero Outage Reduction Value *Storage outage reduction value not considered in RIM test or not realized due to lack of distribution upgrades*	0 MW	>300 MW
Regional Market *Implementation of regional market reduces regional production costs, halving storage production cost savings*	n/a	>400 MW
Zero Avoided Generation Capacity Value *No need for additional generation capacity, e.g. declining load growth and no open capacity position*	n/a	Up to 300 MW

Behind-the-Meter Storage Applications

Overview

We evaluate the economic potential for BTM storage adoption by C&I customers with and without a utility-administered program.

C&I customers most likely to adopt BTM storage in the near- to medium-term

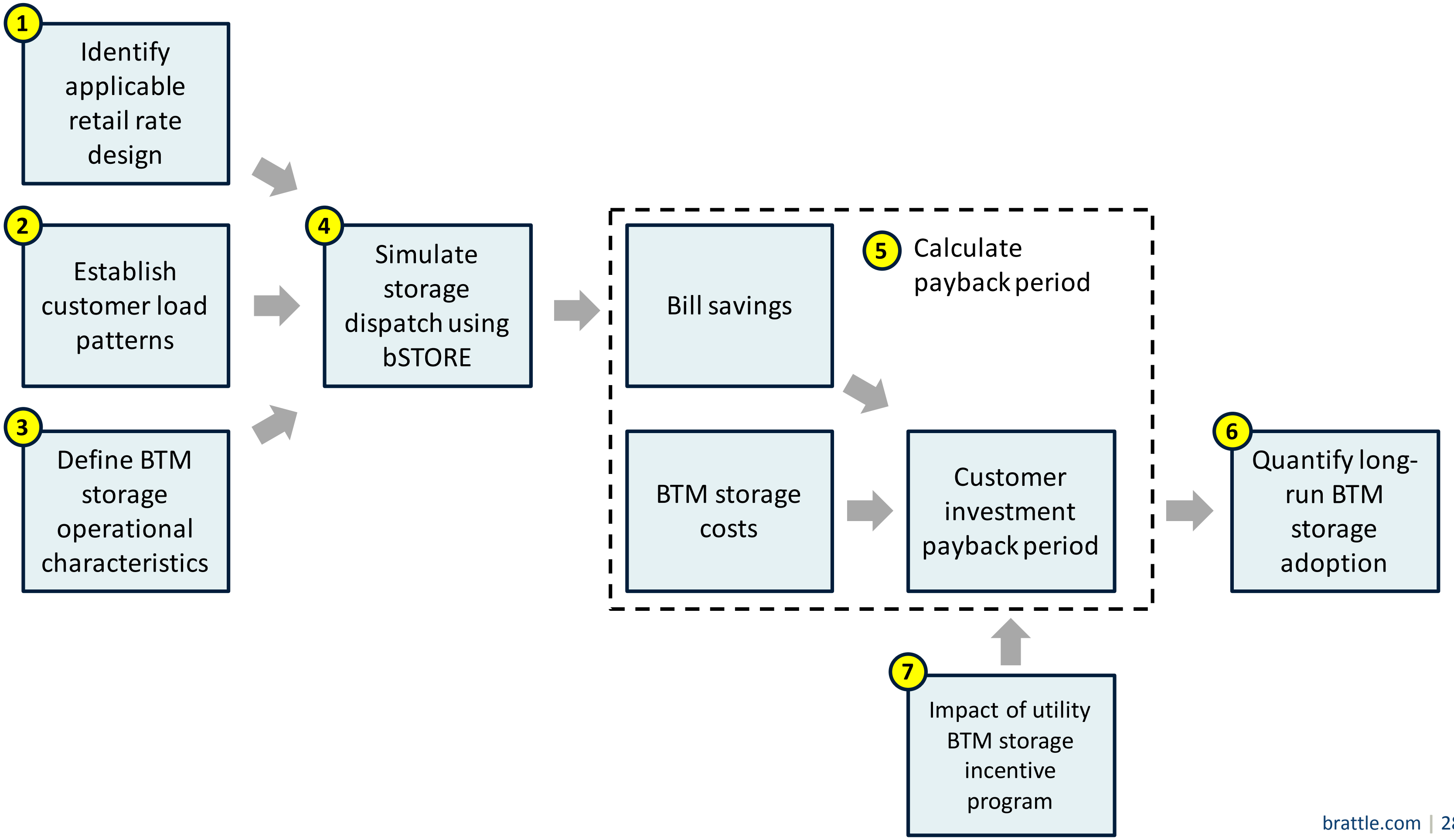
- Uses include retail bill reduction, backup generation, and aggregation as DR
- Significant residential adoption unlikely, absent changes to retail rate design and NEM policy

The utility could incentivize further adoption of BTM storage

- Incentive could take the form of a cost-effective payment
- In return, utility would control device for a limited number of days per year to address resource adequacy needs

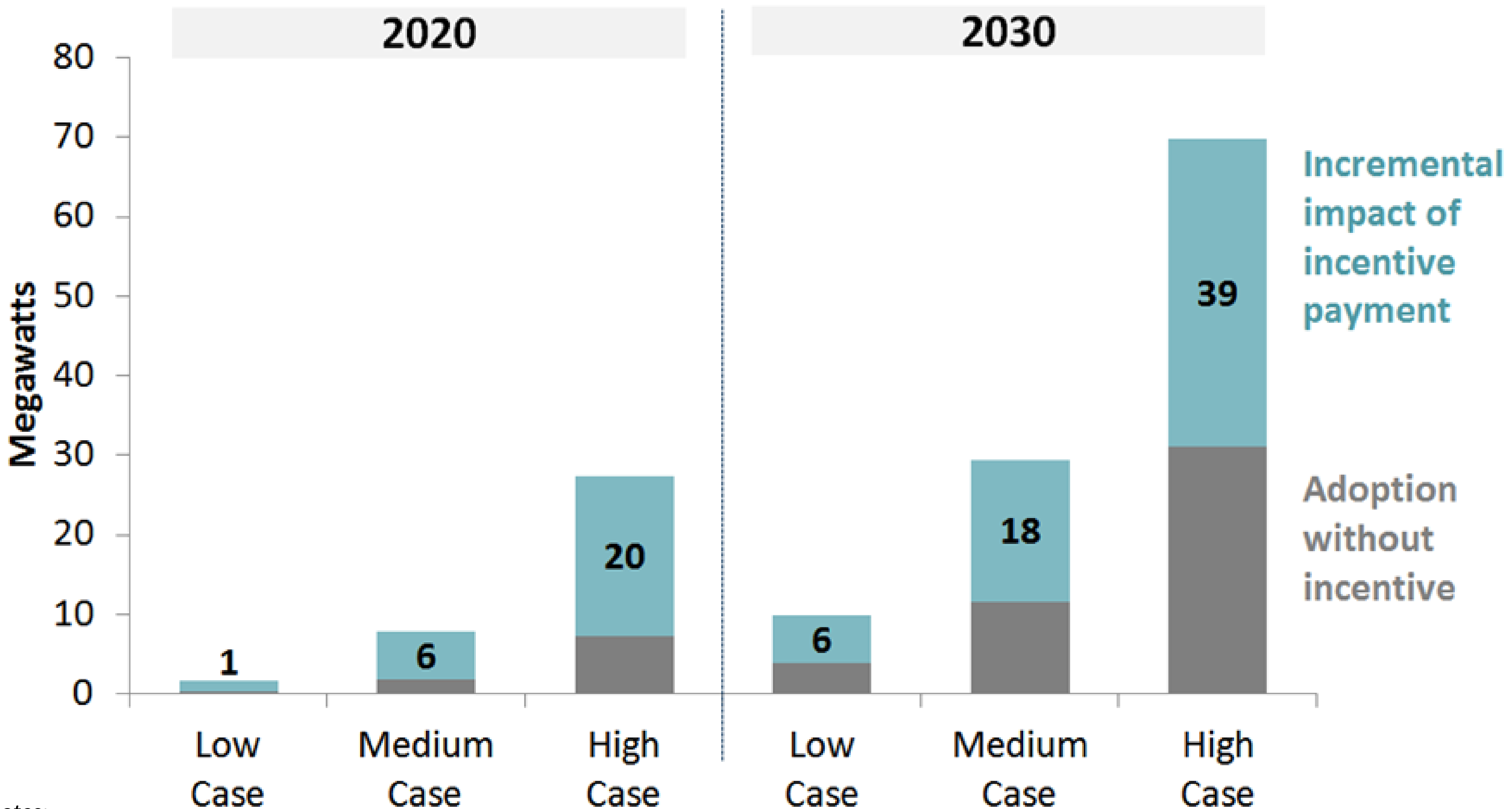
Approach to Quantifying BTM Storage Potential

We use a 7-step process to evaluate BTM adoption with and without a utility-administered program



Projected Cumulative BTM Storage Adoption with and without Utility Incentive Programs

A utility BTM storage program could increase adoption by up to 20 MW in 2020 and 39 MW in 2030.



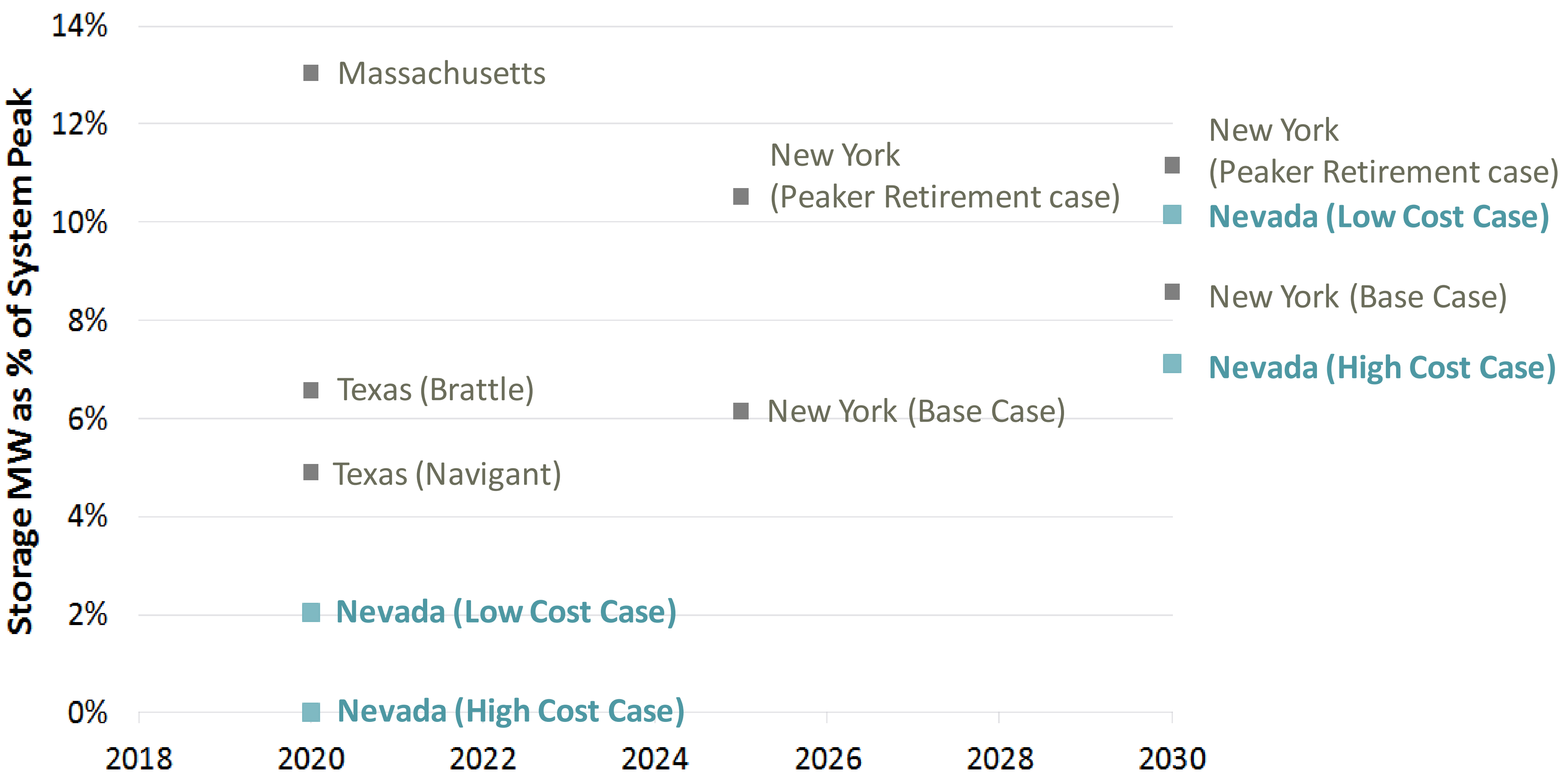
Notes:

The potential estimates represent long-run adoption potential based on assumed storage costs for the years shown in the figure. It would take several years to reach these adoption levels.

Comparison to Other Storage Potential Studies

Comparison of Cost-Effective Storage Deployment Levels Across Studies

We find lower cost-effective storage levels than other studies in 2020 (proportional to system peak). 2030 findings similar to NY study.



Study Conclusions

Conclusions

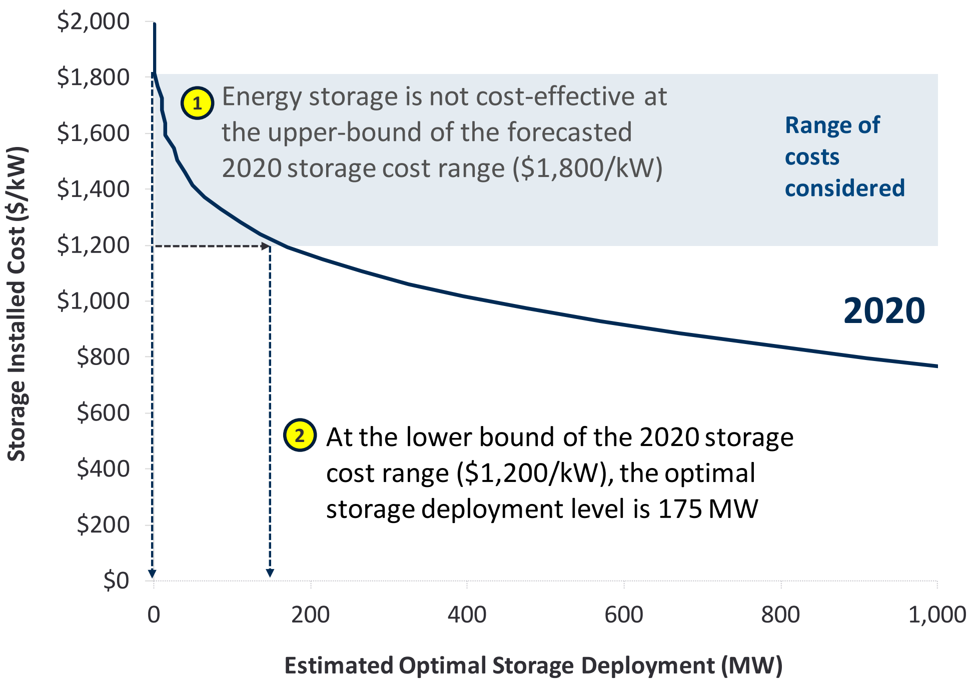
Energy storage deployments can be cost-effectively incorporated into Nevada's future power supply mix.

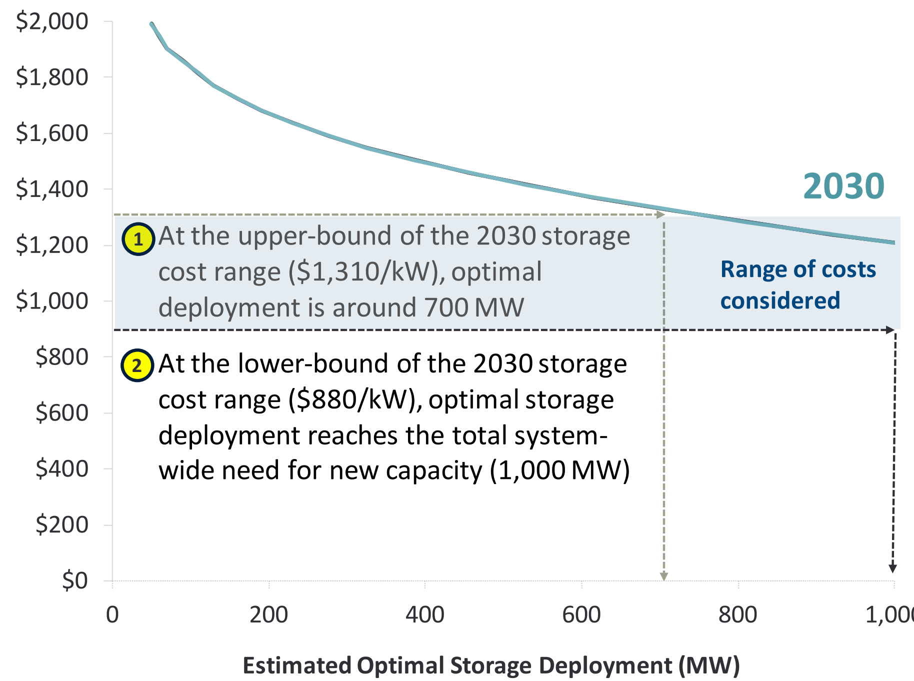
- Energy storage can provide value across several applications. This finding is robust across a range of modeled scenarios
- In 2020, up to 175 MW could be cost-effective if storage at lower end of projected cost range
- By 2030, cost-effective levels exceed 700 MW
- Utility BTM incentive programs could increase adoption by up to 20 MW in 2020 and up to 39 MW in 2030
- Additional feasibility studies would be valuable to further validate these conclusions

Study Conclusions

Optimal Storage Deployment Curves

Future procurements could be expressed as an "optimal deployment curve" to account for cost uncertainty and changing system conditions.





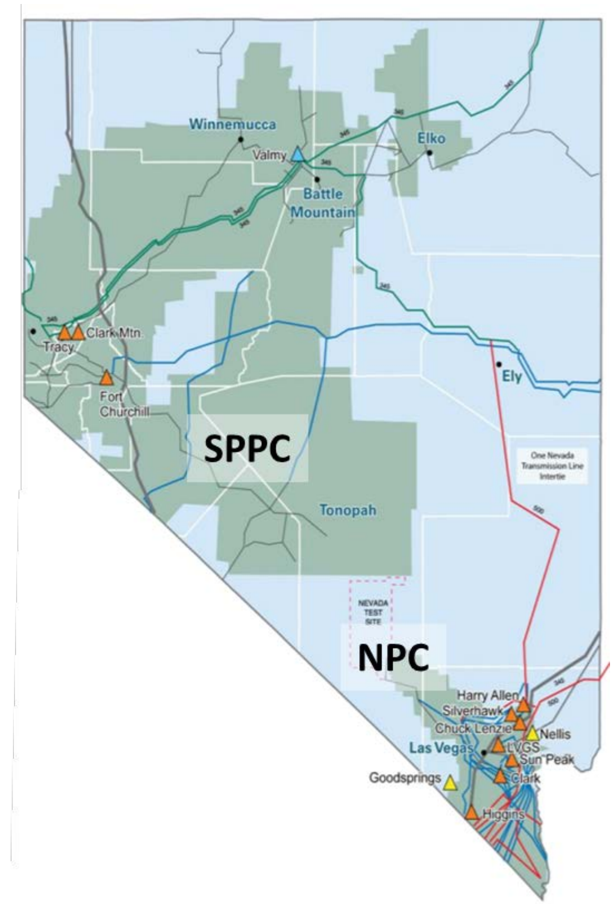
Notes:
Costs are shown in nominal dollars. Values are based on an assumed energy storage configuration of 10 MW / 40 MWh.

Appendix

The Nevada Context

- NV Energy serves 90% of Nevada's population
- In 2017, NV Energy's two utilities served over 1.2 million customers, with an annual energy demand of 31.3 TWh.
  - NPC: peak load of 5,929 MW and an annual energy demand of 21.5 TWh
  - SPPC: peak load of 1,824 MW and an annual energy demand of 9.8 TWh.
  - Peak loads are projected to grow 0.7% per year in NPC's footprint and negative 0.1% per year in SPPC's footprint.
- Gas is 85% of generation portfolio
- RPS requires 25% of renewable sales by 2025

NV Energy Service Territories and Transmission Network



Critical Considerations

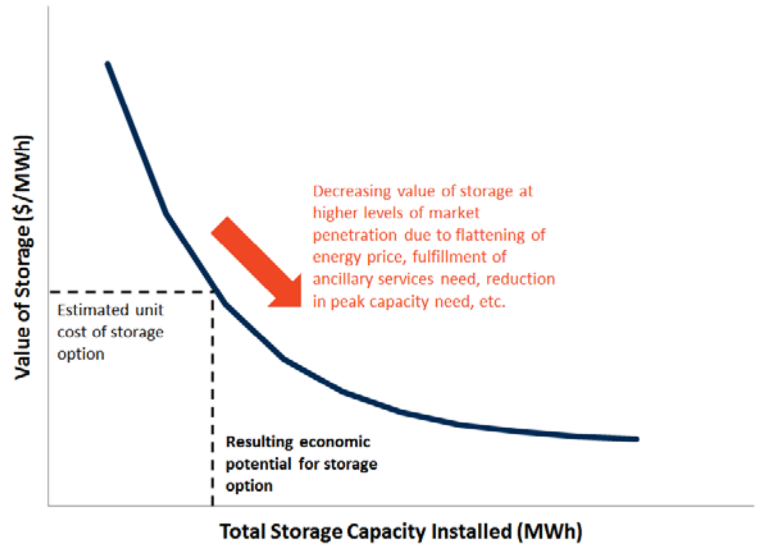
Stacked Value Streams

Uncertainty in Costs and Benefits

The Relationship between Storage Quantity and Benefits

Degree of Foresight in Storage Utilization

Conceptual Illustration of Approach to Identifying Economic Potential of Storage



2020 and 2030 APC Savings

2020 Adjusted Production Cost Savings
(in nominal $million/year)

	Production Cost			Savings (Storage Case minus Base Case)	
	Base	200 MW	1,000 MW	200 MW	1,000 MW
Production Cost	$421	$420	$423	($1.1)	$2.2
Cost of Market Purchases	$132	$129	$124	($3.1)	($7.9)
Revenues from Sales	($46)	($46)	($57)	($0.4)	($10.8)
Total	**$507**	**$502**	**$490**	**($4.5)**	**($16.5)**

2030 Adjusted Production Cost Savings
(in nominal $million/year)

	Production Cost			Savings (Storage Case minus Base Case)	
	Base	200 MW	1,000 MW	200 MW	1,000 MW
Production Cost	$701	$690	$693	($10.1)	($7.7)
Cost of Market Purchases	$568	$572	$559	$4.0	($9.8)
Revenues from Sales	($82)	($86)	($105)	($3.2)	($23.1)
Total	**$1,186**	**$1,177**	**$1,146**	**($9.3)**	**($40.6)**

Average Ancillary Services Provided by Storage

	2020		2030	
	200 MW	1,000 MW	200 MW	1,000 MW
Reg Up	11	21	30	45
Reg Down	5	46	12	54
Spin	11	22	24	35
Freq Reserve	24	35	65	96

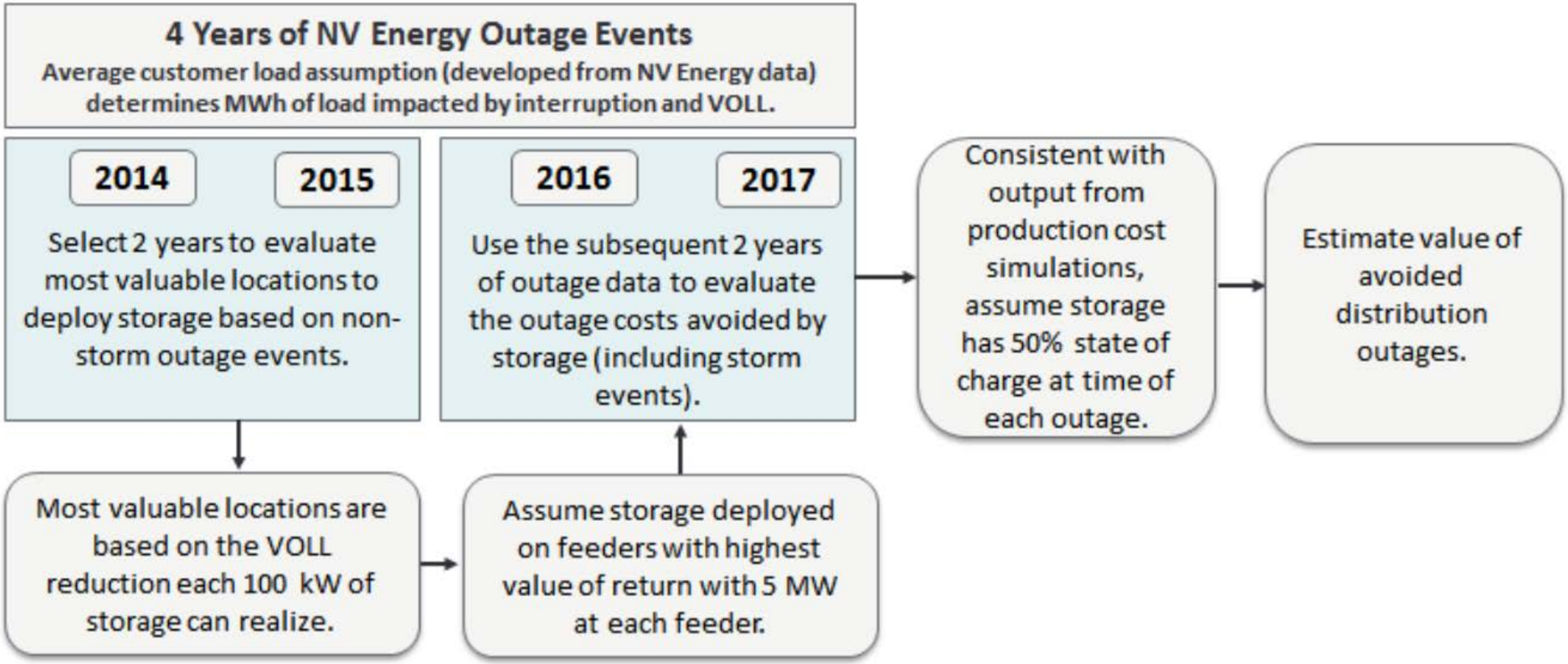
Examples of T&D Cost Deferral by NPC Customer Class

			NPC	
			Residential	C&I
Starting Peak Load	[1]	(MW)	10	10
Peak Load Growth Rate	[2]	(%)	2%	2%
Peak Load in 15 years	[3]	(MW)	13.5	13.5
Required Battery Size / Growth	[4]	(%)	166%	253%
Battery Size to Defer 15 years	[5]	(MW)	5.7	8.7
Substation Upgrade Cost	[6]	($ million)	$3	$3
Cost Avoided by 15-yr Deferral	[7]	(%)	67%	67%
Deferral Savings	[8]	($/kW)	$349	$229
Charge Rate	[9]	(%)	10%	10%
Deferral Savings	**[10]**	**($/kW-yr)**	**$36**	**$23**

Notes:

[1]: Example assumption roughly consistent with substation in NPC.
[2]: Peak load growth assumption uniform for all NV Energy feeders.
[3]: $[1] \times (1 + [2])^{15}$
[4]: Calculated using load shapes derived from NV Energy load data. Equal to 123% for SPPC Residential and 175% for SPPC C&I.
[5]: [4] x ([3] - [1])
[6]: Example assumption roughly consistent with substation in NPC.
[7]: PV of 15-year investment deferral, consistent with NVE financing cost rate
[8]: ([6] x [7])/(1,000 x [5]). Savings in $/kW of storage installed.
[9]: Payment on a level-real annualization of [8], levelized over a 30-year investment life.
[10]: [8] x [9]

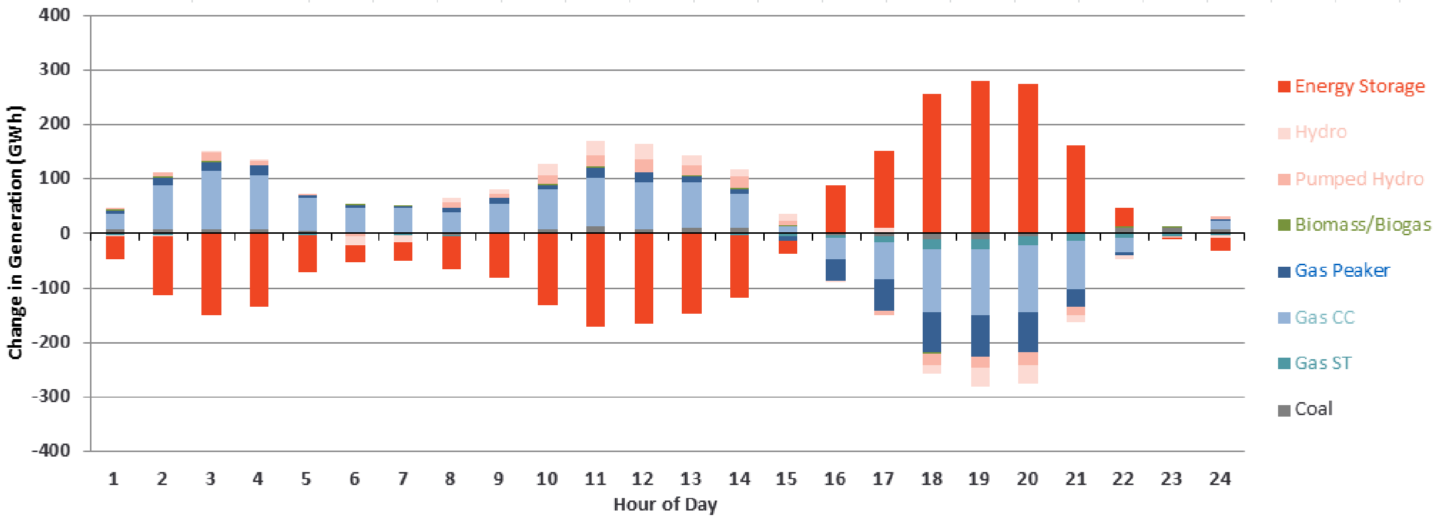
Framework for Determining Value of Storage to Reduce Distribution Outages



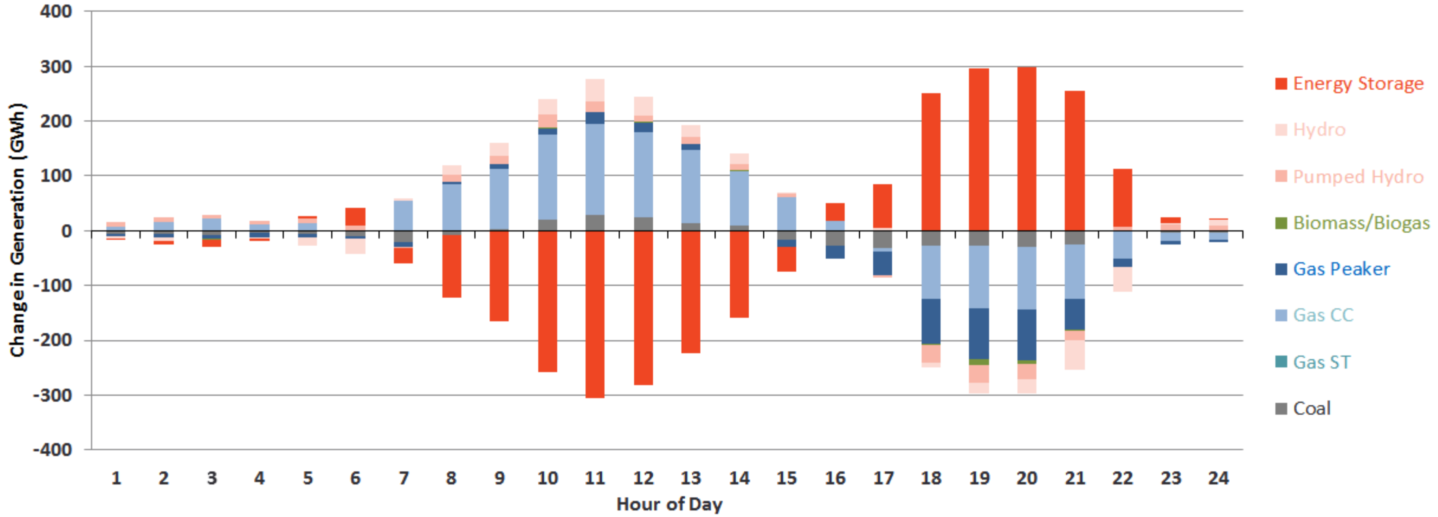
Change in WECC-Wide Generation Due to Storage

By Hour of Day (1,000 MW Case minus Base Case)

2020



2030



Social Cost of Carbon

nominal \$/metric ton of CO_2

Year	5% Average	3% Average	2.5% Average
2010	$11	$33	$53
2015	$13	$42	$66
2020	$16	$54	$80
2025	$20	$66	$97
2030	$25	$79	$115
2035	$31	$96	$136
2040	$40	$115	$161
2045	$49	$136	$189
2050	$61	$162	$223

Sources and Notes:
IAWG (2016). Converted from 2007 dollars to nominal dollars using 2% inflation rate.

Change in Societal Cost Associated with Carbon Emissions

	Change in Societal Costs ($M)		Change in Societal Cost ($/kW-yr)	
	200 MW	1,000 MW	200 MW	1,000 MW
2020 Cases				
Low	-$0.7	-$2.0	-$3.6	-$2.0
Baseline	-$2.6	-$7.2	-$12.8	-$7.2
High	-$3.8	-$10.6	-$18.8	-$10.6
2030 Cases				
Low	-$1.6	-$5.9	-$8.0	-$5.9
Baseline	-$5.0	-$18.5	-$24.9	-$18.5
High	-$7.3	-$27.0	-$36.4	-$27.0

Sources and Notes:

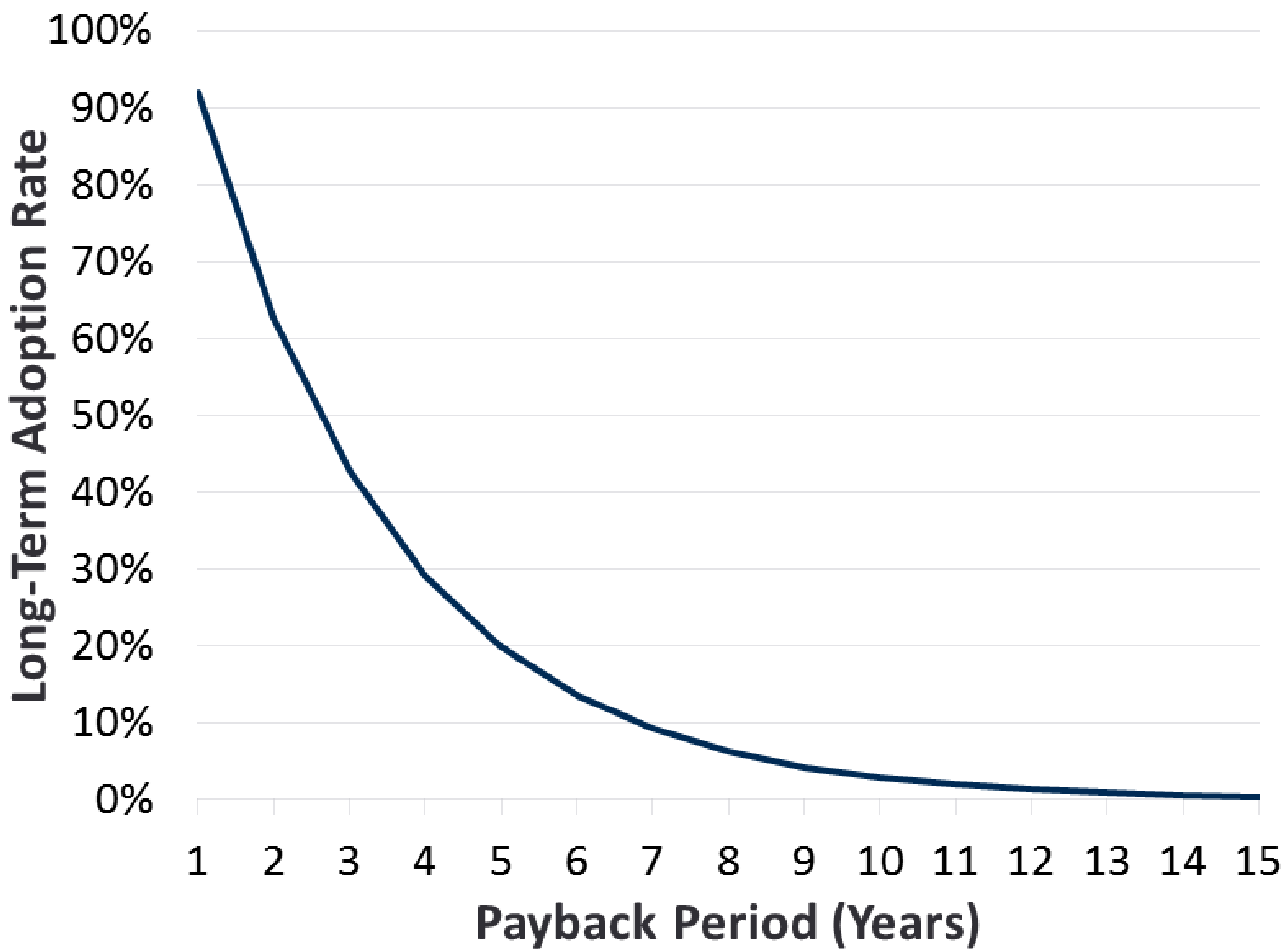
Low estimate uses IWG's 2.5% discount rate SCC estimate, baseline estimate uses IWG's 3% discount rate SCC estimate, and high estimate uses IWG's 5% discount rate SCC estimate. All values are in nominal dollars.

BTM Storage: NV Energy LGS-2 (Secondary Service) Rate, Southern Service Territory

Description	Charge
Basic service charge ($/month)	193.10
Facilities charge ($/kW-month)	3.14
Demand charge	
Winter ($/kW-month)	0.40
Summer on-peak ($/kW-month)	13.35
Summer mid-peak ($/kW-month)	2.04
Summer off-peak ($/kW-month)	0.00
Energy charge	
Winter ($/kWh)	0.05213
Summer on-peak ($/kWh)	0.08508
Summer mid-peak ($/kWh)	0.06449
Summer off-peak ($/kWh)	0.04573
Riders ($/kWh)	0.00105

Notes: Summer season is June through September. On-peak period is 1 pm to 7 pm daily. Mid-peak period is 10 am to 1 pm and 7 pm to 10 pm. Off-peak period is 10 pm to 10 am.

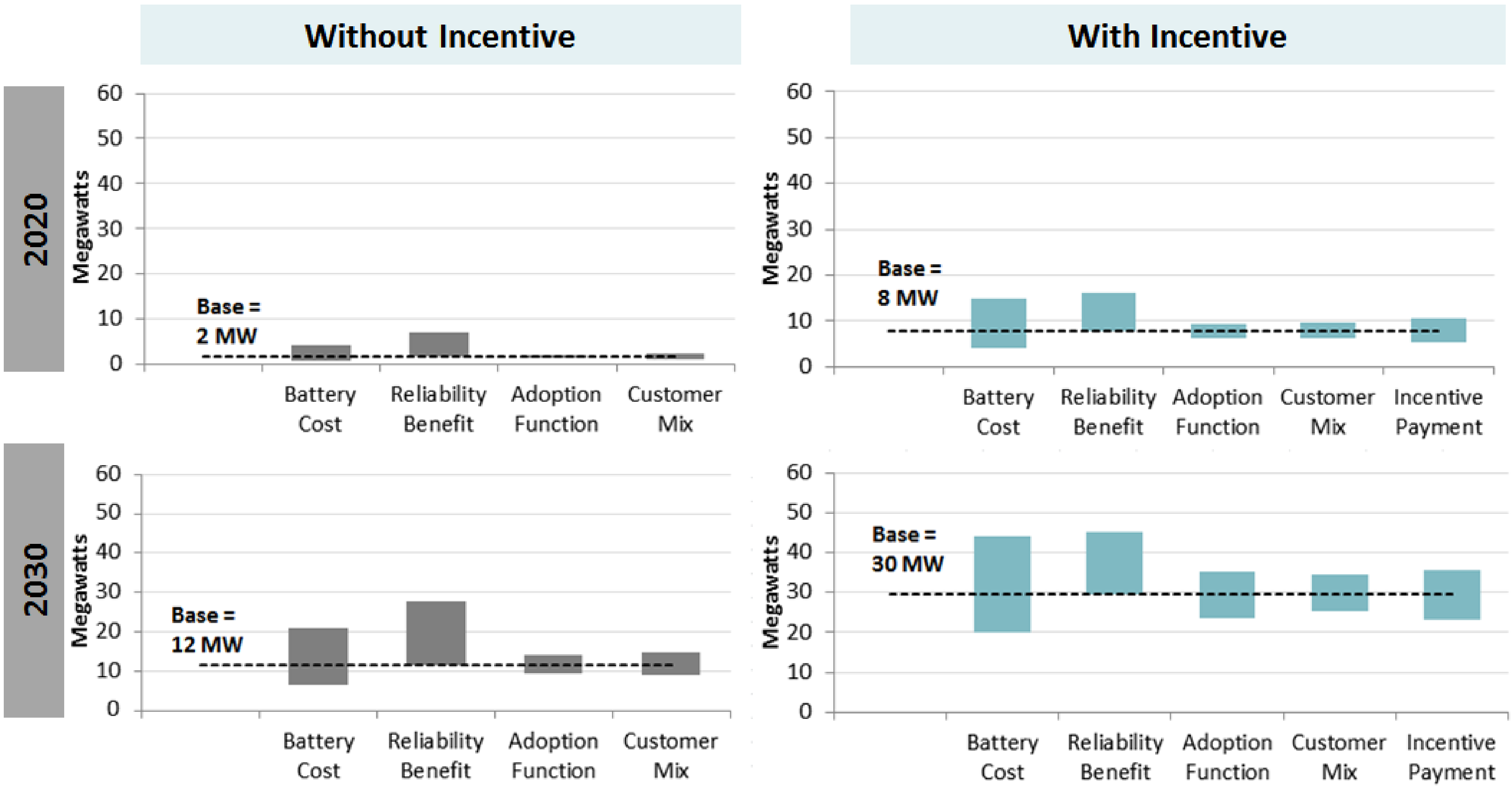
Commercial &Industrial BTM Storage Adoption Function



Assumptions Behind BTM Storage Adoption Cases

	Low Adoption Case	Medium Adoption Case	High Adoption Case
Battery cost	2020: $700/kWh 2030: $400/kWh	2020: $575/kWh 2030: $325/kWh	2020: $450/kWh 2030: $250/kWh
Adoption function	20% reduction from Medium Case	Base adoption function based on investment payback period	20% increase from Medium Case
Utility incentive payment	50% of avoided generation capacity cost	75% of avoided generation capacity cost	100% of avoided generation capacity cost
Customer mix	Skewed toward segments with lower BTM storage value	Average customer mix	Skewed toward segments with higher BTM storage value

Summary of Sensitivity Analysis with BTM Storage



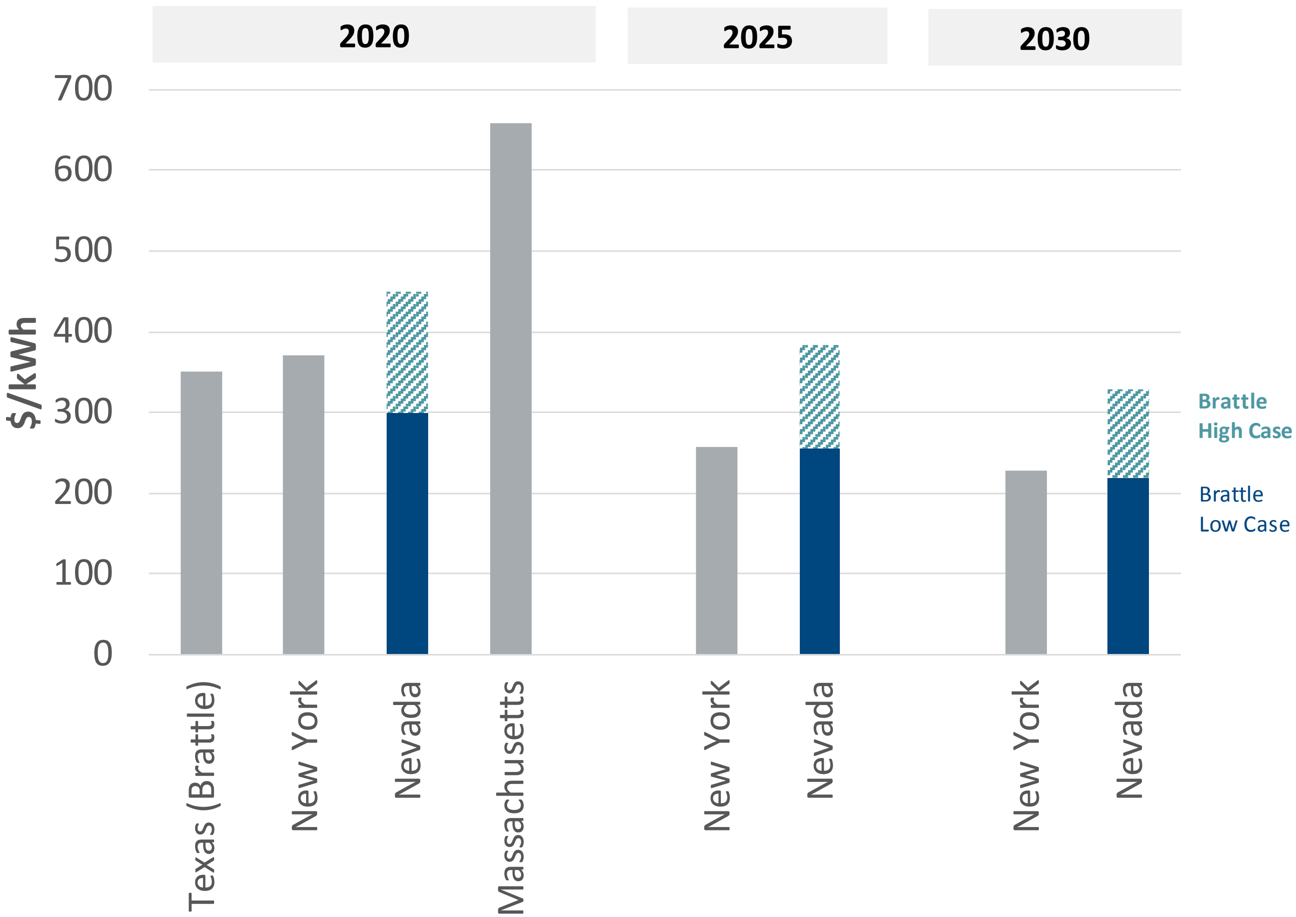
Benefits Considered in Recent Storage Potential Studies

	Nevada	Massachusetts	New York	Texas (Brattle)
Avoided generation capacity costs	X	X	X	X
Reduced energy (fuel) costs	X	X	X	X
Deferred T&D investment costs	X	X	X	X
Ancillary services	X	X	X	X
Environmental impacts	X	X	X	Discussed qualitatively
Outage mitigation	X		X	X
Distribution voltage support	Discussed qualitatively	X		Discussed qualitatively
Behind-the-meter value	X			
Wholesale market cost reduction	N/A	X	X	X

Notes:

Table reflects Brattle's interpretation of the modeled benefits in each study. Approximations have been made to accommodate differences in terminology across the studies. The analysis of Texas by Navigant Research is not included because insufficient detail was provided on specific categories of value streams. The modeling of cost-effective deployment levels in New York and Massachusetts do not specifically account for BTM adoption, but the studies acknowledge behind-the-meter deployment as one of several use cases.

Comparison of Storage Costs Across Studies



Notes:
Battery duration shown in figure is 4-hours for Nevada and New York, 3-hours for Texas, and roughly 2-hours on average for Massachusetts. Massachusetts cost was calculated by dividing the midpoint of the range of total reported statewide storage costs by the total statewide economic storage capacity. Values are in nominal dollars.

NV Energy Model Inputs

		2020	2030
Nevada Power Company			
Total Energy	*(GWh)*	20,985	22,260
Peak Load	*(MW)*	6,000	7,107
Behind-the-Meter Capacity	*(MW)*	149	284
Sierra Pacific Power Company			
Total Energy	*(GWh)*	9,855	9,323
Peak Load	*(MW)*	1,811	1,894
Behind-the-Meter Capacity	*(MW)*	36	100

Sources and Notes:

NV Energy (2018a) reports data for NPC and SPPC, which excludes some load and capacity in the Nevada footprint. We use SNL to account for the difference in our model inputs.

Gas Hub Mappings and Hurdle Rate Assumptions

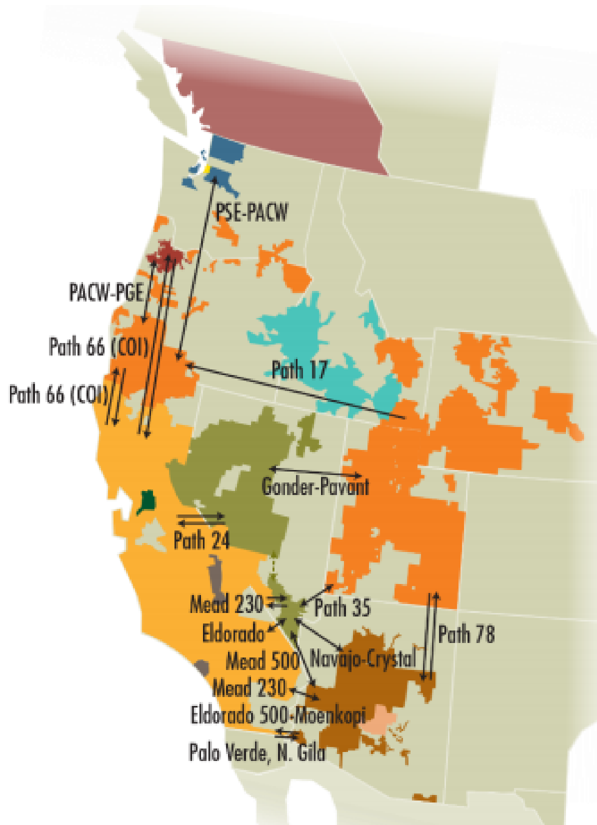
2026 TEPPC Common Case	2018 IRP Hub Mapping
NG_AB	NG_Alberta
NG_AZ North	NG_San Juan
NG_NM North	NG_San Juan
NG_CA SoCalB	NG_SOCAL
NG_CA PGaE BB	NG_SOCAL
NG_CA SDGE	NG_SOCAL
NG_CO	NG_Rockies
NG_BC	NG_Sumas
NG_MT	NG_Rockies
NG_ID North	NG_Alberta
NG_OR Malin	NG_Malin
NG_ID South	NG_Sumas
NG_WY	NG_Rockies
NG_WA	NG_Sumas
NG_NV North	NG_Malin
NG_NV South	NG_SOCAL
NG_CA SJ Valley	NG_SOCAL
NG_TX West	NG_Permian
NG_UT	NG_Rockies
NG_NM South	NG_Permian
NG_CA SoCalGas	NG_SOCAL
NG_CA PGaE LT	NG_SOCAL
NG_Baja	NG_SOCAL
NG_AZ South	NG_SOCAL
NG_OR	NG_Sumas

Balancing Authority	Modeled Hurdle Rate for Dispatch	Additional Hurdle Rate Applied During Unit Commitment
AESO	$7.2	$4.0
AVA	$7.8	$4.0
APS	$6.1	$4.0
BANC	$4.1	$4.0
BCHA	$7.4	$4.0
BPA	$6.3	$4.0
CAISO	$13.5	$4.0
CFE	$4.3	$4.0
CHPD	$6.3	$4.0
DOPD	$6.3	$4.0
EPE	$5.2	$4.0
GCPD	$6.3	$4.0
IID	$3.0	$4.0
IPCO	$4.7	$4.0
LDWP	$7.1	$4.0
NEVADA	$5.8	$4.0
NWMT	$6.3	$4.0
PACE	$5.3	$4.0
PACW	$5.3	$4.0
PGE	$2.7	$4.0
PNM	$8.0	$4.0
PSCO	$6.6	$4.0
PSEI	$4.5	$4.0
SCL	$3.1	$4.0
SRP	$4.2	$4.0
TEPC	$5.1	$4.0
TIDC	$4.5	$4.0
TPWR	$5.0	$4.0
WACM	$7.4	$4.0
WALC	$4.2	$4.0
WAUW	$6.0	$4.0

Sources and Notes:

S&P Global Market Intelligence (2018) for hub mapping. Hurdle rates: Brattle analysis based on Schedule 8 of Open Access Transmission Tariffs (OATTs) and other public data on transmission rates. ($2016 dollars)

EIM Transfer Capabilities



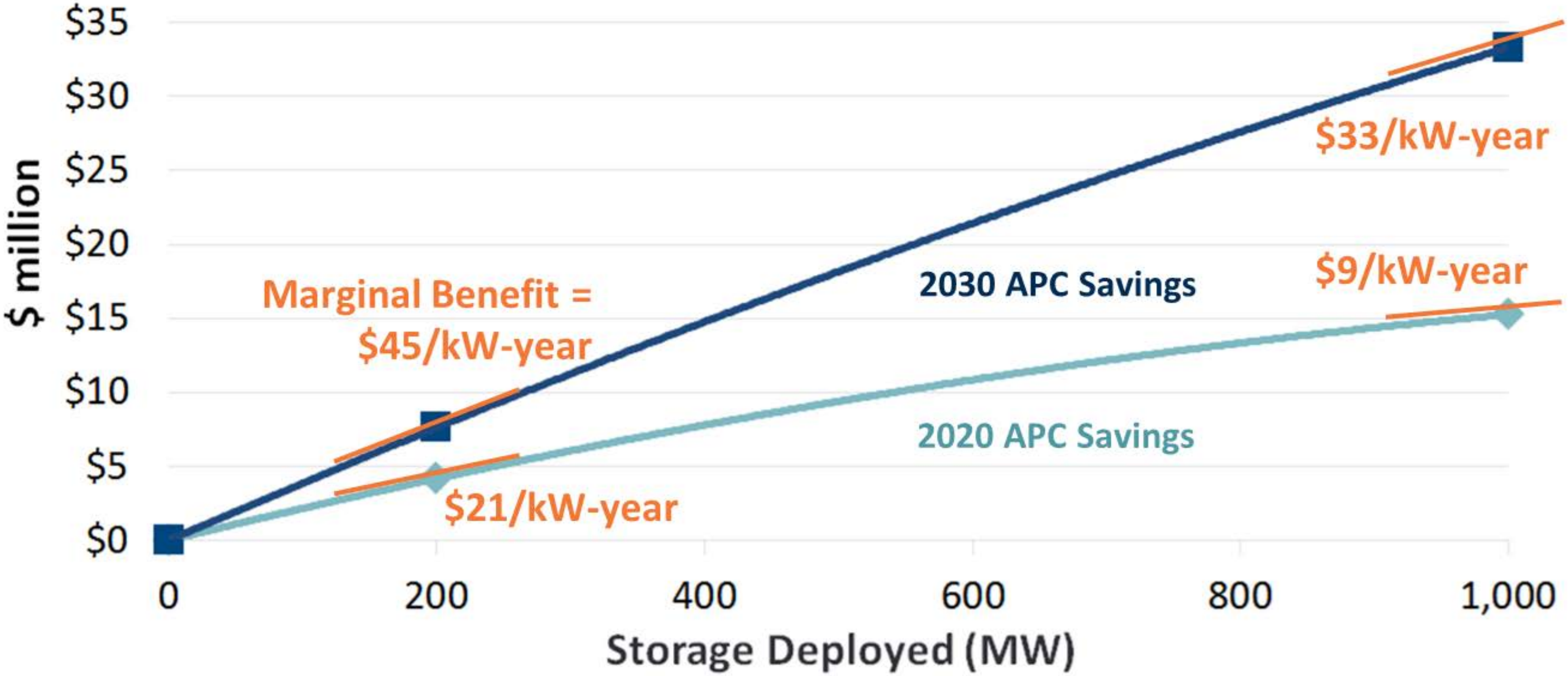
Path	Estimated Max Capacity (MW)
Path 24 *(west to east)*	100
Path 24 *(east to west)*	35-90
Eldorado	797
Path 35 *(west to east)*	580
Path 35 *(east to west)*	538
Gonder-Pavant	130
PACW to PGE	320
Path 66 *(ISO to PGE)*	627
Path 66 *(PGE to ISO)*	296
Path 66 *(ISO to PACW)*	331
Path 66 *(PACW to ISO)*	432
Path 17	400
PSE to PACW	300
Eldorado 500-Moenkopi	732
Palo Verde, N. Gila	3,151
Path 78 *(PACE to APS)*	625
Path 78 *(APS to PACE)*	660
Navajo-Crystal	522
Mead 500	349
Mead 230 *(APS <-> ISO)*	236
Mead 230 *(ISO to NVE)*	3,443
Mead 230 *(NVE to ISO)*	3,476

one direction — bi-directional

- California ISO
- PacifiCorp
- NV Energy
- Arizona Public Service
- Portland General Electric
- Puget Sound Energy
- Idaho Power Company *(entry April 2018)*
- Powerex *(entry April 2018)*
- BANC/SMUD *(planned entry 2019)*
- Seattle City Light *(planned entry 2020)*
- Los Angeles Dept. of Water & Power *(planned entry 2020)*
- Salt River Project *(planned entry 2020)*

Sources and Notes: CAISO (2018). Imports into California are charged a generic carbon price for the 2020 model runs.

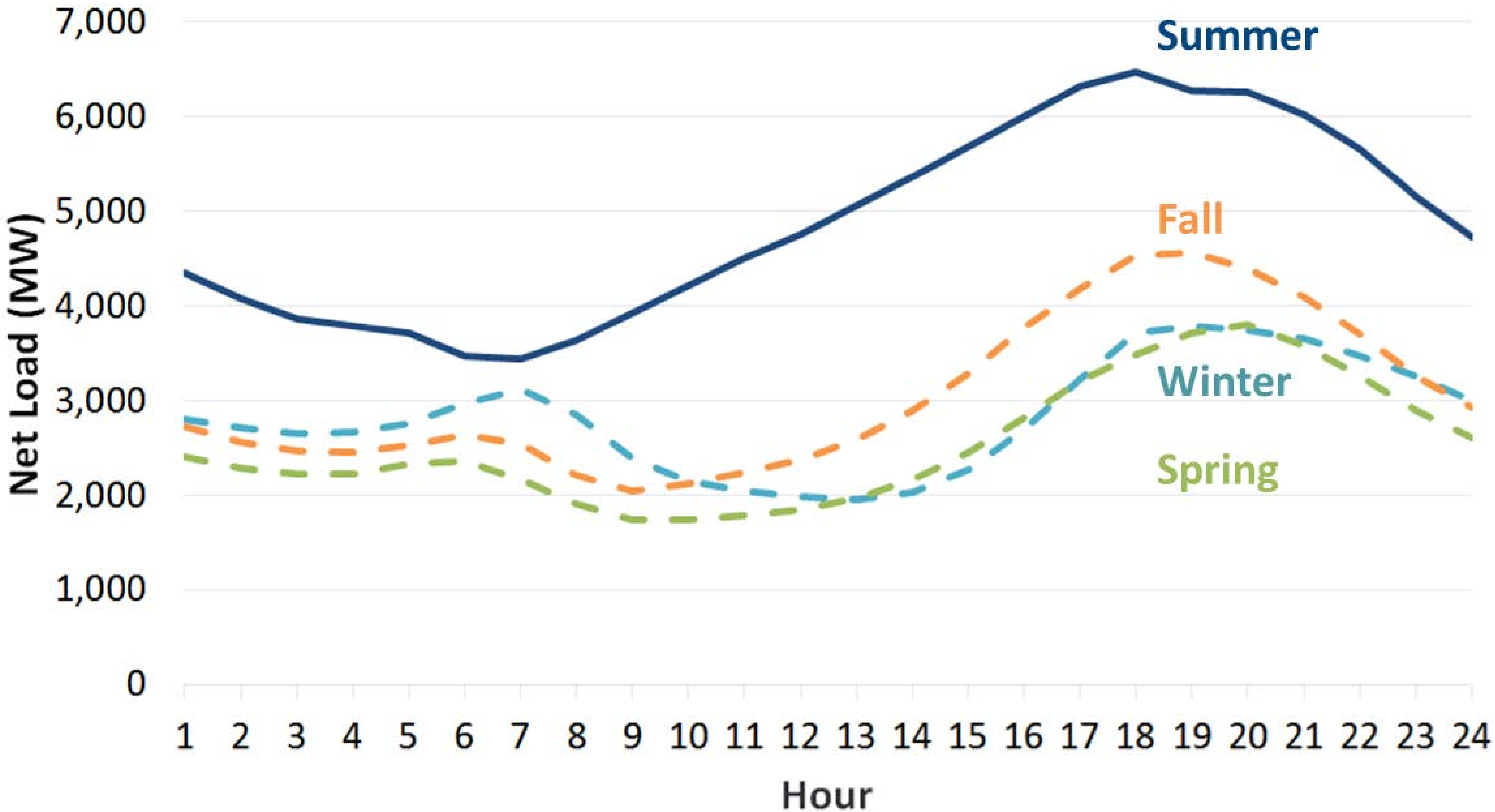
Incremental Adjusted APC Savings



Sources and Notes:

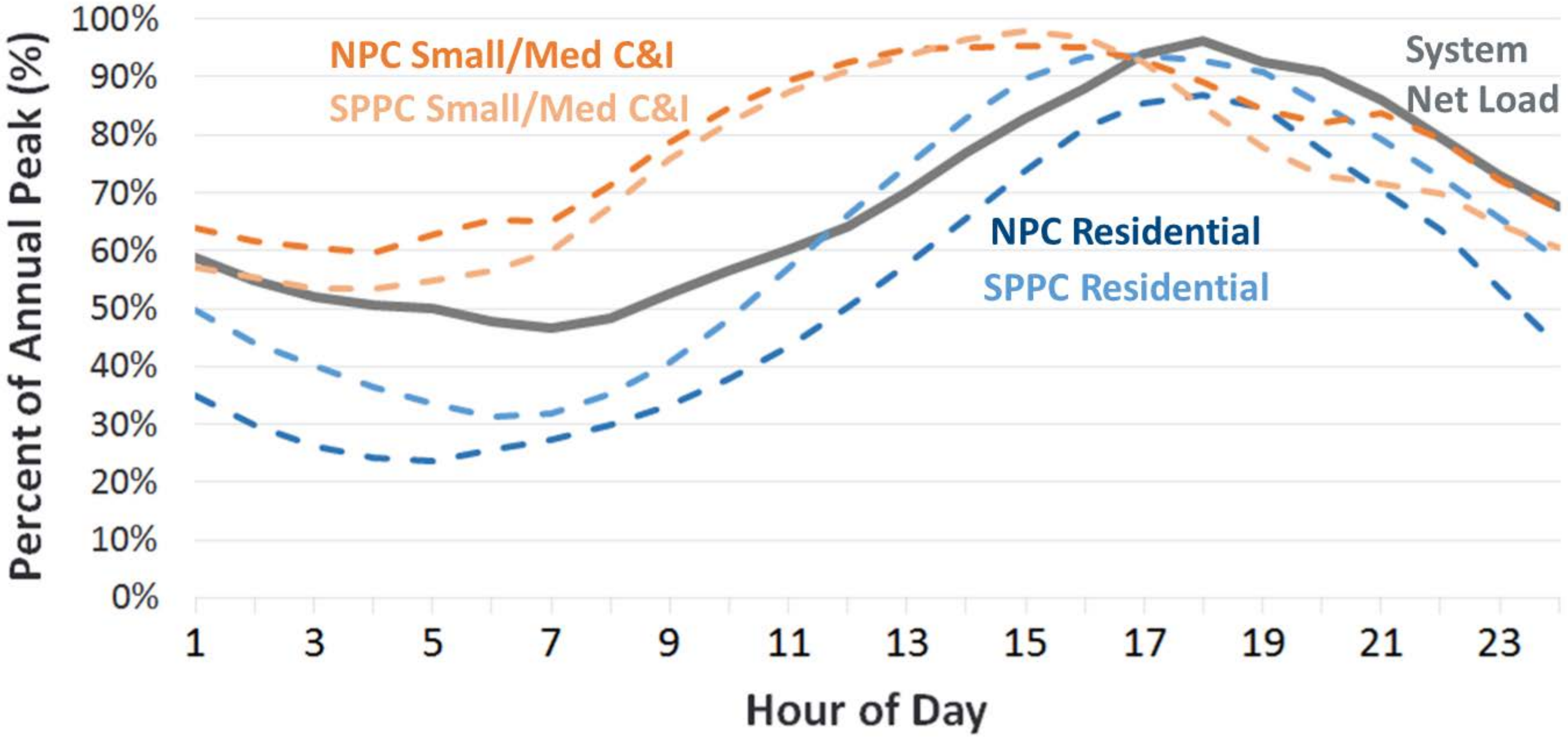
Savings estimated using a quadratic fit. All values in nominal dollars. Orange lines represent estimates of marginal benefit at each simulated deployment level.

Nevada Average Daily Load Shapes, by Season



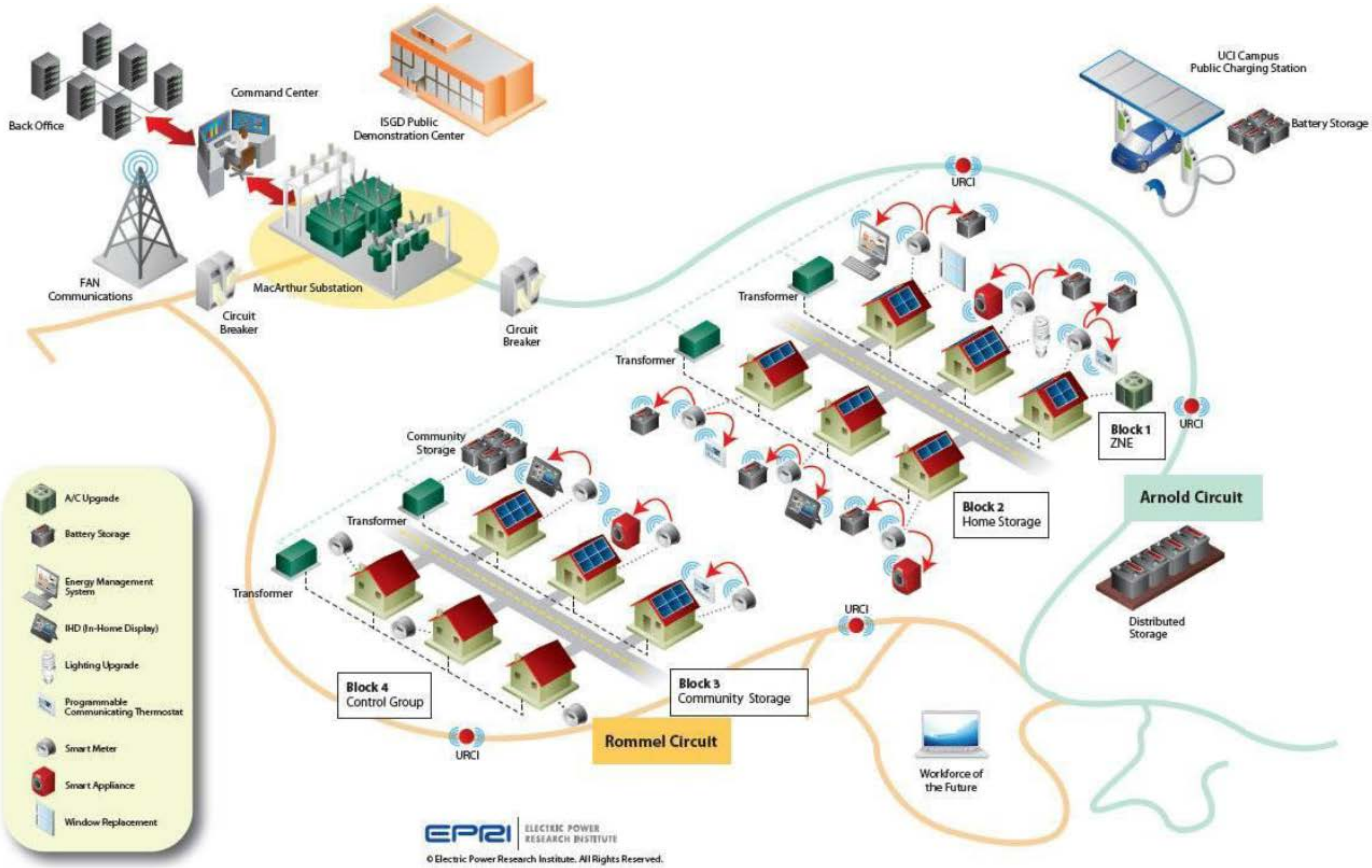
Sources and Notes: Hourly load data from 2026 TEPPC Common Case. Net load is net of renewables, distributed generation, and energy efficiency.

Average Peak Load Shapes by Customer Class



Sources and Notes: Load by Customer Class data, provided by NV Energy. Load Shapes are averaged over top 10 peak days.

Examples of Storage Deployment on Distribution Networks



Sources and Notes: SCE (2016)

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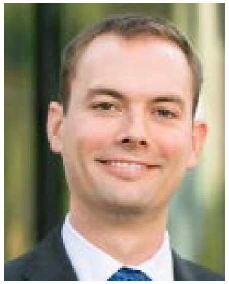

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Additional Reading

"Maximizing the Market Value of Flexible Hydro Generation ," Pablo Ruiz, James A. Read, Jr., Johannes Pfeifenberger, Roger Lueken, and Judy Chang, Comments in Response to DOE's Request for Information DE-FOA-0001886, April 4, 2018

"Getting to 50 GW? The Role of FERC Order 841, RTOs, States, and Utilities in Unlocking Storage's Potential," Roger Lueken, Judy Chang, Johannes P. Pfeifenberger, Pablo Ruiz, and Heidi Bishop, Presented at Infocast Storage Week, February 22, 2018

"Battery Storage Development: Regulatory and Market Environments," Michael Hagerty and Judy Chang, Presented to the Philadelphia Area Municipal Analyst Society, January 18, 2018

"U.S. Federal and State Regulations: Opportunities and Challenges for Electricity Storage," Romkaew Broehm, Presented at BIT Congress, Inc.'s 7th World Congress of Smart Energy, November 2, 2017

"Stacked Benefits: Comprehensively Valuing Battery Storage in California," Ryan Hledik, Roger Lueken, Colin McIntyre, and Heidi Bishop, Prepared for Eos Energy Storage, September 12, 2017

"The Hidden Battery: Opportunities in Electric Water Heating," Ryan Hledik, Judy Chang, and Roger Lueken, Prepared for the National Rural Electric Cooperative Association (NRECA), the Natural Resources Defense Council (NRDC), and the Peak Load Management Alliance (PLMA), February 10, 2016

"Impacts of Distributed Storage on Electricity Markets, Utility Operations, and Customers," Johannes Pfeifenberger, Judy Chang, Kathleen Spees, and Matthew Davis, Presented at the 2015 MIT Energy Initiative Associate Member Symposium, May 1, 2015

"The Value of Distributed Electricity Storage in Texas - Proposed Policy for Enabling Grid-Integrated Storage Investments," Ioanna Karkatsouli, James Mashal, Lauren Regan, Judy Chang, Matthew Davis, Johannes Pfeifenberger, and Kathleen Spees, Prepared for Oncor, March 2015

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