Title
Implications of Rate Design for the Customer-Economics of Behind-the-Meter Storage

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Implications of Rate Design for the Customer-Economics of Behind-the-Meter Storage

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Rate design and the customer-economics of BTM storage: An essential piece of the rate reform puzzle

- Electricity bill savings from behind-the-meter (BTM) storage are intrinsically linked to retail electricity rate design
- As regulators look to balance policy objectives related to rate reform and storage deployment, understanding how proposed changes in rate design may impact the customer economics of storage will be essential
- Previous work (e.g., McKinsey & Co. 2018, NREL 2017) has focused primarily on the nominal $/kW demand charge rate as the key driver for bill savings from BTM storage

  → **Other aspects of demand charge design, as well as the details of time-varying energy rates and net billing rates for PV customers, may also be critical to BTM storage economics**

- This work aims to fill in these gaps and provide additional insights into which rate design elements are most important to the customer-economics and market potential of BTM storage

Project overview

This analysis explores how the details of retail electricity rate design can impact customer bill savings from behind-the-meter (BTM) storage

Scope

- Focus is on the *customer*-economics
  - We do not consider the utility costs changes from BTM storage dispatch
- Addresses just one aspect of the customer-economics: utility bill savings (demand and energy charges)
  - Not considered here are other potential value/revenue streams for BTM storage owners (e.g., participation in wholesale markets, customer reliability and resilience benefits, voltage support, T&D deferral, etc.), though some of those are "implicit" in retail rates
  - We also do not address storage costs

Approach: Compute/compare utility bill savings from BTM storage across a range of rate structures and load shapes

Key rate design features impacting bill savings from BTM storage

Demand-charge savings depend on:

- Size of the demand charge rate ($/kW)
- Non-coincident vs. peak-period demand charges
- Timing and duration of peak period
- Averaging interval for measuring billing demand
- Seasonal variation in demand charge rates
- Ratchets

The analysis characterizes the *relative significance* and *manner* in which these rate design features impact BTM storage economics

Energy-charge arbitrage savings depend on:

- Price differential between high/low price periods
- Daily/monthly structure of price variability
- Duration of high/low price periods

Vary among: Time-of-Use (TOU), Critical Peak Pricing (CPP), Real-Time Pricing (RTP), and Net Billing rate structures

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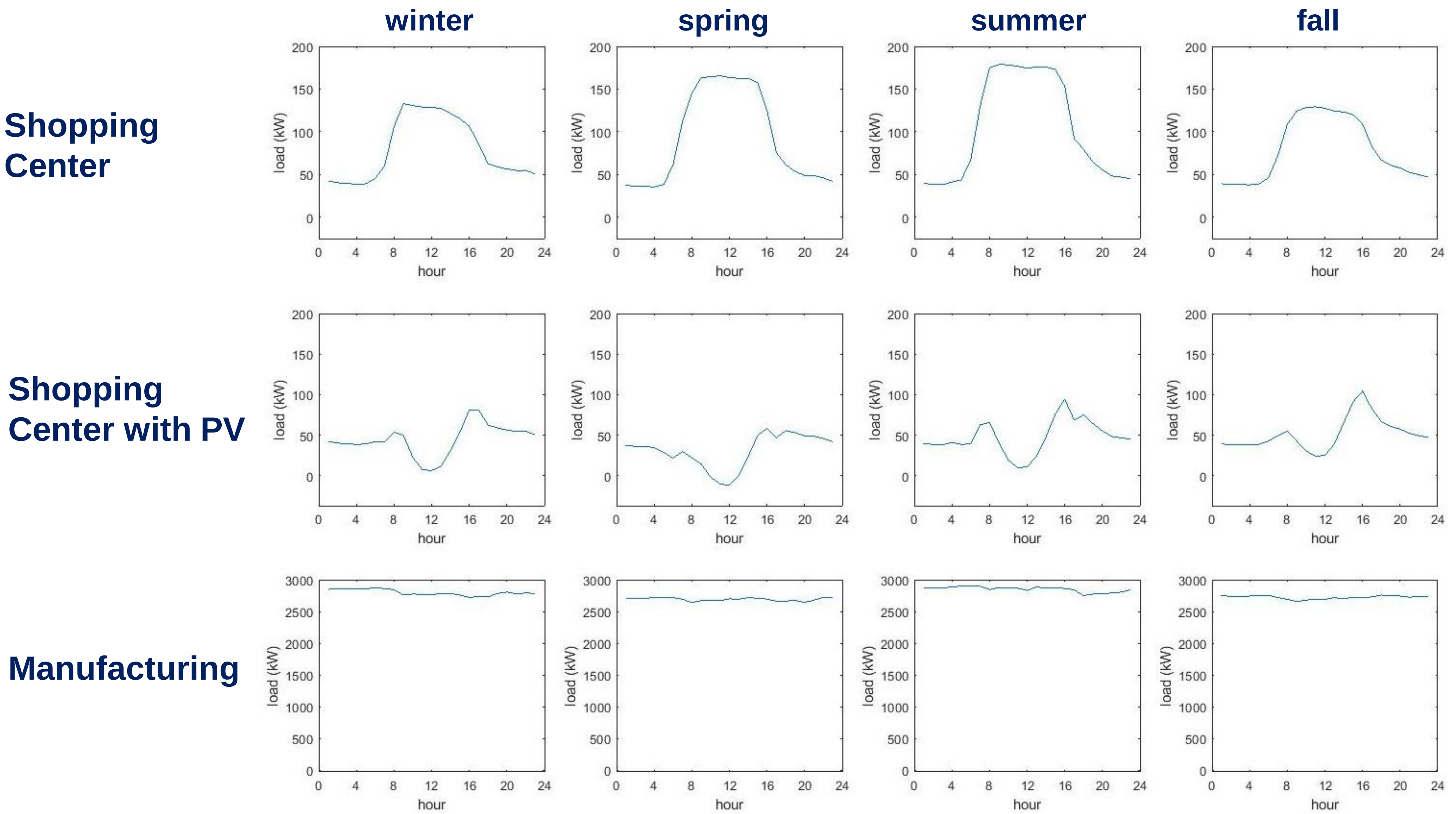
Load data for demand charge analysis

- Demand charge analysis focuses on commercial customers, given much greater prevalence of demand charges in the commercial sector (and more readily available interval load data)
- 5-minute interval load data collected and published by EnerNOC, for 100 anonymized commercial customers over a single year (2012)
- Selected three representative customer loads: (1) a shopping center, (2) a shopping center with a PV system, and (3) a manufacturing plant—see next slide
  - For shopping center with PV, solar profile constructed from the National Renewable Energy Laboratory (NREL)'s National Solar Resource Database converted to solar generation data using NREL's System Advisor Model
  - PV system sized to generate 50% of the building's annual energy consumption
- The three individual customers selected are located in Chicago; previous analyses of commercial demand charges have shown that geographic location is secondary to building type

Selected customer types span range of customer characteristics and bill savings from storage



The three building loads selected for analysis capture the relevant range of load-shape attributes

- **Shopping center:** wide midday peak loads
- **Shopping center with PV** “skinny” peaks in net load, shifted to late afternoon/evening
- **Manufacturing:** relatively flat load shape

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Rate design and analytical methods

Demand charge modeling

Rate Design

- Demand charges calculated with and without storage
- Reference demand charge: $7/kW, non-coincident, 15 minute averaging window, no ratchet
  - Based on median demand charge level in the OpenEI Utility Rate Database (URDB)
- We also calculate demand charge savings for alternative demand charge rate designs with:
  - Demand charge levels ranging from $2-$15/kW
  - Peak period demand charges with varying peak period definitions (8am-6pm, 12-6pm, 5-10pm)
  - Averaging intervals ranging from 5-60 minutes
  - Seasonal demand charge (summer and winter peak)
  - Ratchets (≥90% of max. billing demand of past 12 months, ≥60% of max. billing demand)

Storage Modeling

- Perfect foresight dispatch algorithm using HOMER
- Storage dispatch optimized for demand charge reduction
  - Though energy arbitrage could occur in conjunction if highest-priced hours coincide with peak demand
- Storage capacity (in kW) sized to meet 20% of customer's peak annual load
- Various hours of storage modeled (1, 2, and 4 hours)
- Compare demand charge savings across rate designs primarily in terms of *annual bill savings per kW of storage capacity ($/kW-yr)*

Rate design and analytical methods

Energy charge arbitrage

Rate Design

- **Time-of-use (TOU):** Analyzed a range of TOU structures, informed by review of rates in the URDB
- **Critical Peak Pricing (CPP):** Analyzed specific CPP rates currently in place
- **Real-time pricing (RTP):** Volumetric rate equal to hourly day-ahead wholesale market price, based on historical nodal data for nine markets
- **Net billing:** Exports from PV generation compensated at some price other than (typically less than) retail rates; considered export rates ranging from 1-10 cents/kWh below retail rates

Storage Modeling

- Storage dispatch optimized for energy arbitrage
- Assume 85% round-trip efficiency
- **TOU, CPP, and RTP:** Assume the battery can be fully charged in the two lowest priced hours and fully discharged in the two highest priced hours
- **Net billing:** Assume that storage can be fully charged from PV generation each day that would otherwise be exported to the grid
- Energy charge savings are largely independent of the underlying customer load shape; results are not specific to either residential or commercial customers
- Compare energy charge savings across rate designs primarily in terms of *annual bill savings per kWh of storage capacity ($/kWh-yr)*

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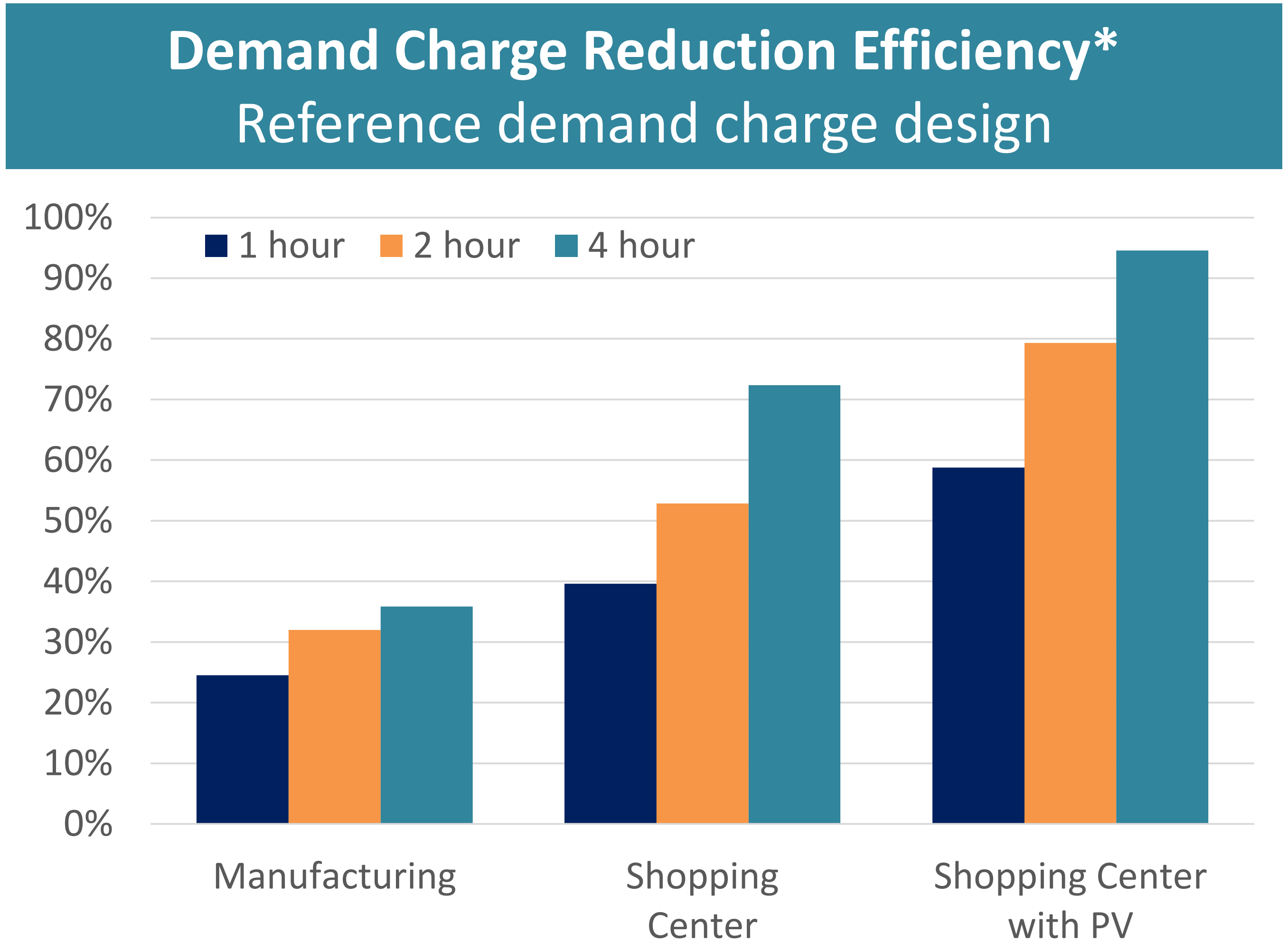
Demand charge savings from storage vary by load shape and storage duration



$$\text{* Demand Charge Reduction Efficiency} = \frac{\text{Demand Charge Reduction (kW)}}{\text{Storage System Size (kW)}}$$

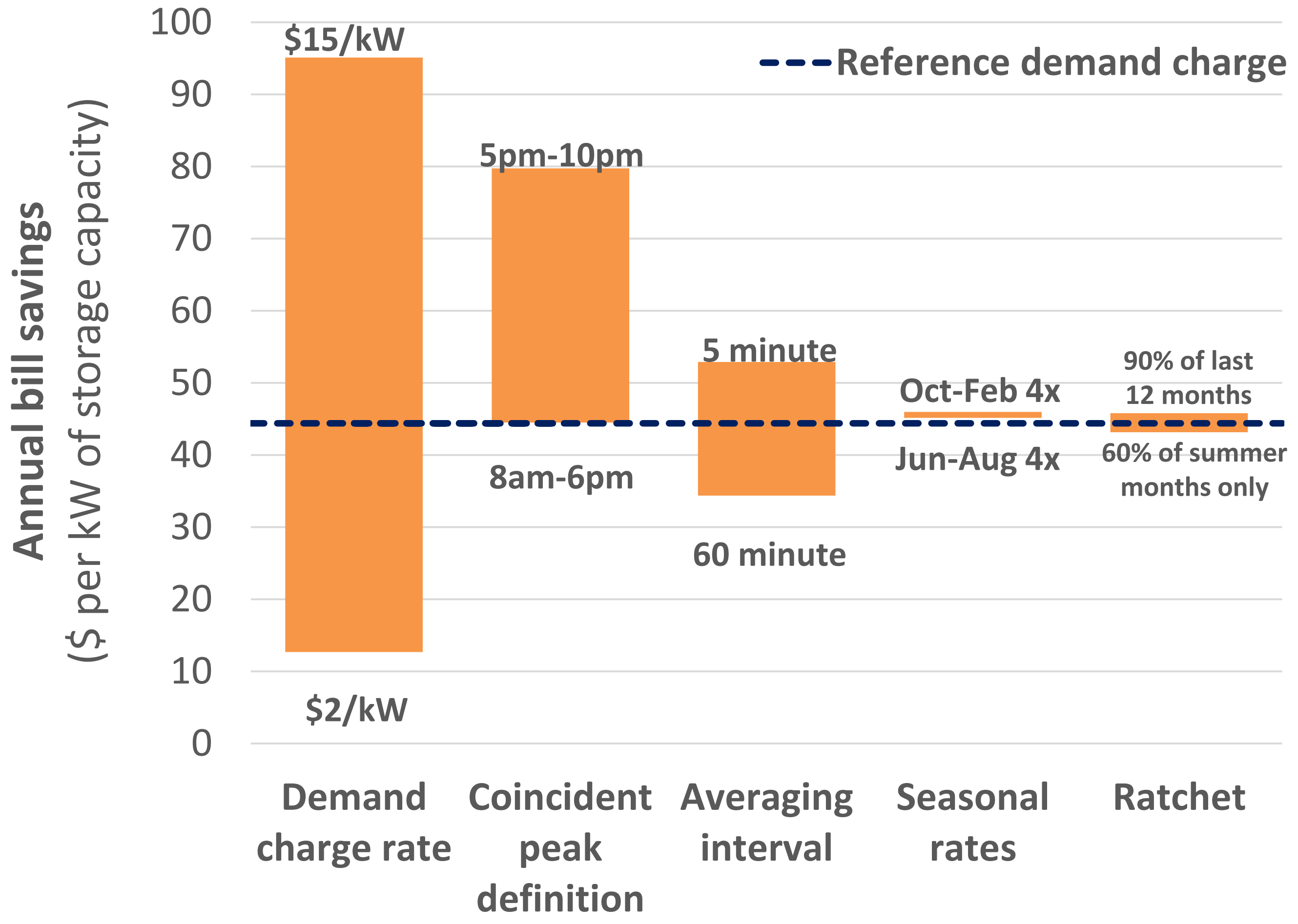
- Storage is most effective at reducing demand charges for customers with narrow peaky loads
  - For peaky loads (e.g. customers with PV), even storage with shorter durations can be effective at shaving the narrow load peaks
  - For flatter load profiles (e.g. manufacturing), storage cannot sustain the required discharge to reduce peak demand
- Longer duration storage can more effectively reduce demand charges than systems with shorter durations
  - Longer duration storage can sustain discharge rates longer, potentially reducing wider peaks, though there are diminishing returns to duration
- Cross-customer differences in demand charge reduction efficiency hold across most demand charge rate designs

The focus of our analysis is on the change in demand charge savings from these baseline levels when modifying individual elements of demand charge design

Impact of demand charge design on bill savings from BTM storage

Example: Shopping center, 2-hour storage

Annual bill savings ($/kW of storage capacity)



Note: The corresponding figures for the other two building load profiles are in the Appendix.

- **Demand charge rate** is the most-critical design feature in terms of demand charge savings
  - Most demand charge rates range from $2-15/kW, but a few utilities have rates as high as $30/kW or more
- **Peak period demand charges** can boost demand charge savings (by ~80% in this example), if based on relatively narrow windows
- **Averaging intervals** also have a distinct impact (±20% in this example), with greater demand charge savings the shorter the averaging interval
- **Season rates** and **ratchets** have little effect on bill savings

The following set of slides delve more deeply into these demand charge design elements

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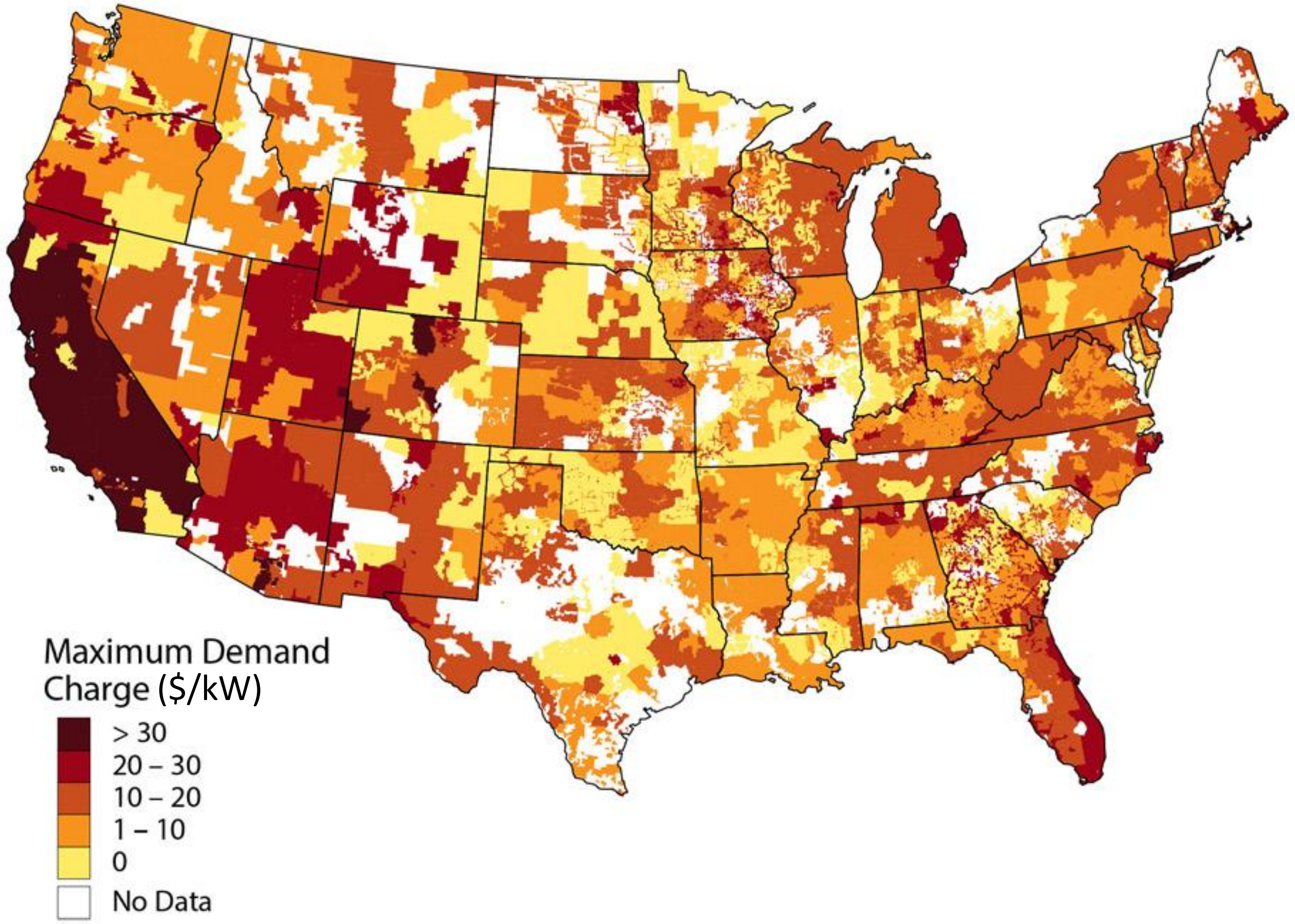
Demand charge levels vary widely: At “borderline” levels, other rate design details can drive BTM storage cost-effectiveness

- Demand charge rates can vary significantly by utility and by customer class and size
  - Depending on: underlying utility costs, cost allocation across customer classes, and which specific cost elements are recovered through demand charges
  - For large C&I customers, 50% or more of the total bill is often based on demand charges
- Prior analyses (NREL 2017, McKinsey 2017) have identified demand charge rates of \$10-15/kW as a typical threshold for BTM storage cost-effectiveness
  - Demand charge rates at this level occur in most states (at least on a limited basis—see figure)
  - Our analysis of NREL’s Utility Rate Database found that 80% of all demand charge rates fall between \$2/kW and \$15/kW (the 10th & 90th percentile values, respectively), with an overall median of \$7/kW

Maximum C&I Demand Charge Rate by Utility

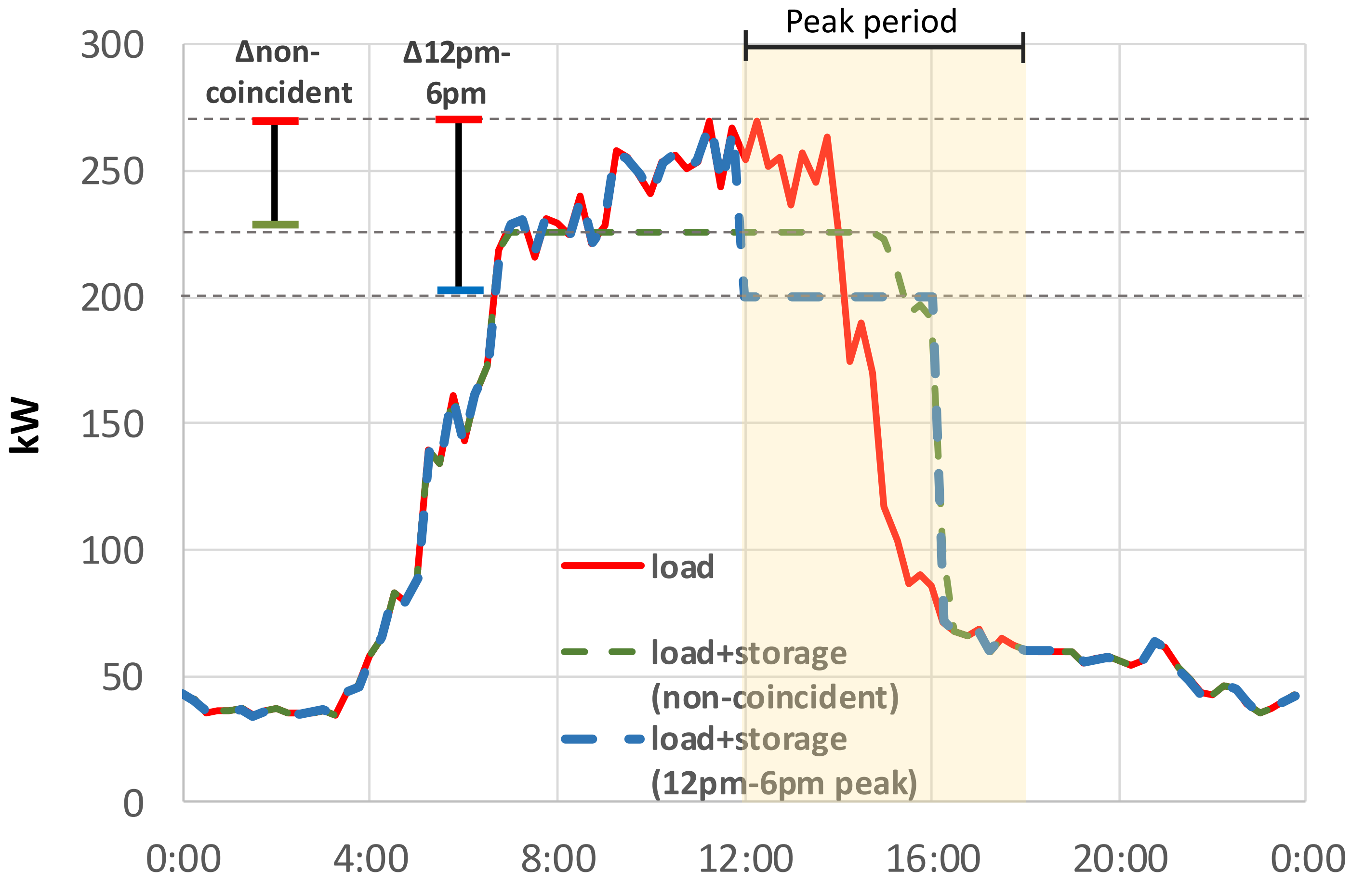


Source: NREL. 2017. *Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges*. Golden, CO: National Renewable Energy Laboratory.

Storage is generally more effective at reducing demand charges when based on "peak period" demand

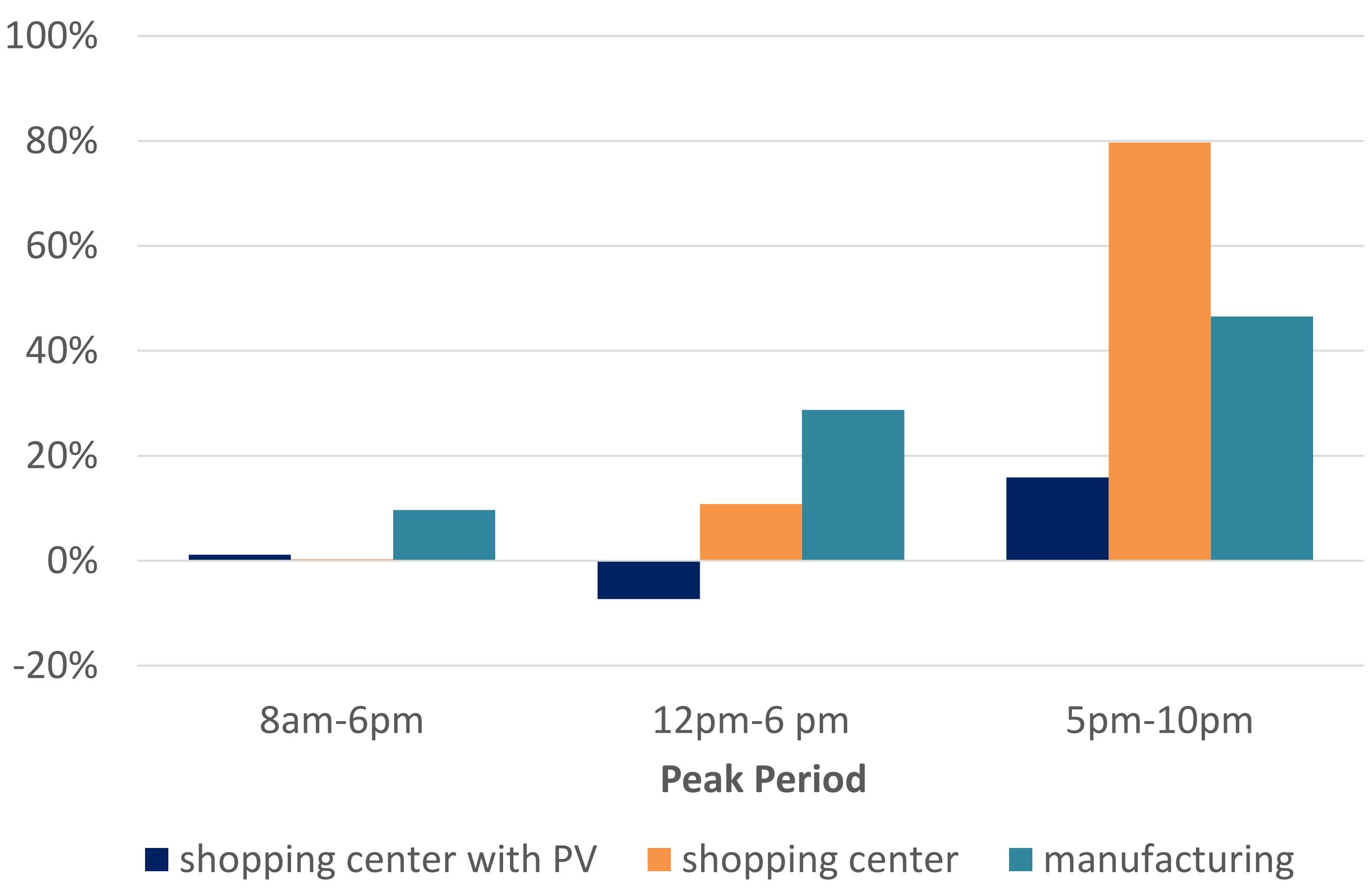
- Peak period demand charges are an alternative to non-coincident demand charges; are based on maximum demand during designated peak periods
  - Typically beginning between 12pm-2pm and ending between 6-8 pm, though specific timing and duration can vary considerably
- Peak period demand charges create skinnier demand peaks, leading to greater bill savings from storage
- Demand charge reductions from storage are greater the shorter the peak period window
- Demand charge reductions also depend on timing and on the underlying load shape during the peak period
  - If the timing of the demand charge peak period coincides with when load is ramping up or down, the resulting sharp load peaks inside the window can more easily be clipped by storage

Billing demand reduction from storage with peak period demand charges



An illustration of how peak period timing and duration can impact demand charge savings from storage

Change in demand charge reduction relative to the reference (non-coincident) demand charge design

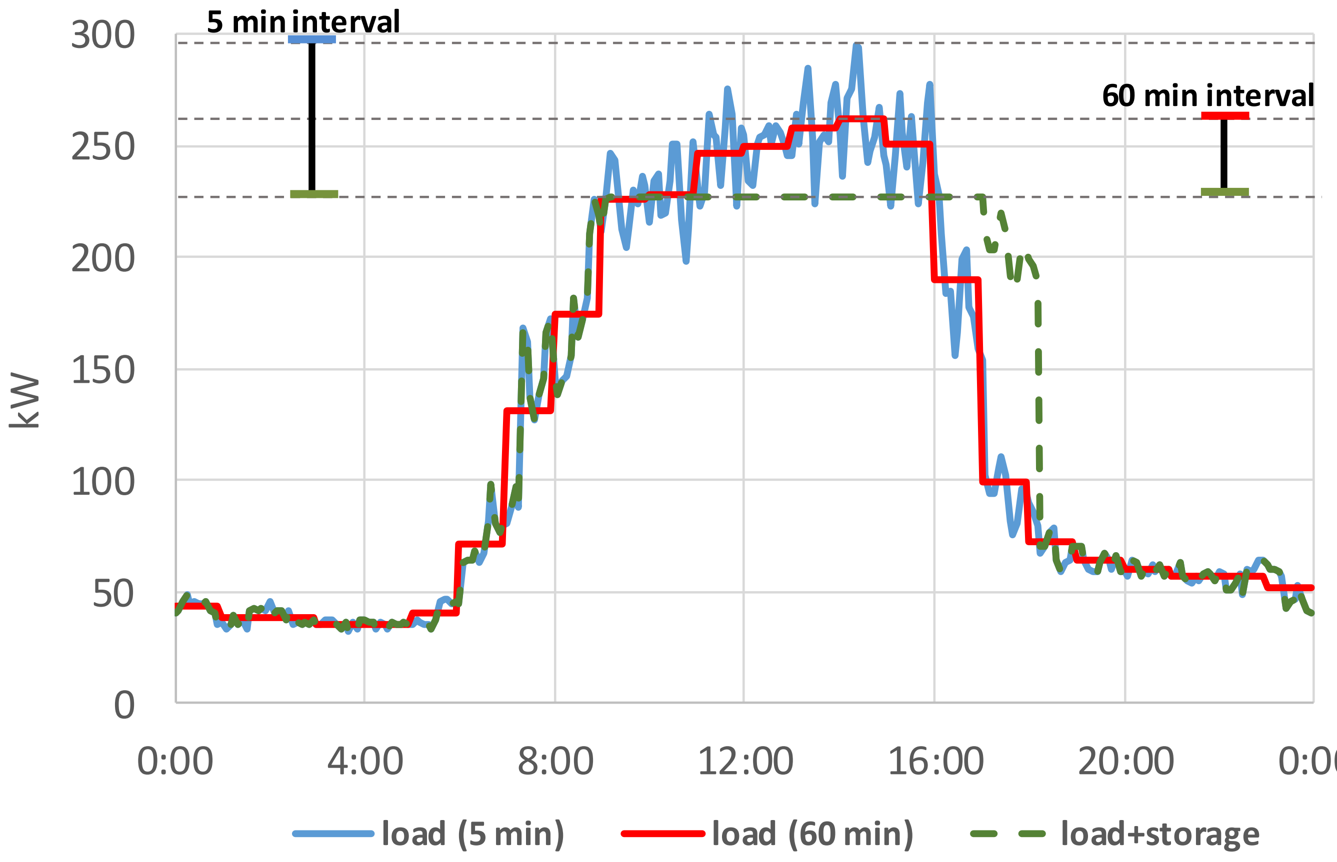


- **Shopping center:** the 5pm-10pm window coincides with the down-ramp of the load profile, leading to a steep peak within the window that storage can effectively reduce
- **Shopping center with PV:** net load profile has a skinny peak (and hence greater demand charge saving under a non-coincident design), so the incremental savings from moving to a peak period design are much smaller
- **Manufacturing:** Demand charge savings from storage depend primarily on the duration of the peak period window

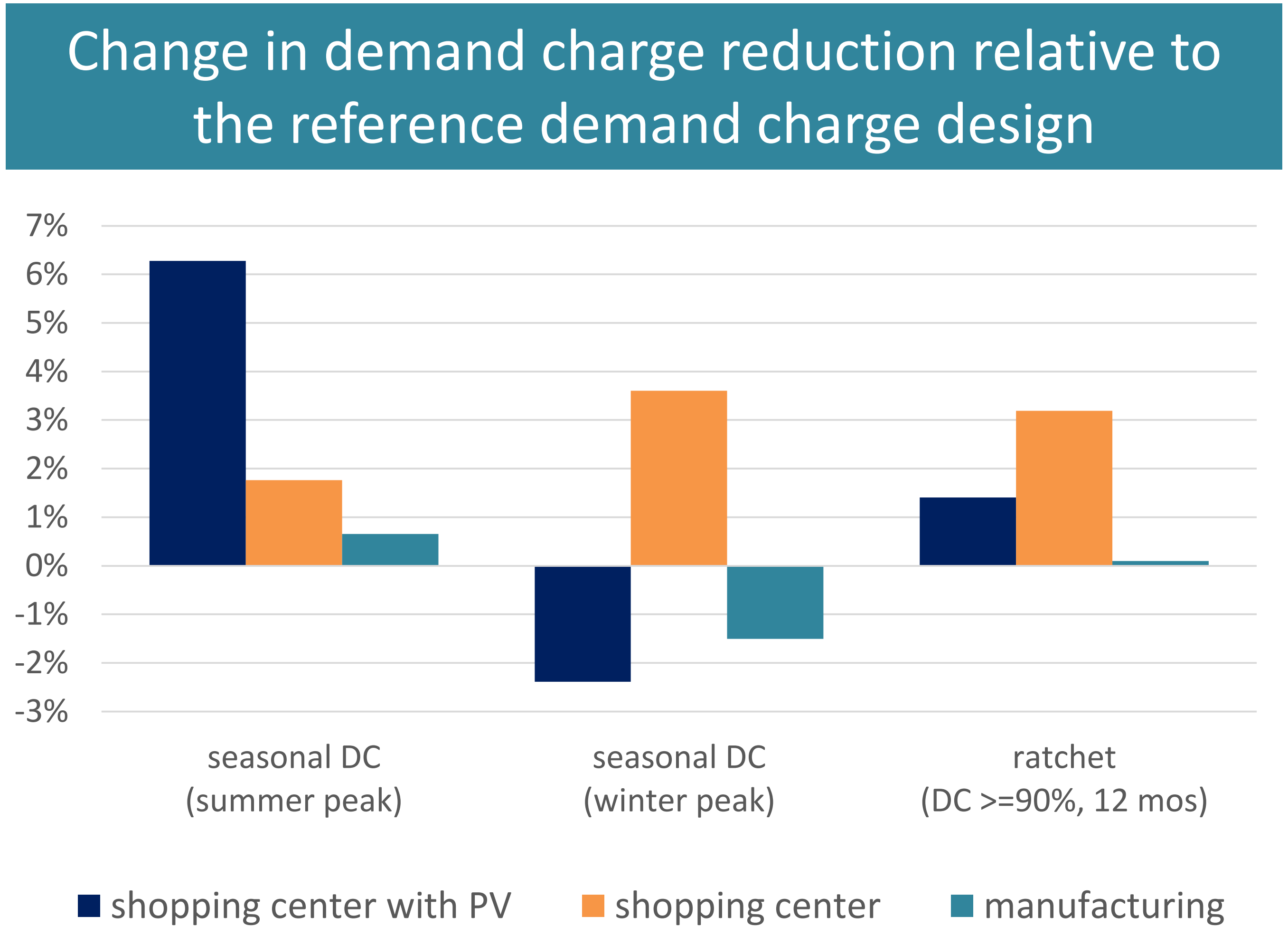
Demand charge savings from storage are greater under demand charges with short averaging intervals

- Demand charges are typically based on demand averaged over 15-minute intervals, though averaging intervals can range from 5-60 minutes (depending in part on metering technology)
- Longer averaging intervals smooth out billing demand variability, leading to lower billing demand without storage (i.e., the blue vs. the red line in the figure)
- In effect, longer averaging intervals are a proxy for storage, thereby eroding the opportunity for further demand reductions from storage
- The significance of averaging interval differs across customers depending on the variability ("noisiness") of their underlying load profile

Billing demand reduction from storage for 5 min and 60 min averaging intervals



Seasonal demand charge rates and ratchets have little impact on demand charge savings from storage



Notes: Summer and winter peaks have demand charge level increased fourfold from June through August and November through February, respectively.

- Seasonal demand charge and ratchet definitions are diverse among utilities
  - Seasonal demand charges can either have higher priced summer or winter peak seasons
- For seasonal demand charges, impacts of storage on demand reduction is small regardless of seasonal definition
  - For customers with PV, storage is more effective at reducing the demand charge in the summer months, when PV is most reliable at creating the “skinny peaks”
  - Though the change in demand charge reduction efficiency can be positive or negative depending on the load profile, the overall impact remains small
- Ratchets can slightly increase the average demand charge reduction efficiency of storage for loads with large month-to-month variation in peak load
  - We also considered a less-binding ratchet (with a 60% threshold) but this had no impact on demand charge reduction efficiency relative to the reference design

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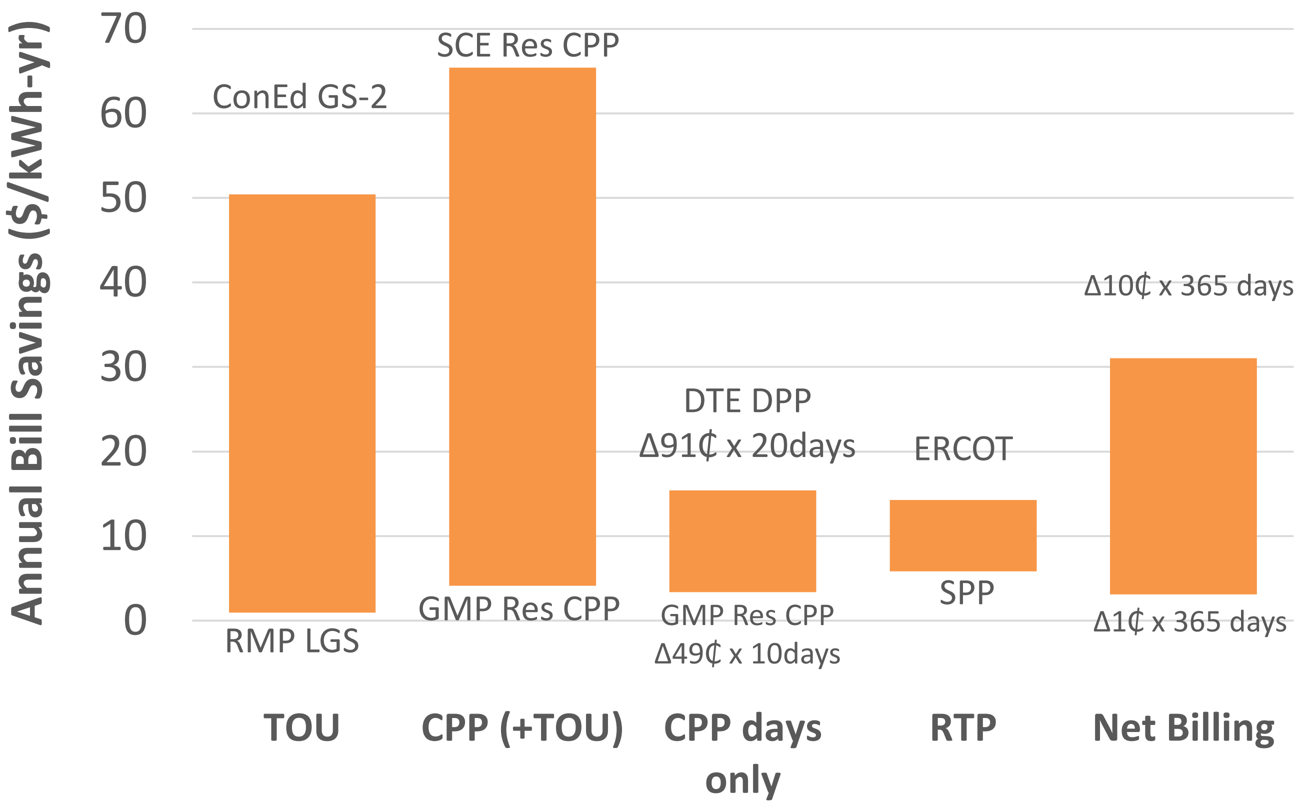
Energy-charge arbitrage savings from BTM storage

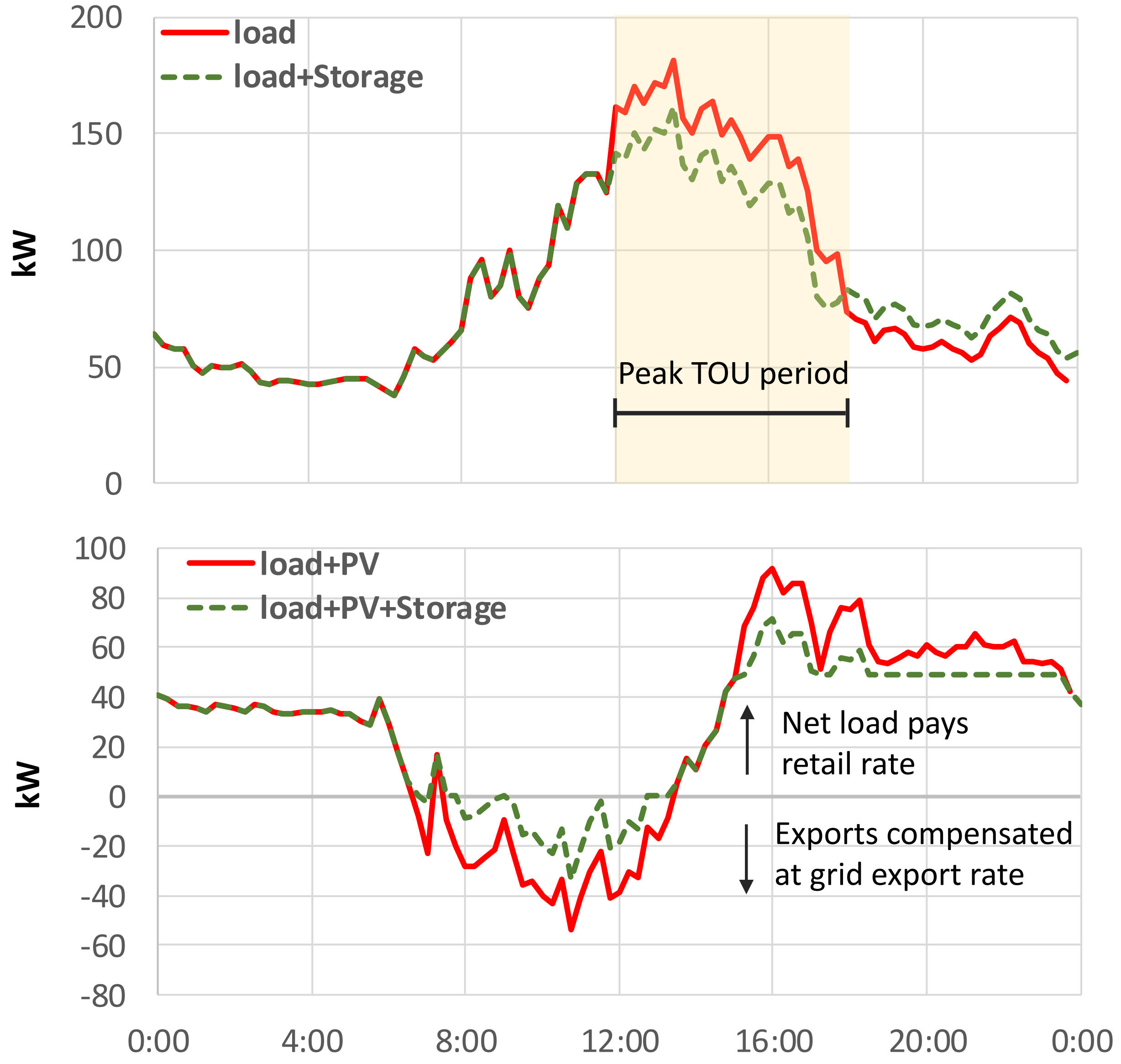
Range in annual bill savings from energy arbitrage (some illustrative examples)



Notes: We use $/kWh-yr as the bill savings metric, rather than $/kW-yr, as in the case of demand charge savings. See appendix for utility abbreviations and tariff names.

- **TOU:** Wide variation, depending on peak-to-off-peak differential and seasonal definition (i.e., number of summer vs. winter months)
- **CPP:** Savings driven by arbitrage from TOU differential + critical peak price events
- **RTP:** Limited arbitrage opportunities if based solely on wholesale energy market prices, given average peak-to-off-peak spreads
- **Net Billing:** Daily arbitrage savings driven by the delta between retail and PV grid-export rates, the latter *potentially* based on some construct of avoided costs

Energy price differences enable storage to reduce electricity bills through arbitrage

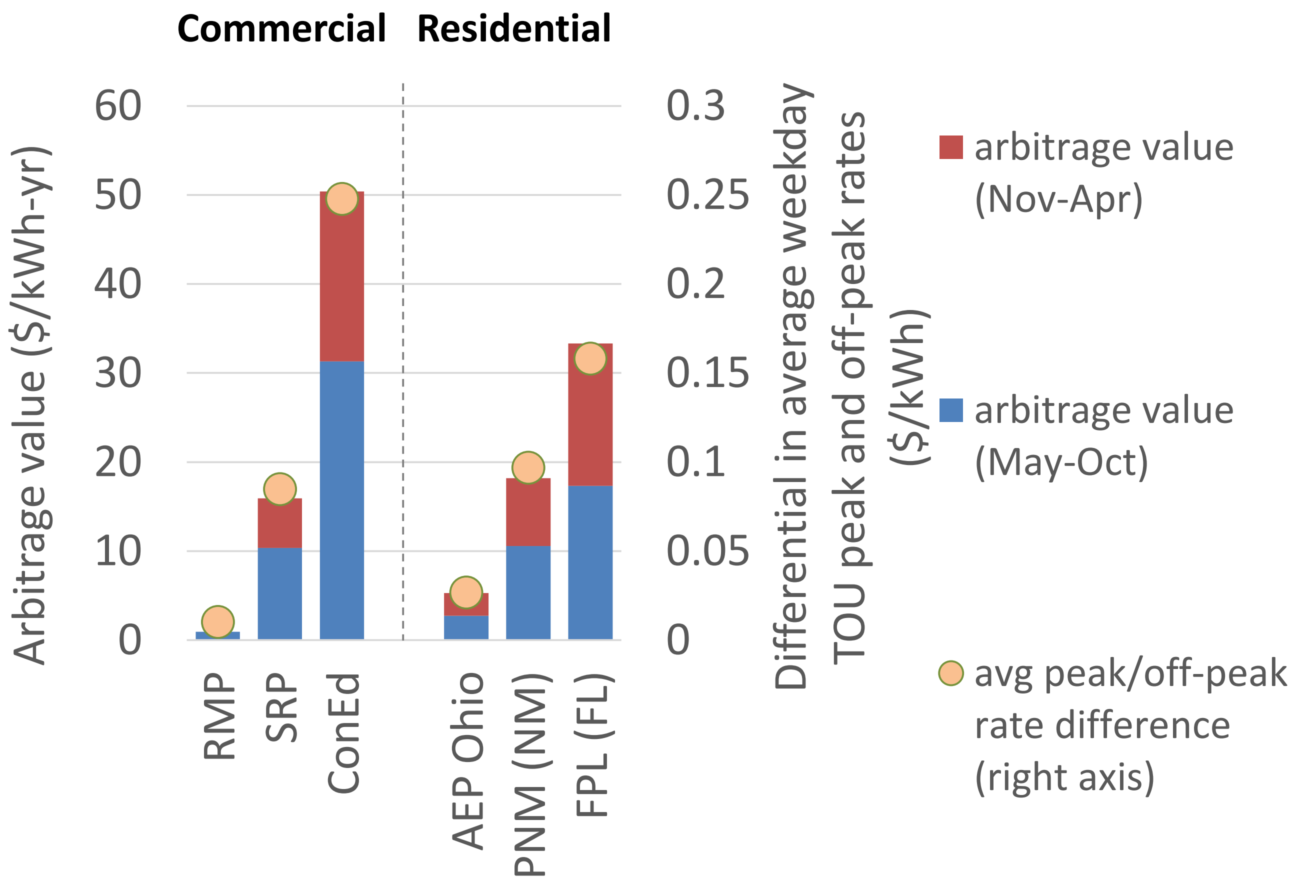


TOU, CPP, and RTP: Bill savings from storage achieved by charging during low priced hours and discharging during high priced hours

Net billing: Storage manages PV exports to the grid, arbitraging between retail rates and the PV grid export rate

Under TOU rates, arbitrage value varies widely depending on differential between peak-period and off-peak rates

Annual value of bill savings from TOU arbitrage for commercial and residential rates

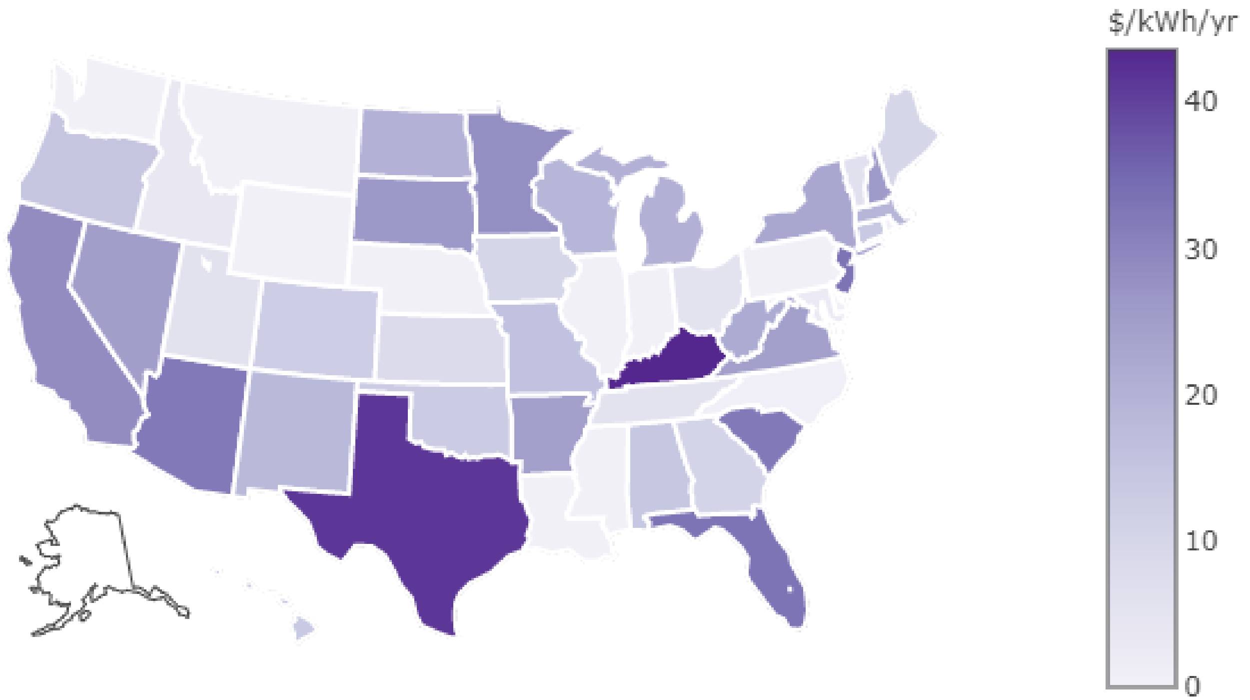


Notes: See Appendix for utility abbreviations and tariff names.

- Computed value of energy arbitrage from storage across large number of TOU rates
- Specific examples shown here illustrate the range in arbitrage-value (~$2-$53/kWh of storage capacity per year)
- Greater bill savings driven by peak-to-off-peak TOU rate differential
  - Differential varies widely across utilities and tariff schedules (<2 cents to >20 cents per kWh)
- Bill savings value from TOU arbitrage can occur disproportionately during May-October
  - Peak period rates may only apply (or are much higher) during these months

TOU arbitrage opportunities vary by state and utility, primarily reflecting retail rate design choices (more so than wholesale prices)

Annual value of bill savings from residential TOU arbitrage for the largest utility of each state

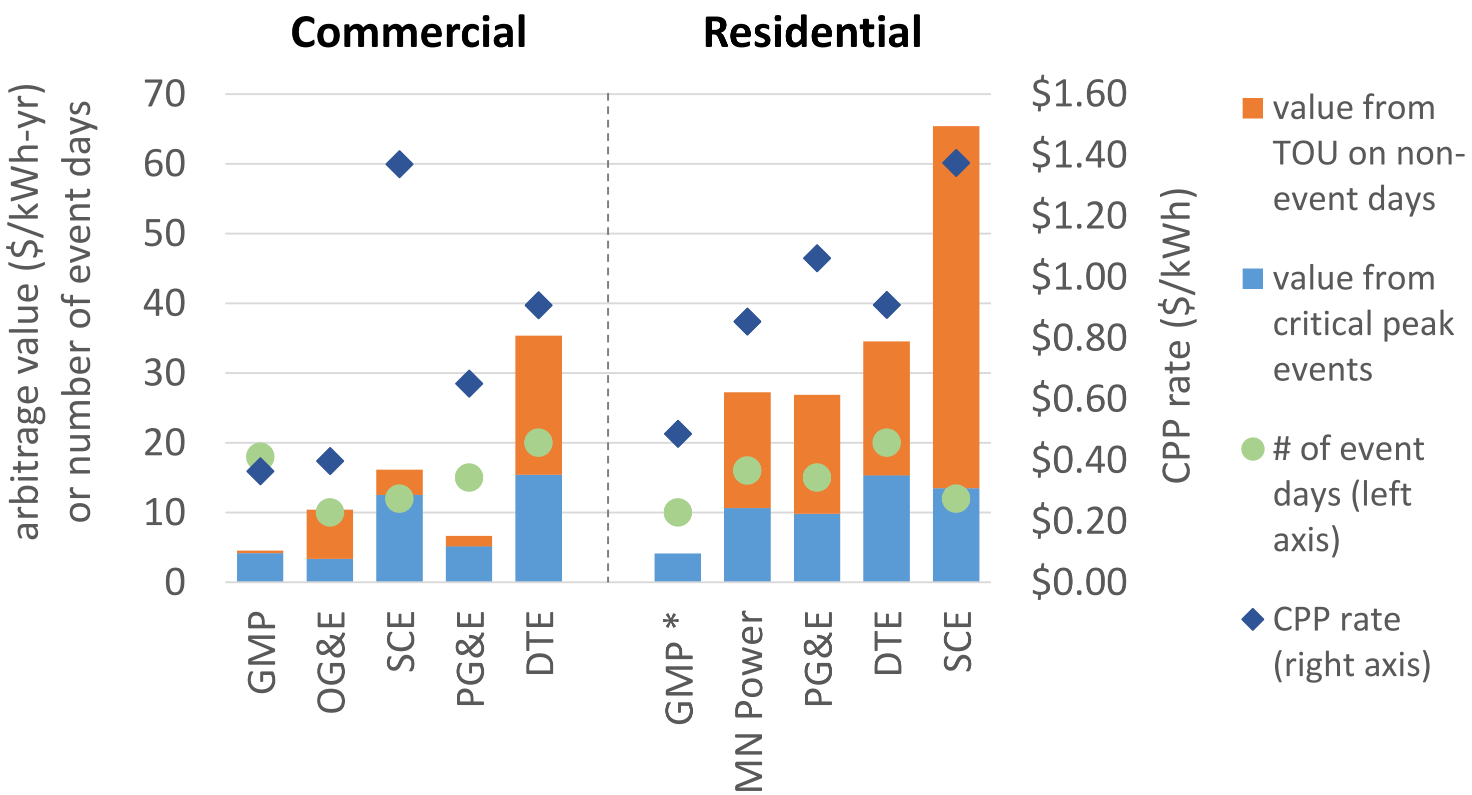


Notes: See Appendix for utility and tariff names used for each state.

- Calculations use residential TOU rate from largest utility selected for each state (ranked by number of residential customers)
  - Optional TOU rates are offered for residential customers by the largest utility in 38 states
- Values shown not indicative of other utilities in state
  - Wide variety of TOU peak to off-peak differentials also exist within each of the states
- No geographic trends emerge from map as TOU rates are only loosely tied to regional wholesale electricity prices
- Map shown for residential customers only as commercial customer rate also have demand charge element which makes total bill savings dependent on load profile

Arbitrage value under CPP rates derives mostly from underlying TOU structure, but also depends on level and frequency of critical peak prices

Annual value of bill savings from CPP arbitrage for residential and commercial customers



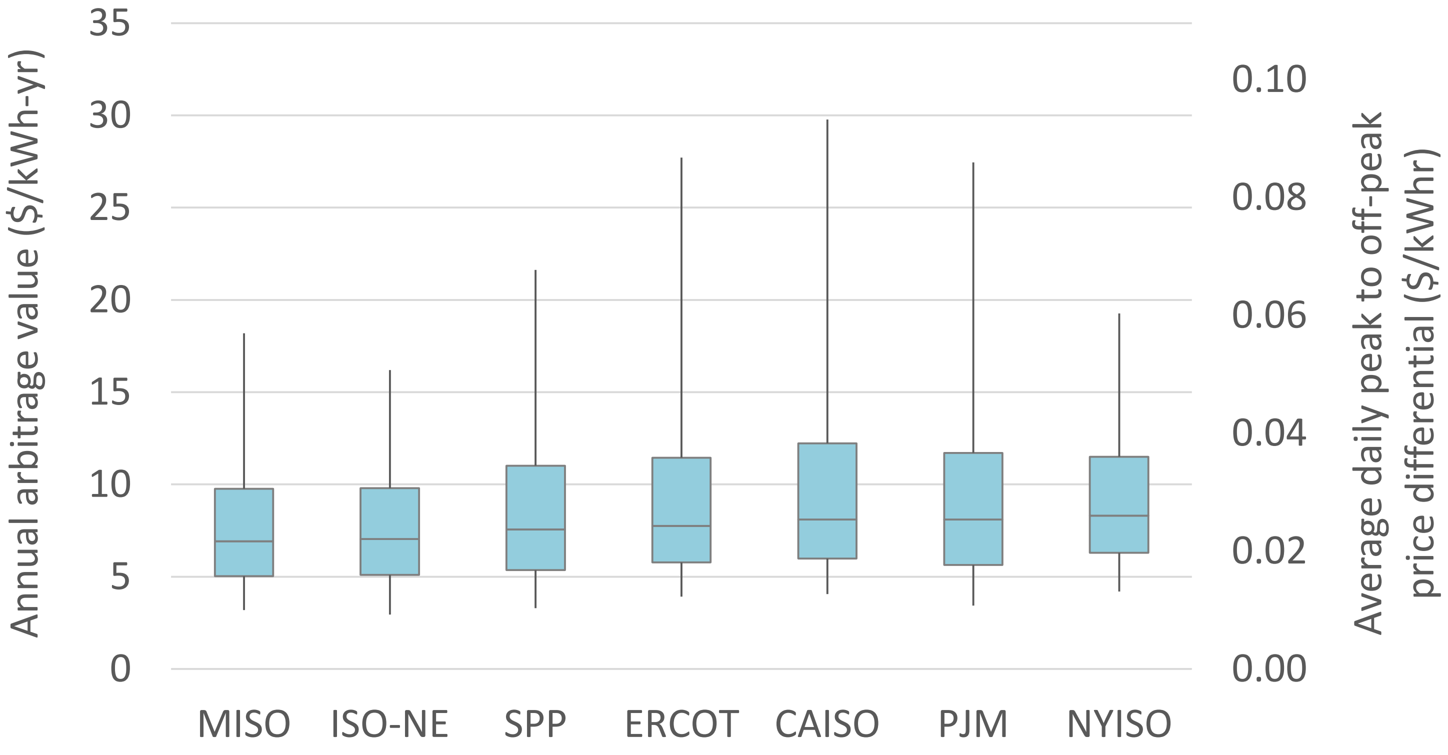
Notes: See Appendix for utility abbreviations and tariff names. *GMP residential CPP rate has no TOU component.

- Aside from pilot tariffs, relatively few CPP rates are currently available
  - Figure shows a sample of commercial and residential CPP rates illustrating a general range in bill savings from storage
- Large range in critical peak price levels (~$0.30-1.40/kWh) and event days per year (~10-20)
- Arbitrage value from storage varies from ~$4-56 per kWh of storage per year
  - Arbitrage from CPP events typically comprises one-quarter to two-thirds of overall energy charge savings
  - Under many of the CPP rates, most of the bill savings are from TOU arbitrage during non-CPP-event days
- Arbitrage value on CPP days may be lower if customers reduce load below storage capacity during events, as storage then would not fully discharge

Arbitrage value under RTP rates is relatively low compared to the other time-varying rates

Annual value of bill savings from RTP arbitrage

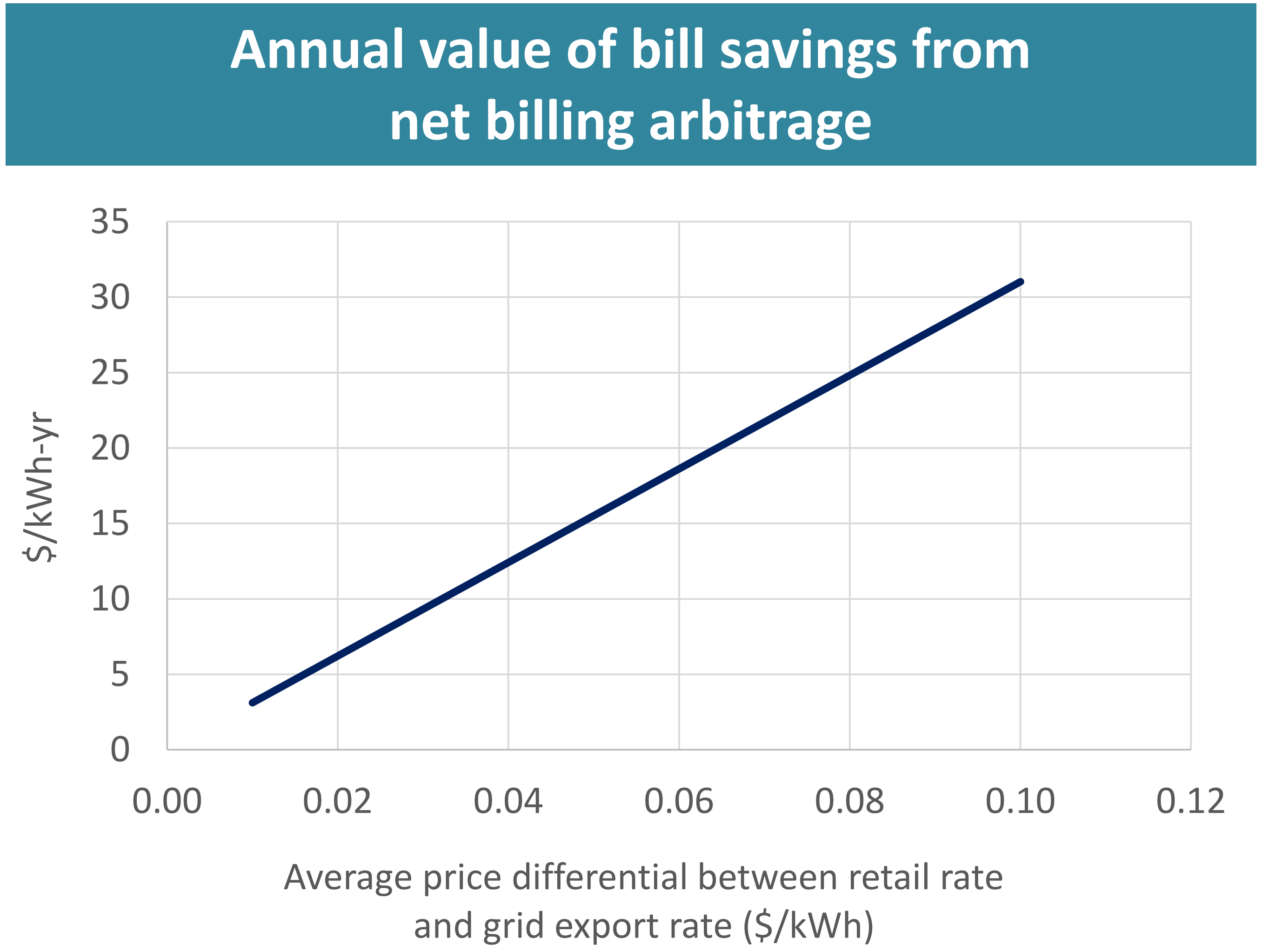
Based on historical day-head hourly prices



Notes: Based on prices from 100 randomly selected price nodes for each ISO from 2009 or latest market redesign (whichever is later) through August 2018. Storage assumed to be able to charge and discharge fully in the two lowest and highest priced hours of each day, respectively. Box plots represent 5th, 25th, 50th, 75th, and 95th percentiles.

- RTP most common among industrial customers though overall number of customers small compared to TOU (Nezamoddini and Wang 2017)
- RTP arbitrage value has relatively low range and variability across years and markets
  - Typically \$6-\$14 per kWh of storage per year, though some nodes experience higher price volatility
- Reflects fairly limited differential between average peak and off-peak prices
- Greater hourly variability and arbitrage value possible if:
  - Retail RTP also reflects temporal variability in marginal transmission and distribution costs
  - Growing PV penetration leads to greater price volatility

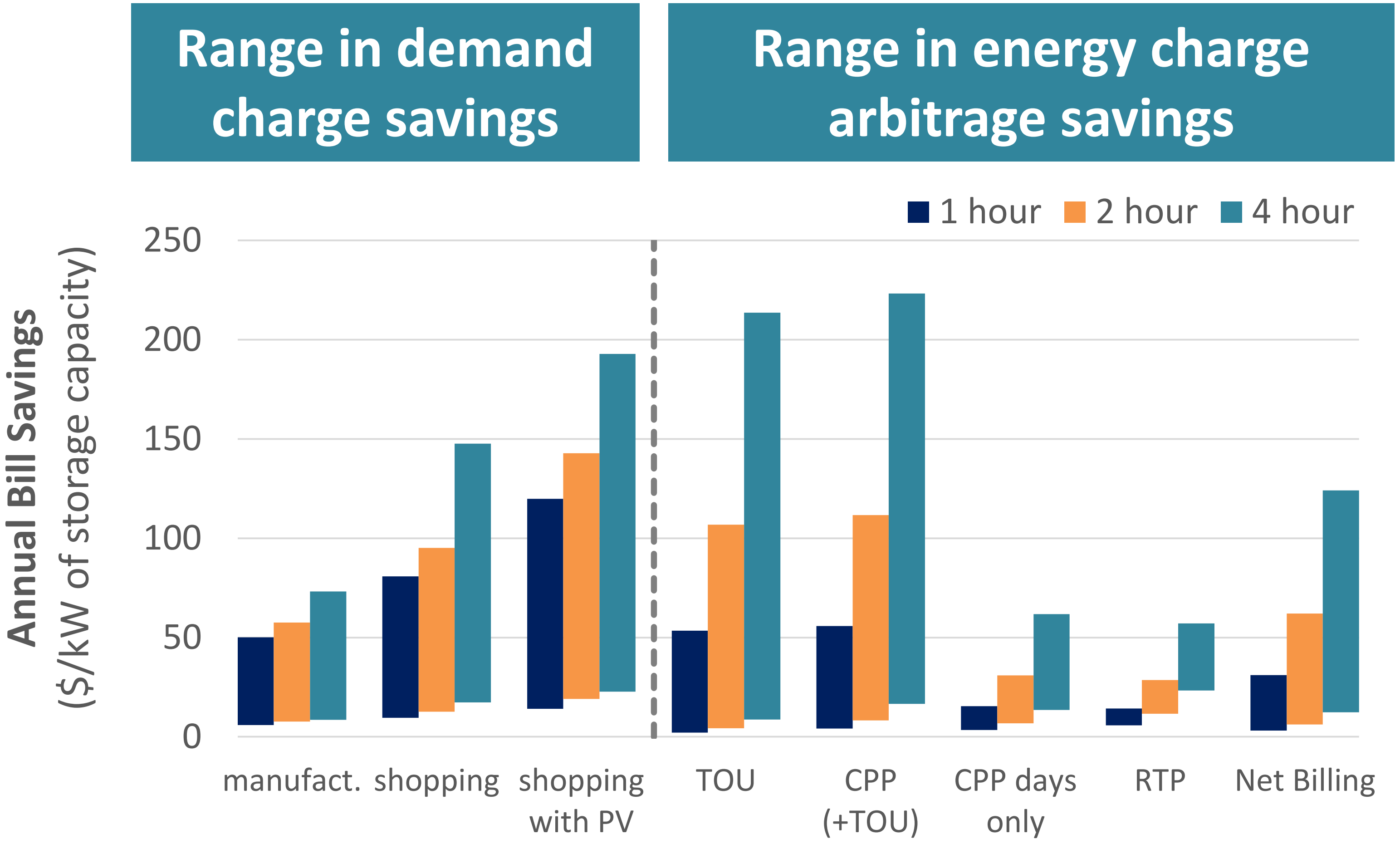
Arbitrage value under net billing is driven by differential between retail rate and grid export rate



Notes: Assumes enough PV grid exports every day to fully charge storage.

- Net billing has become the successor to NEM in some states: PV exports to the grid are compensated at some designated grid export rate (rather than at retail rates)
- Grid export rates may be based on avoided cost value or in some cases may be more of a political compromise (e.g., during transitional periods away from NEM)
- Differentials between retail rate and grid export rate vary
  - CA Net Metering 2.0: ~$0.02-0.03/kWh differential
  - Rocky Mountain Power: ~$0.02-0.04/kWh differential
  - Arizona Public Service: ~$0.10/kWh differential
- Linear relationship between arbitrage value and retail-to-grid-export price differential (assuming enough grid exports every day to fully charge storage)—see figure
- More applicable to residential customers, which *tend* to have proportionally greater grid exports than commercial customers with PV

Energy arbitrage savings can rival demand charge savings, especially with longer-duration storage



Notes: Range in demand charge savings based on $2-15/kW range in demand charge rate. Range in energy arbitrage savings reflect the specific set of illustrative rates featured in previous slides. Energy charge savings shown here in terms of $ per kW of storage capacity in order to allow comparability to demand charge savings.

- Some TOU rates and net billing rates offer bill savings on par with, or greater than, demand charge savings—depending on the details of the rate design
- The relative importance of demand vs. energy charge savings also depends on storage duration
  - Energy arbitrage savings scale more-or-less linearly with storage duration, while demand charge savings face diminishing returns to scale
  - This has implications for rate design and BTM storage adoption, as longer duration storage becomes more economically viable

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Conclusions

- It's not just about the size of the demand charge: other rate design features are also key to understanding the customer-economics of BTM storage
  - Peak-period demand charge designs, demand charge averaging intervals, and TOU peak-to-off-peak energy price differential are all significant to determining the customer bill savings from storage
  - The details of demand charge design are more important for some customers than others (e.g., depending on how peaky or variable the customer load shape is and the timing of load peaks)
- Among the rate design elements and customer types considered, demand charge savings range from $8-$143 per kW of storage capacity per year whereas arbitrage savings can range from $4-$112 per kW of storage capacity per year (for a 2 hour duration storage system)
- With longer duration storage, energy arbitrage savings can be (sometimes substantially) larger than demand charge savings
  - Arbitrage savings roughly scale with storage duration, whereas there are diminishing returns to demand charge reductions with increasing storage duration

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Utility and rate abbreviations (slides 23 and 25)

			utility	rate
Time-of-use rates	*commercial*	*RMP*	Rocky Montain Power - Utah	Large General Service (No. 8)
		SRP	Salt River Project	Time-of-Use General Service (E-32)
		ConEd	Consolidated Edison Company of NY	General - Small - Time-of-Day (No. 2, Rate II)
	residential	*AEP*	AEP Ohio (Ohio Power Co)	Residential Service - Time-of-Day (RS-TOD)
		ConEd	Consolidated Edison Company of NY	Residential and Religious - Voluntary Time-of-Day (No. 1, Rate III)
		APS	Arizona Public Service	Optional Residential Time-Of-Use (RT)
Critical Peak Pricing	*commercial*	*GMP*	Green Mountain Power	Critical Peak Rider for Commercial and Industrial
		OG&E	Oklahoma Gas and Electric	General Service Variable Peak Pricing
		SCE	Southern California Edison	Critical Peak Pricing
		PG&E	Pacific Gas and Electric	Peak Day Pricing
		DTE	DTE Energy	Dynamic Peak Pricing Rate
	residential	*GMP*	Green Mountain Power	Residential Critical Peak Pricing
		MN Power	Minnesota Power	Critical Peak Pricing
		PG&E	Pacific Gas and Electric	Time-of-Use Rate + Smart Rate
		DTE	DTE Energy	Dynamic Peak Pricing Rate
		SCE	Southern California Edison	Time-of-Use Domestic + Critical Peak Pricing

Utility and rate abbreviations (slide 24)

State	utility	rate
AL	Alabama Power Co	Residential Time Advantage (RTA)
AR	Entergy Arkansas Inc	Optional Residential Time-Of-Use (RT)
AZ	Arizona Public Service Co	Residential Time-of-Use Service, Saver Choice (TOU-E)
CA	Southern California Edison Co	Time-of-Use Domestic (TOU-D)
CO	Public Service Company of Colorado (Xcel Colorado)	Residential Time-of-Use Service (RE-TOU)
CT	Eversource CT	Residential Time-of-Day Electric Service (Rate 7)
DC	Pepco (Exelon)	none
DE	City of Dover - (DE)	none
FL	Florida Power & Light Co	Residential Service (RS-1) + Residential Time-of-Use Rider (RTR-1)
GA	Georgia Power Co	Time of Use - Residential Energy Only (TOU-REO-10)
HI	Hawaiian Electric Co Inc	Residential Time-of-Use Service (TOU-R)
IA	MidAmerican Energy Co	Residential Time-of-Use Service (RST)
ID	Idaho Power Co	Time-of-Day Pilot Plan (schedule 5)
IL	Commonwealth Edison Co	none
IN	Duke Energy Indiana, LLC	none
KS	Westar Energy Inc	Time of Use Pilot
KY	Kentucky Utilities Co	Residential Time-of-Day Energy Service (RTOD-Energy)
LA	Entergy Louisiana LLC	none
MA	National Grid (MA)	Time-of-Use (R-4)
MD	Baltimore Gas & Electric Co	Residential Optional Time-of-Use (schedule RL)
ME	Central Maine Power Co	Residential Service - Optional Time-of-Use
MI	DTE Electric Company	Residential Time-of-Day Service Rate (D1.2)
MN	Northern States Power Co (Xcel)	Residential Time of Day Service (A02)
MO	Union Electric Co - (MO)	Residential Service Rate (No 1(M))
MS	Entergy Mississippi Inc	none

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Utility and rate abbreviations (slide 24, continued)

State	utility	rate
MT	NorthWestern Energy LLC - (MT)	none
NC	Duke Energy Carolinas, LLC	Residential Service, Time of Use (RT)
ND	Northern States Power Co - (Xcel Minnesota)	Residential Time of Day Service (D02)
NE	Omaha Public Power District	none
NH	New Hampshire Elec Coop Inc	Residential Time of Day (TOD)
NJ	Public Service Elec & Gas Co	Residential Load Management Service (RLM)
NM	Public Service Co of NM	Residential Service Time-of-Use Rate
NV	Nevada Power Co (NVEnergy)	Optional Residential Service, Time-of-Use (OD-1-TOU)
NY	Consolidated Edison Co-NY Inc	Residential and Religious - Voluntary Time-of-Day (Rate III)
OH	Ohio Power Co (AEP Ohio)	Residential Service - Time-of-Day (RS-TOD)
OK	Oklahoma Gas & Electric Co	Residential Time-of-Use (R-TOU)
OR	Portland General Electric Co	Residential Service (Time-of-Use Portfolio)
PA	PECO Energy Co	none
RI	The Narragansett Electric Co	none
SC	South Carolina Electric&Gas Company	Residential Service Time of Use (Rate 5)
SD	Northern States Power Co (Xcel South Dakota)	Residential Time of Day Electric Service
TN	City of Memphis - (TN)	Time-of-Use Residential Rate (RS-TOU)
TX	TXU Energy Retail Co, LLC	Free Nights and Solar Days 12
UT	PacifiCorp (Rocky Mountain Power)	Residential Service + Optional Time-of-Day Rider -Experimental
VA	Virginia Electric & Power Co (Dominion Power)	Residential Service (1T)
VT	Vermont Electric Cooperative, Inc.	Residential Time of Use
WA	Puget Sound Energy Inc	none
WI	Wisconsin Electric Power Co	Residential Service - Time-of-Use
WV	Appalachian Power Co	Residential Service Time-of-Day (R.S.-T.O.D.)
WY	PacifiCorp	none

Results summary: Comparing demand charge reduction and energy arbitrage value for three customer types

Annual value of bill savings from BTM storage

2-hour storage, storage capacity = 20% of peak demand