BGE School Bus Electrification Benefit-Cost Analysis

FINAL RESULTS

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Brattle

Electric School Bus BCA Overview

Purpose: Estimate the benefit-cost ratio for BGE's proposed school bus electrification program

Approach: Estimate costs and benefits based on MD PSC electrification working group BCA

- *Costs*: BGE is proposing an $80 million program that includes the incremental electric school bus costs, charging infrastructure costs, and other program implementation costs
- *Base Benefits*: We estimated the benefits of avoided fuel costs, avoided fuel emissions (GHG and air pollutants), avoided maintenance costs, and resilience benefits, net of incremental power system costs and emissions
- *V2G Benefits*: We also estimated the incremental power system benefits of operating the buses as V2G resources, including avoided energy and ancillary service costs, avoided generation capacity costs, avoided T&D costs, and avoided GHG emissions

Electric School Bus BCA Results

Base Results: B/C ratio ranges from 0.5 for lower mileage buses without V2G to 1.4 for higher mileage buses with V2G capabilities

- Electric buses primarily reduce fuel, emissions, and maintenance costs ($34 million at 80 VMT/day and $80 million at 190 VMT/day)
- Serving demand during outages adds $3 million of benefits
- V2G capabilities add $20 million benefits by reducing power sector energy, ancillary service, capacity and T&D costs

Sensitivity Results: Benefits increase in the following cases:

- Higher diesel prices ($3/gallon to $5.50/gallon in 2030) based on AEO High Oil Price case increase benefits by $10-24 million
- EPA's proposed SCC increases emissions benefits by $3-8 million
- In the case with V2G, targeting locations with distribution upgrade needs increases benefits by $8-16 million

Approach

Base Electrification Benefits and Costs

- **Develop school bus usage and cost assumptions**
  - Review BGE's existing analysis and cross-check it against industry sources
  - Identify additional inputs necessary
  - Discuss with BGE likely school bus charging locations (if known) and the potential impact on the avoided (for V2G) or incremental (without V2G) T&D costs; if not available, use the weighted system average costs, as we have done for Pepco
  - Finalize school bus usage assumptions, including days of operation, range of daily VMTs to model, seasonal efficiencies, hours of operation, and charging patterns
  - Finalize school bus cost assumptions: incremental school bus costs, charger costs, EVSI costs
- **Estimate benefits and costs of school bus electrification**
  - Adapt BG&E PIM BCA analysis for school bus electrification based on demand assumptions developed in previous task, including electricity costs, fuel costs, emissions costs (GHG & CAP), vehicle costs
  - Review incremental/avoided T&D assumptions based on E3 study and potential value of incremental/avoided generation capacity (based on ability to participate in PJM capacity market)
  - Develop qualitative summary of additional resilience benefits of school bus electrification
  - Estimate benefits and costs over school bus life (about 15 years) for each component

School Bus V2G Benefits

- **Estimate incremental V2G value of school bus electrification using bStore**
  - Pull 2020 to 2022 BGE zone DA and RT energy and AS prices
  - Develop school bus driving periods and discharge rates based on the first task
  - Run bStore to optimize V2G operations, accounting for school bus driving patterns (based on historical prices)
  - Calculate incremental V2G value (accounting for potential changes in market prices)

Complete BCA Deliverables

- **Estimate school bus electrification BCA under alternative scenarios**
  - Base BCA value
  - Incremental V2G value
  - High/low avoided distribution value
  - High/low capacity market value
  - High/low avoided GHG and CAP value
- **Prepare summary presentation slides of assumptions and results**

Data Received from BGE

- Program deployment schedule
- Program Costs
- School bus usage data
- School bus storage capacity and charger ratings
- Historical DA and RT LMPs for BGE zone
- BGE RPS Mandate and REC Prices
- Energy and Power Loss Factors
- Distribution system peak demand hours/seasons

Base School Bus BCA

Program Costs (Utility and Participant)

- Utility costs for EVSB program amount to a net present value of **~$70M** for 238 school buses, or $295k per bus
  - Discounted using a 4.55% nominal societal discount rate, in line with MD PSC electrification BCA
  - Estimate electric bus adoption accounting for $40,000 federal tax credit and 3% annual cost decline (see next slide)
  - Currently assuming no ongoing costs associated with the programs for charger and infrastructure maintenance

Program Cost Summary

Cost Type	Responsible for Cost	2024	2025	2026	2027	**Total**	NPV
Bus Electrification (Incremental)	NA	33	60	61	85	**238**	
Bus Rebates	Utility	$6,779,221	$11,765,090	$11,550,721	$15,584,025	**$45,679,058**	
EVSE Direct Cost	Utility	$1,984,162	$3,571,492	$3,637,631	$5,092,683	**$14,285,969**	
EVSE Installation	Utility	$992,081	$1,785,746	$1,818,815	$2,546,342	**$7,142,984**	
EVSE Line Side Make-Ready	Utility	$661,387	$1,190,497	$1,212,544	$1,697,561	**$4,761,990**	
Incremental G&A Rebates	Utility	$520,843	$915,641	$910,986	$1,246,031	**$3,593,500**	
Program Administration	Utility	$525,000	$550,000	$575,000	$600,000	**$2,250,000**	
Program Marketing	Utility	$286,567	$494,462	$492,642	$669,166	**$1,942,838**	
Total Utility-Incurred Costs		**$11,749,262**	**$20,272,929**	**$20,198,339**	**$27,435,808**	**$79,656,338**	**$70,421,694**

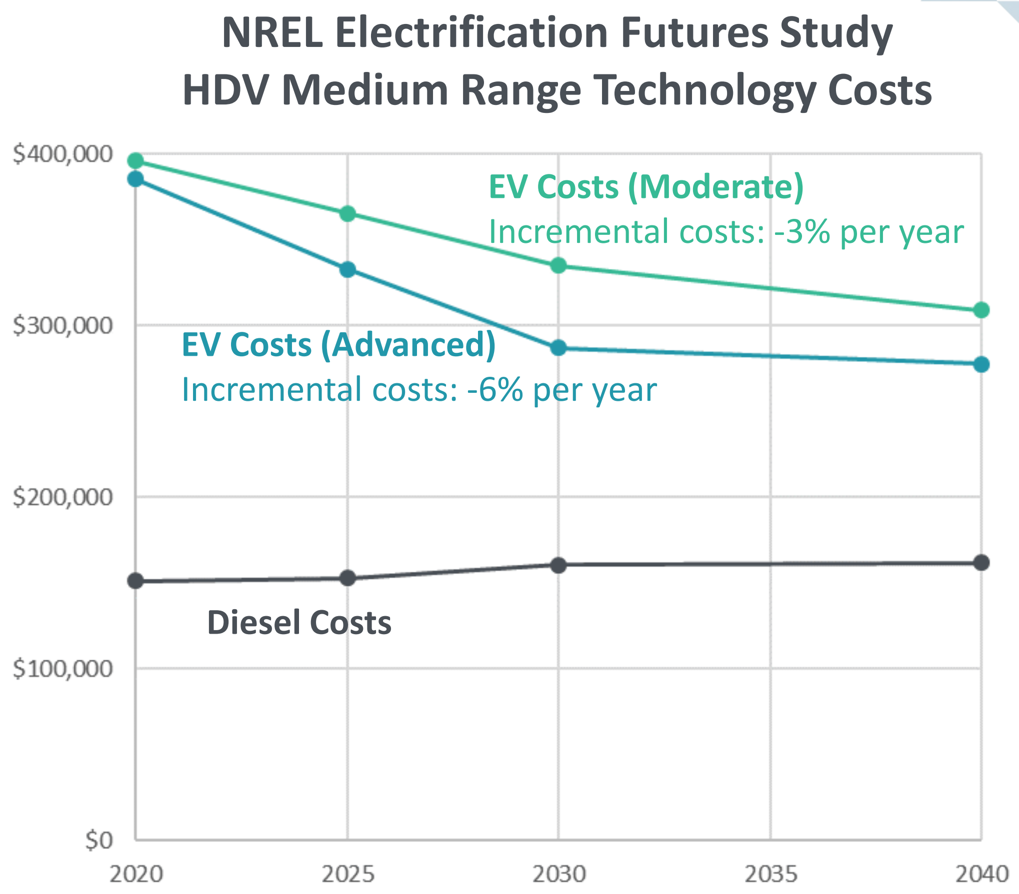
EV Bus Cost Declines

The NREL EFS study forecasts long-term HDV cost declines driven by storage cost reductions (see figure)

- Under moderate cost declines, the incremental costs decrease by 3% per year
- Advanced case results in a 6% decrease per year

We assume 3% cost decline as a base assumption and 6% as a high sensitivity

- 3% cost decline results in 238 buses adopted
- 6% cost decline results in 249 buses adopted



School Bus Daily Driving Assumptions & Energy Usage

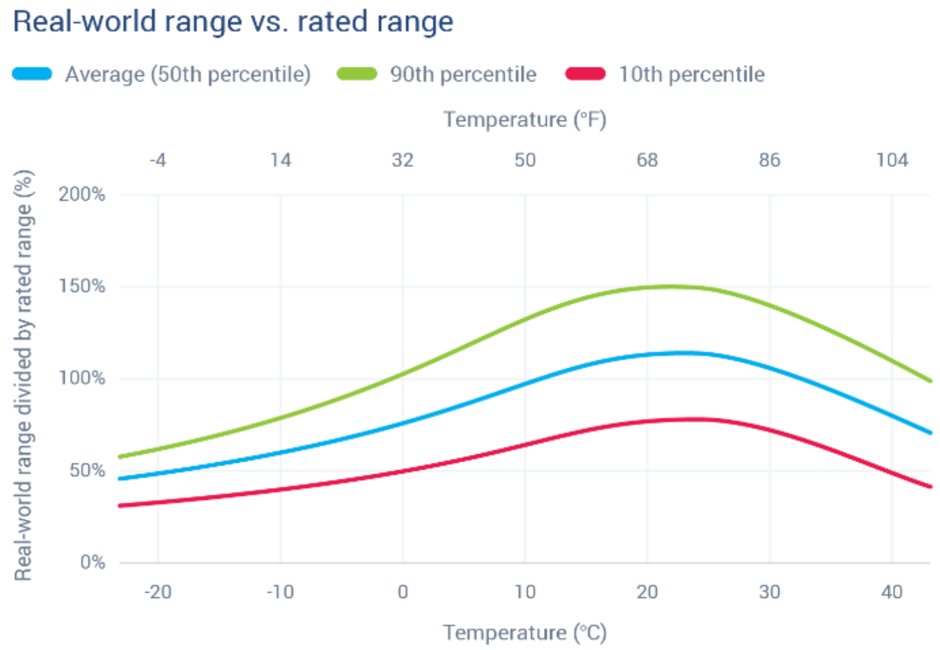
- We assume buses drive two routes of equal length each day, driving 80 to 190 miles per bus per day
  - **HB 7 – HB 10**
  - **HB 13 – HB 16**
- We use data from BGE detailing the range, capacity, and efficiency of three electric school bus models to calculate average energy usage parameters for a representative school bus

Key Driving and Energy Usage Assumptions

Assumption	Value	Source
Daily VMT per Bus	80 miles/day, 140 miles/day, 190 miles/day	BGE
Factory-Stated Range	153 miles	Average of Proterra, Cummins, Navistar Bus ranges
Battery Capacity	212 kWh	Average of Proterra, Cummins, Navistar Bus capacities
Battery Efficiency	1.4 kWh/mi	Average of Proterra, Cummins, Navistar Bus efficiencies
Diesel Bus Efficiency	6.5 miles/gal	ElectricSchoolBusFactSheet.pdf (edf.org)
Avoided Maintenance Cost	$0.37/mile	Argonne National Lab AFLEET Tool

School Bus Efficiencies and Cold Weather Range Penalty

- We represent the non-linear relationship between temperature and the vehicle's range/efficiency
  - 35% "cold weather" range penalty occurs between temperatures of 14°F and 32°F.
  - Consistent with relationships we've previously utilized
- We calculate the available range and bus efficiency on each day of the year using daily average temperatures for Baltimore
- For the forward-looking analysis, we calculate seasonal efficiencies using daily average temperatures from a *typical meteorological year (TMY)* for BWI.



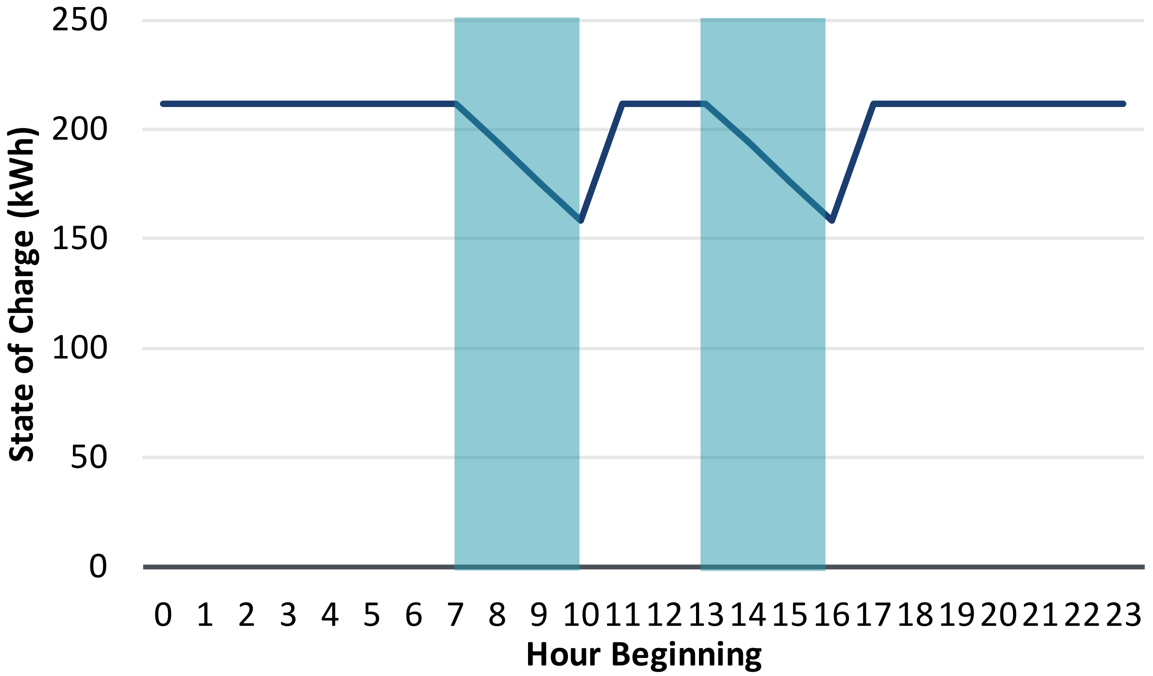
Source: EV Range vs. Temperature Range Comparison Tool | Geotab

Electric School Bus Charging Profile

- Provided the daily VMT is 80 miles per day, a school bus is expected to drive roughly **15,000** miles per year.
  - This translates to roughly **22 MWh** of energy required each year to support driving, assuming vehicle efficiencies follow the TMY temperatures.
- Initial modeling assumes **60 kW** chargers are used to replenish energy lost during driving
- Assumes bus begins charging immediately after it has completed a route
  - Each bus can replace all load lost during driving within 1-2 hours of charge
  - Includes one charge session midday between driving routes, and one evening session
  - Sensitivity analysis will include adjustments to the assumed start hour for evening charging

2024 Typical School Day Driving/Charging Schedule

60kW Charger/212kWh Bus



BCA Benefit Streams

- Brattle's Benefit Cost Analysis framework quantifies ***benefits*** from the following streams:
  - Avoided diesel costs
  - Avoided carbon emissions from fuel
  - Avoided criteria air pollutant emissions from fuel
  - Avoided vehicle maintenance costs
- The modeling also includes a number of added costs (termed ***"dis-benefits"*** throughout the analysis) related to increased usage of the electric grid to support bus charging:
  - Generation costs
  - Generation capacity costs
  - Transmission & distribution capacity costs
  - Costs associated with increased generation from RECs to meet Maryland's RPS requirement
  - Increased power sector emissions

Key BCA Global Price and Emissions Inputs

Input	Purpose	Source
Hourly Electricity Prices	To estimate costs to charge EV on an hourly basis	NREL Cambium
Marginal Generation Capacity Cost	To estimate additional gen. capacity costs due to increased charging	NREL Cambium/PJM BRA
Marginal Distribution Capacity Cost	To estimate additional dist. capacity costs due to increased charging	BGE
Capacity Line Losses	To account for power losses during peak (assume 8.9%)	BGE
Energy Line Losses	To account for power losses in T&D (assume 5.9%)	BGE
REC Prices	To estimate incurred costs from meeting added electricity demand with renewable resources	BGE
RPS Mandate	To quantify the percentage of added load that will be met by renewables per the MD RPS	BGE
Renewables Profiles	To calculate electricity emissions net of emissions from load met by renewables	NREL Cambium
Social Cost of Carbon	To quantify economic value of reduced CO2 emissions from burning fuel net of added carbon emissions from increased power demand	“Establishing A Value of Carbon” study by NYS DEC

Key BCA Global Price and Emissions Inputs, cont.

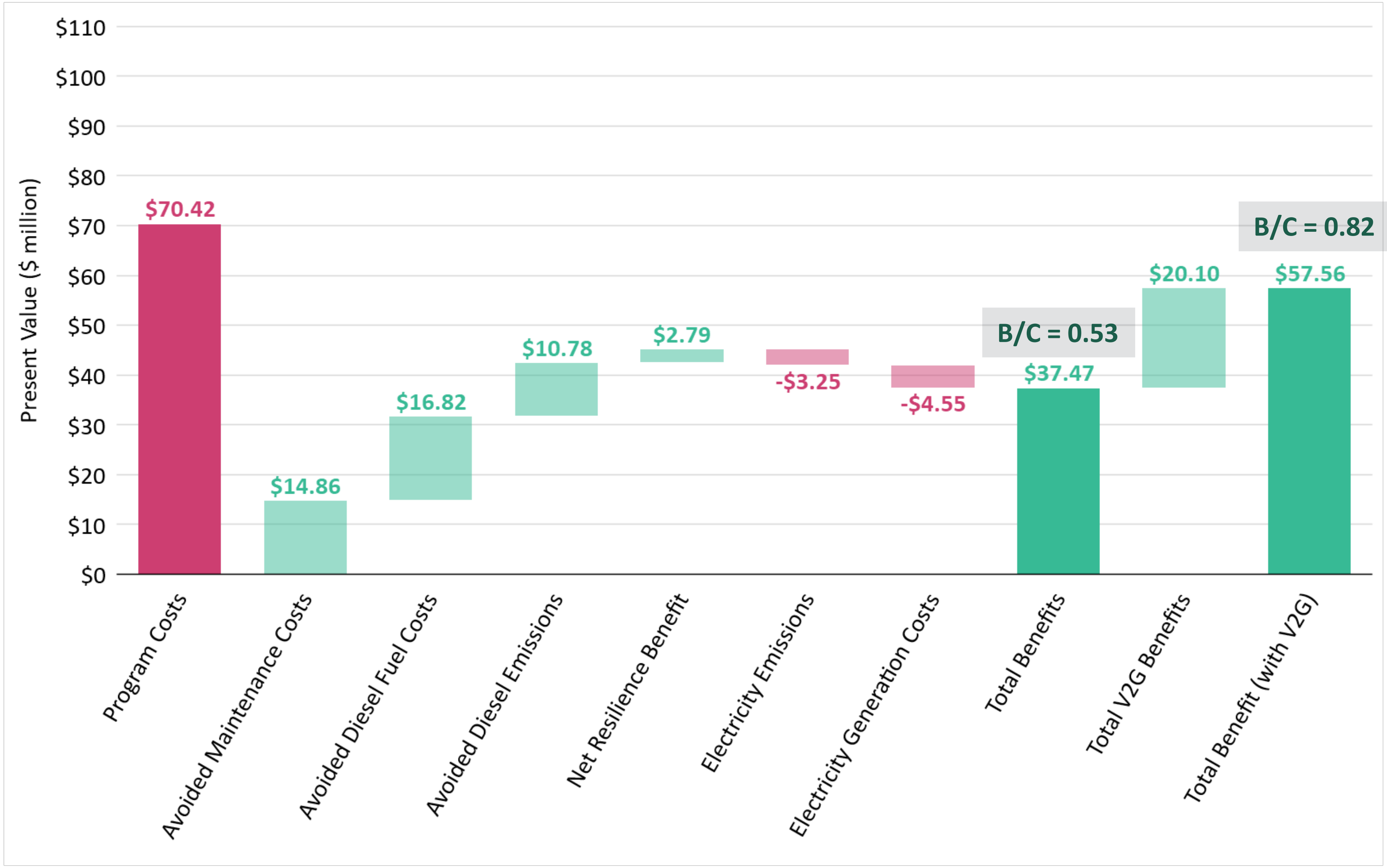
Input	Purpose	Source
Criteria Air Pollutant Emission Rates from Fuel	To estimate avoided NOx, SOx, and PM2.5 emissions from burning fuel	EIA
Criteria Air Pollutant Emission Rates from Grid	To estimate added NOx and SOx from increased grid usage	PJM 2016-2020 CO2, SO2, and NOx Emission Rates
Value of Avoided Criteria Air Pollutant Emissions	To quantify economic benefits of reduced CAPs from fuel	NHTSA
Marginal Grid Carbon Emissions Forecast	To calculate marginal emissions due to increased electric load on an hourly basis	NREL Cambium
Diesel Carbon Emissions Coefficient	To calculate avoided carbon emissions from burning fuel	EIA
Diesel Fuel Prices	To estimate fuel savings from decreasing ICE fleet	AEO 2022 Reference Case
ICE School Bus Fuel Efficiency	To calculate gallons of avoided diesel from electrifying buses (assume **6.5 mpg**)	BGE
Incremental Maintenance Cost Savings	To estimate reduced cost of electric bus maintenance (assume **$0.37/mi** savings)	Argonne National Laboratory AFLEET Tool
Federal Tax Credits for Buses and Chargers	To subtract from the incremental cost of electrification (assume **$40,000/bus**)	IRA

Resilience Benefit

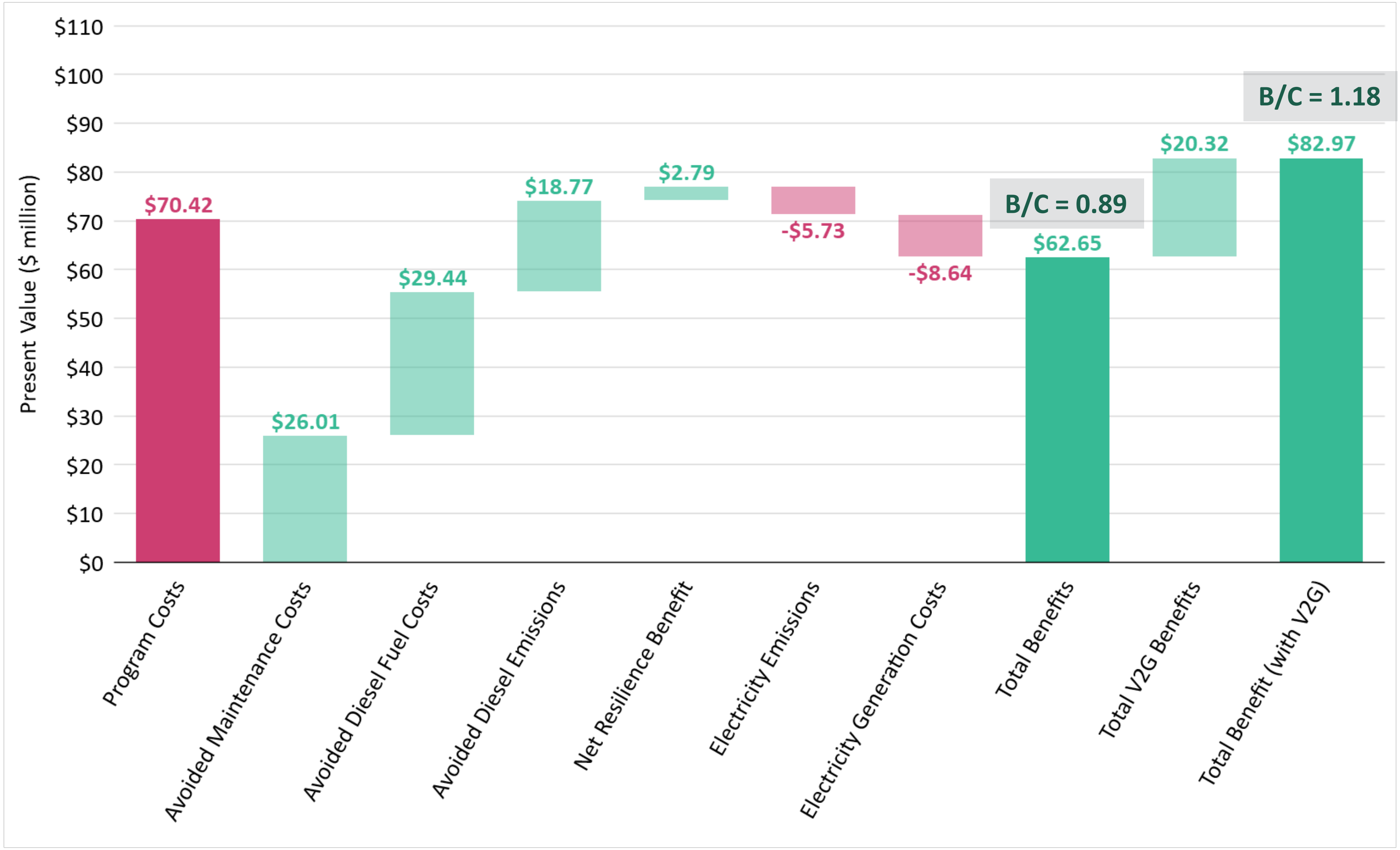
- We quantify the benefits incurred when school buses serve load during system-wide outages
  - We rely on the ICE Calculator and BGE-specific parameters from EIA Form 861 to estimate the cost per event and cost per unserved kWh associated with outages
  - We assume that each bus will power a community center or similar facility that serves 500 people
  - Each bus will be called up on to provide these capabilities once every 5 years
- Providing power during system outages increased the NPV of benefits by **$2.9 million**

Component	Ref.	Unit	Value	Source
# Buses Adopted	[1]	Buses	**248**	BGE Adoption Schedule
Probability of Bus Availability During Event	[2]	% of buses available per event	**20%**	Brattle Assumption
Customers Impacted	[3]	Customers/bus	**500**	Brattle Assumption
Cost/Event (Residential)	[4]	$/customer	**$15.34**	ICE Calculator for MD
Events/Year	[5]	# Events	**1**	Brattle Assumption
ANNUAL IMPACT	**[6]**	**$**	**$191,000**	**= [1] * [2] * [3] * [4] * [5]**

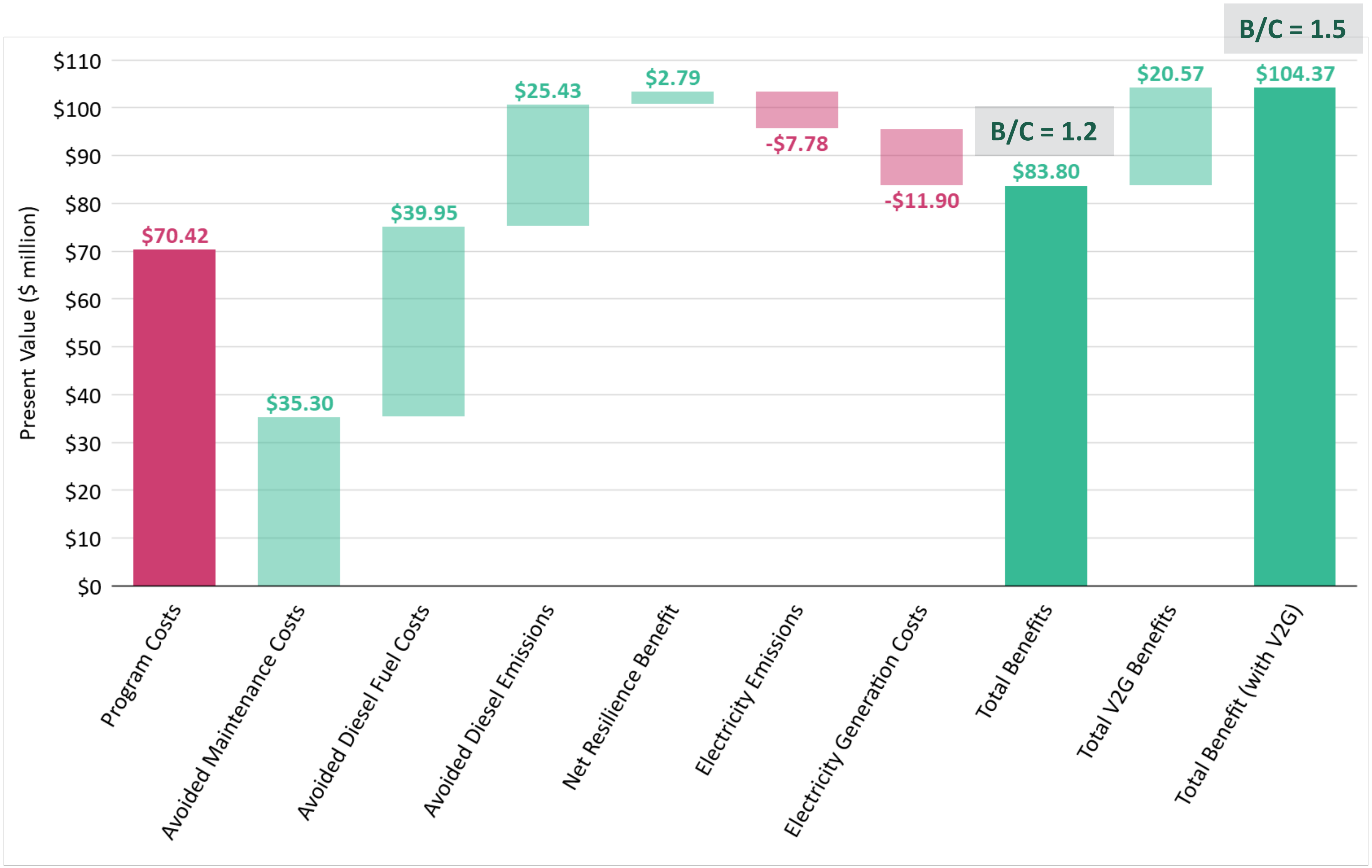
Benefit Cost Analysis Results – 80 Miles per School Day



Benefit Cost Analysis Results – 140 Miles per School Day



Benefit Cost Analysis Results – 190 Miles per School Day



Benefit Sensitivity Analysis

Input Assumption	Base Value	Sensitivity Value	80 VMT Case	140 VMT Case	190 VMT Case
Higher Diesel Fuel Prices	AEO Reference Case	AEO High Oil Price Case	+$10M	+$18M	+$26M
Higher Social Cost of Carbon	NY DEC	Proposed EPA Updates	+$5M	+$9M	+13M
Larger School Bus Cost Decline	3% per year	6% per year	+$2M	+$3M	+9M
Higher V2G Distribution Benefits	$30/kW-year	$90/kW-year	+$5M	+$5M	+$5M
Higher Air Pollutant Benefits	NHTSA Low Case	NHTSA High Case	+$0.4M	+$0.6M	+$0.8M

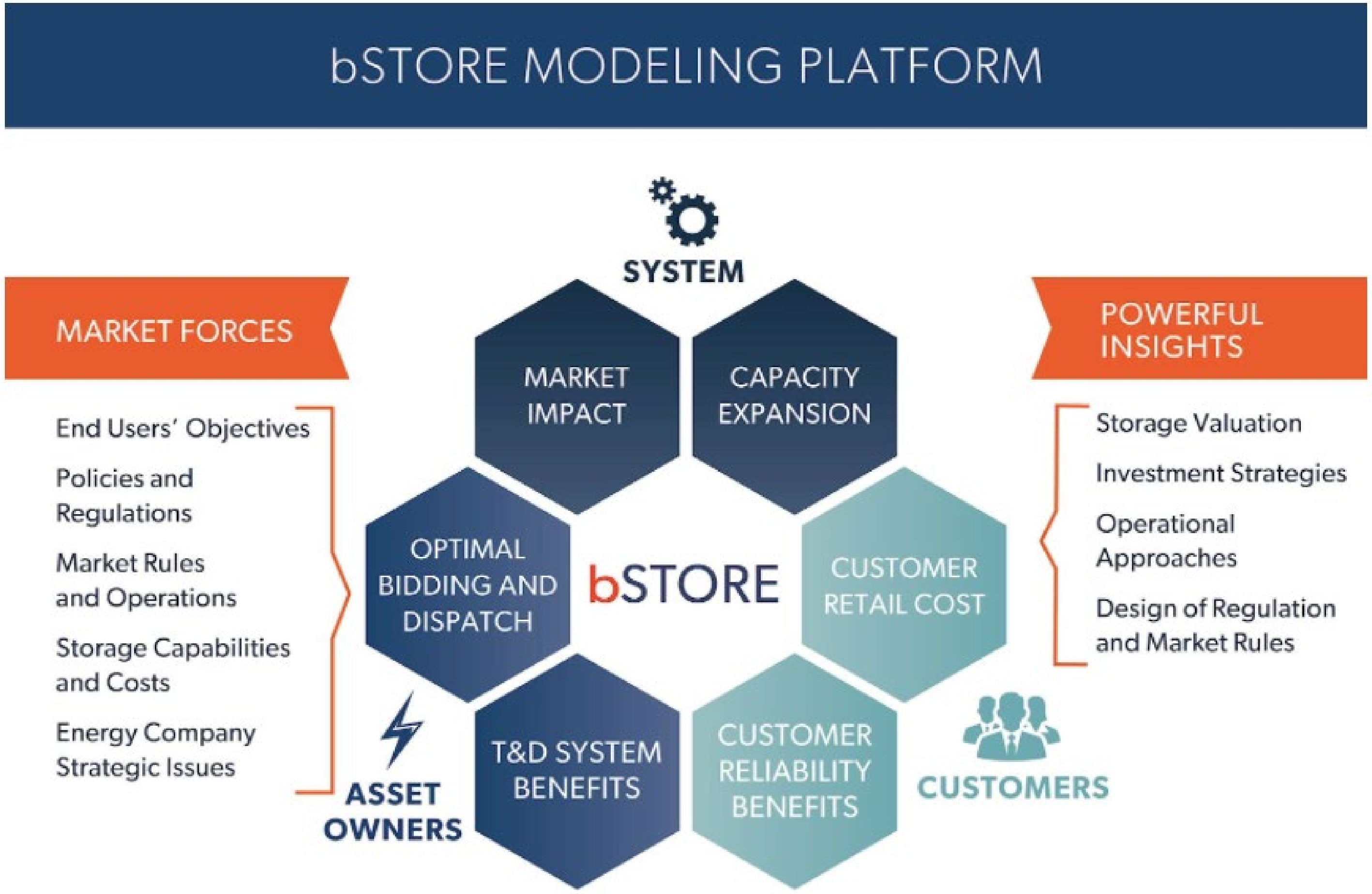
School Bus V2G Modeling

V2G Charging Profile

Bus vehicle-to-grid charging was done in bStore using the following assumptions:

- Assets have a 60kW or 100kW charger with a total battery capacity of 212kWh
- Round-trip efficiency of 85%
- VOM is set to $0
- State of Charge Assumptions
  - The min state of charge during the start of each driving period is 100%
  - The min state of charge at any time is 100%
- Foresight
  - Perfect day-ahead market foresight
  - 6 hour real-time market foresight
  - Real-time energy look-ahead calculated as a blend of current real-time prices and following hour day-ahead prices to further simulate dispatch uncertainty into the real-time market
- Regulation capacity is determined in the day-ahead market and any dispatch is fixed in the real-time market

bSTORE Model Features



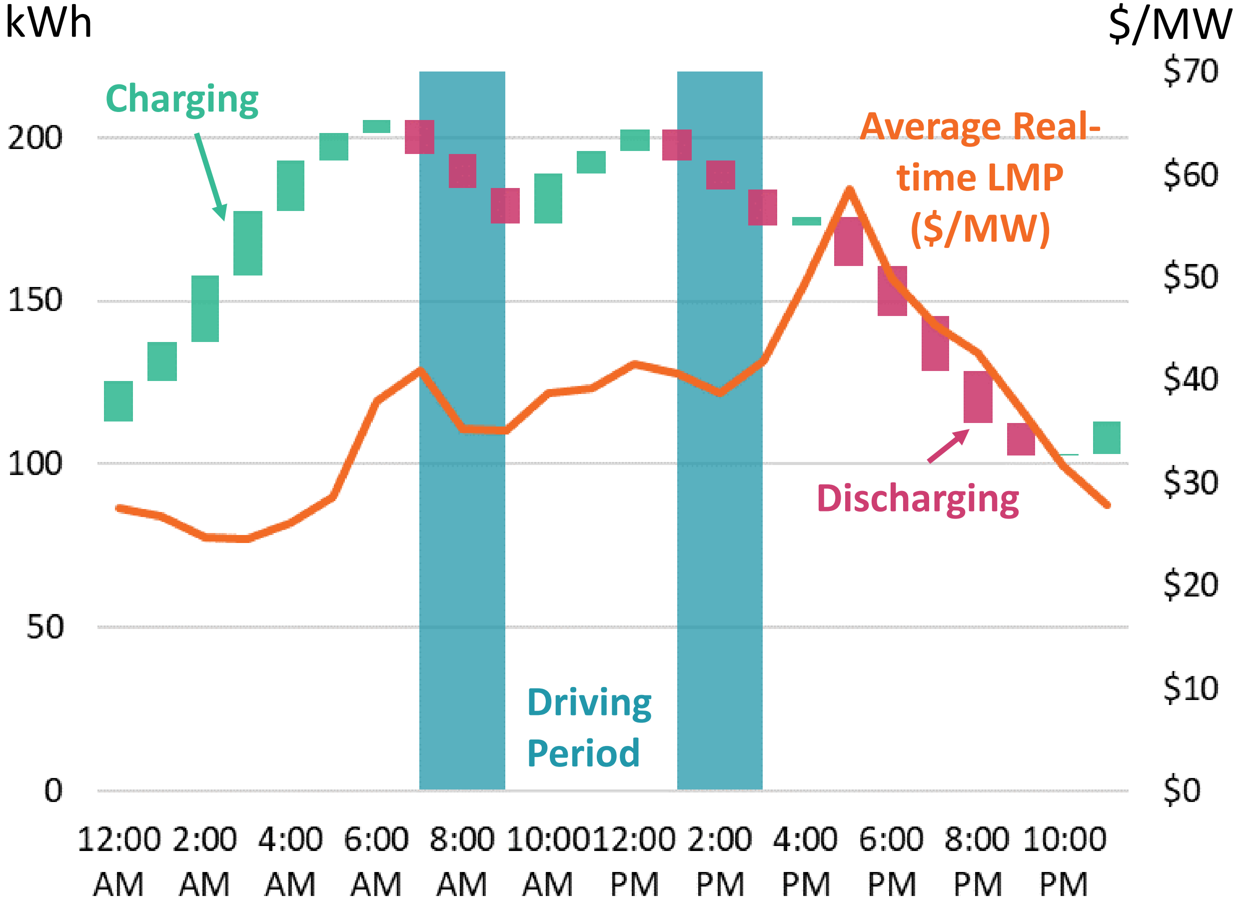
bSTORE Optimal Bidding and Dispatch Module:

- Optimal bidding and scheduling strategies under real-world market conditions
- Maximize wholesale market value of storage assets through co-optimization of day-ahead energy, ancillary services, and real-time energy markets under uncertainty
- Co-optimized wholesale market value, distribution system value, and customer retail rate savings
- Optimized bidding and scheduling of "renewable generation+storage" assets

V2G Energy Market Participation: Typical School Day

An electric school bus will behave like a stationary storage asset, charging during low price hours and discharging during high price hours

- As an additional constraint buses must drive during the morning and afternoon discharging off the grid and unavailable for energy market participation
- On an average school day the bus…
  - Charges to full capacity between overnight to take advantage of low prices
  - Is forced to discharge during driving hours as it moves along its route
  - Discharges during the evening during high price hours
- We see a similar pattern throughout the year, including summer months but without the driving periods

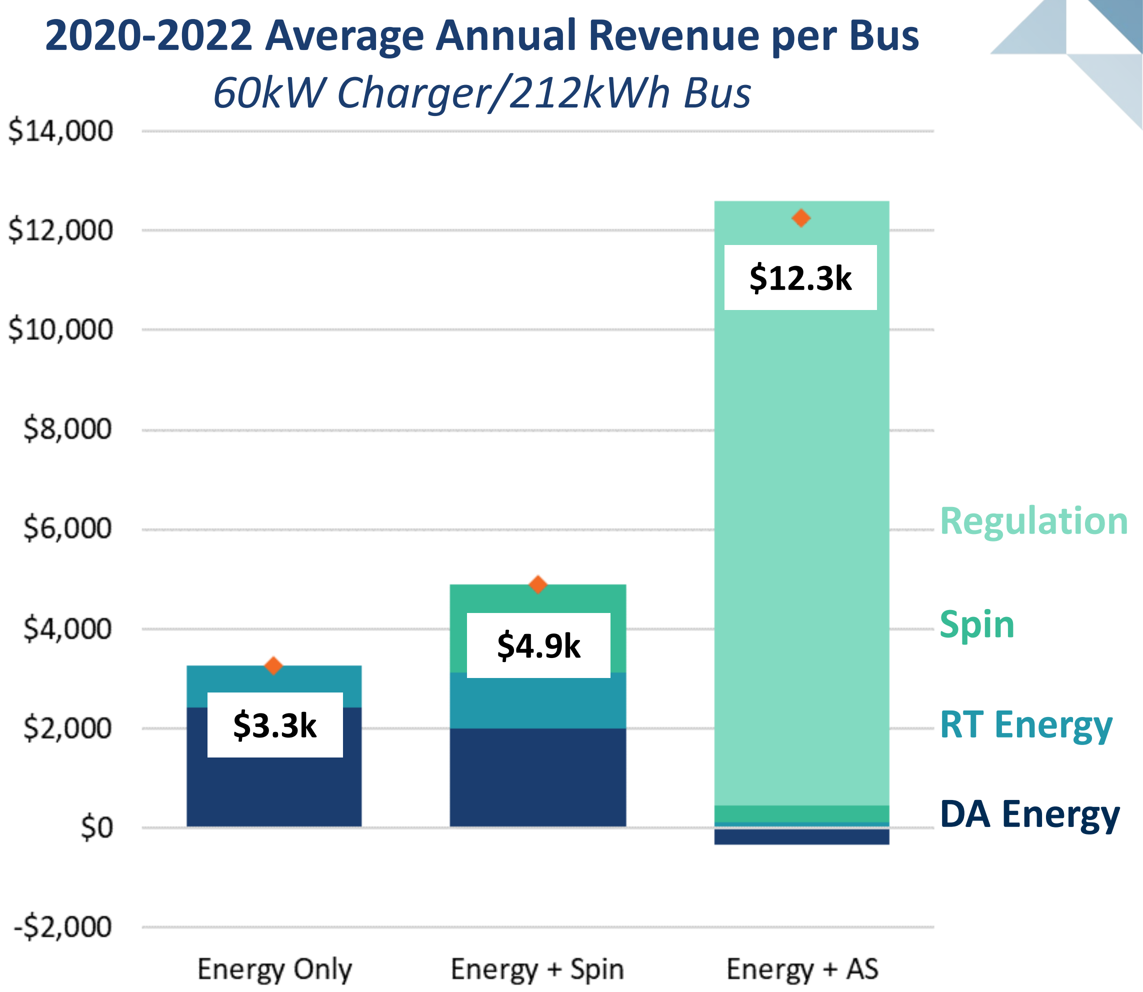


Market Participation Strategy

DA+RT Energy-only is a lower-bound on revenues that could be earned with a simple energy oriented market participation strategy.

DA+RT Energy + Spin highlights the increase in value associated with participating in the ancillary service market.

DA+RT+A/S illustrates the significant revenue opportunity currently seen in the regulation market. These revenues are unlikely to remain at historical levels as battery capacity comes online and overwhelms the comparatively smaller regulation market



Note: 100kW configurations earn around 55% more revenue but the relationship between market participation strategies is comparable

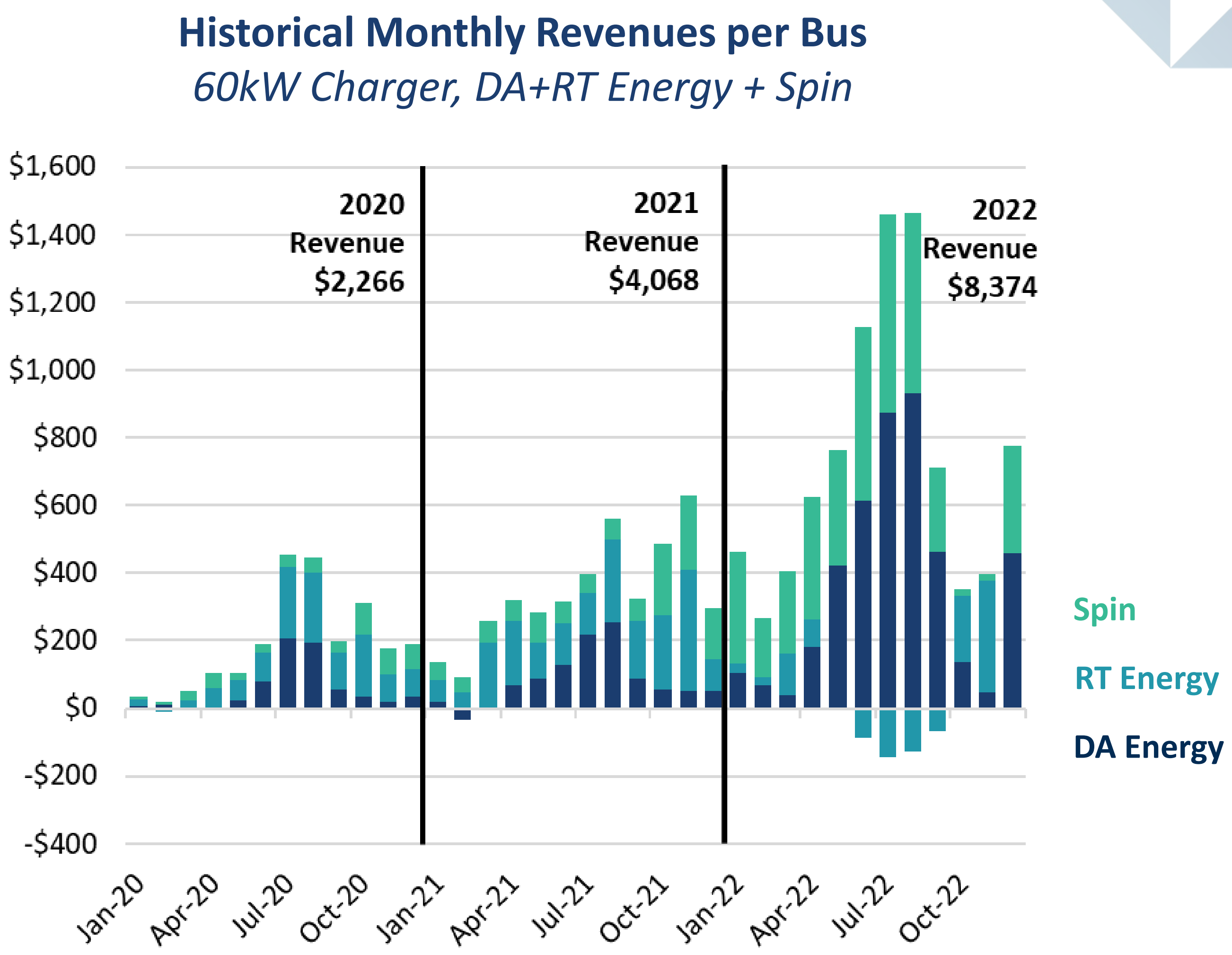
Inter and Intra Year Revenue Volatility

Monthly revenues, driven by the price volatility in each month, are typically higher during summer months during high load periods and tight supply periods but are lower during winter and shoulder months

- Revenues in the highest month can be 4x to 12x higher than revenues in the lowest revenue month

Year-to-year revenues can vary dramatically due to weather variability and other macro-economic conditions such as gas prices and long-term market trends

- Revenues in 2022 were on average 3x higher than they were for 2020 due to rising gas prices and winter storms

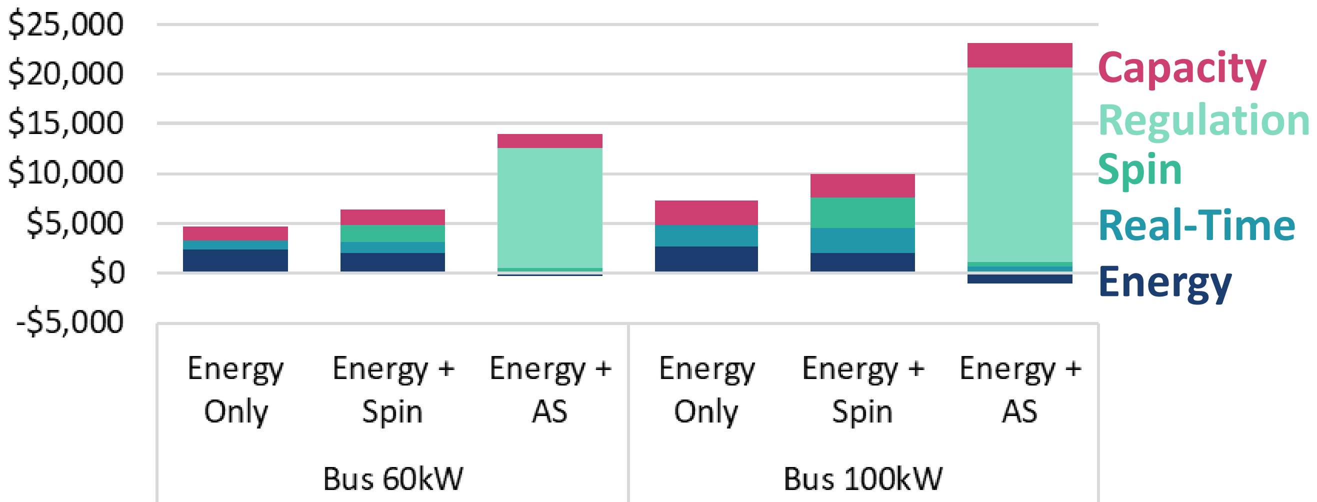


Revenue Estimates for All Cases

- An energy only market strategy historically could have earned between $1.7 to $5.2 thousand while participating in the regulation market would have earned $5.4 to $21.6 thousand – significantly more revenue than other strategies
  - The regulation market is currently very lucrative for storage assets, but is small and revenue will become dampened as storage capacity comes online across the next decade
- Bus configurations with a 100kW charger earn approximately 57% more than configurations with a 60kW charger
  - The larger charger allows the asset participate in a more narrow set of high-profit hours while a smaller charger spreads discharging across more less-profitable hours
- Capacity payments in the PJM capacity market could account for an additional $24/kW-year

2020-2022 Average Annual Revenue ($000s/bus)

Charger Capacity	Market Participation	Annual Revenue ($000s)			
		2020	2021	2022	Average
Bus 60kW (3.5 hours)	Energy Only	$1.7	$2.8	$5.2	$3.3
	Energy + Spin	$2.3	$4.1	$8.4	$4.9
	Energy + AS	$5.4	$9.8	$21.6	$12.3
	Capacity	$1.45	$1.45	$1.45	$1.45
Bus 100kW (2.1 hours)	Energy Only	$2.8	$4.7	$7.1	$4.9
	Energy + Spin	$3.6	$6.5	$12.5	$7.6
	Energy + AS	$8.7	$16.0	$33.9	$19.5
	Capacity	$1.45	$1.45	$1.45	$1.45



Distribution System Benefits

BGE advised that 50% of their system is summer peaking (hour ending 7 pm), 25% winter peaking and 25% summer and winter loading is roughly equal

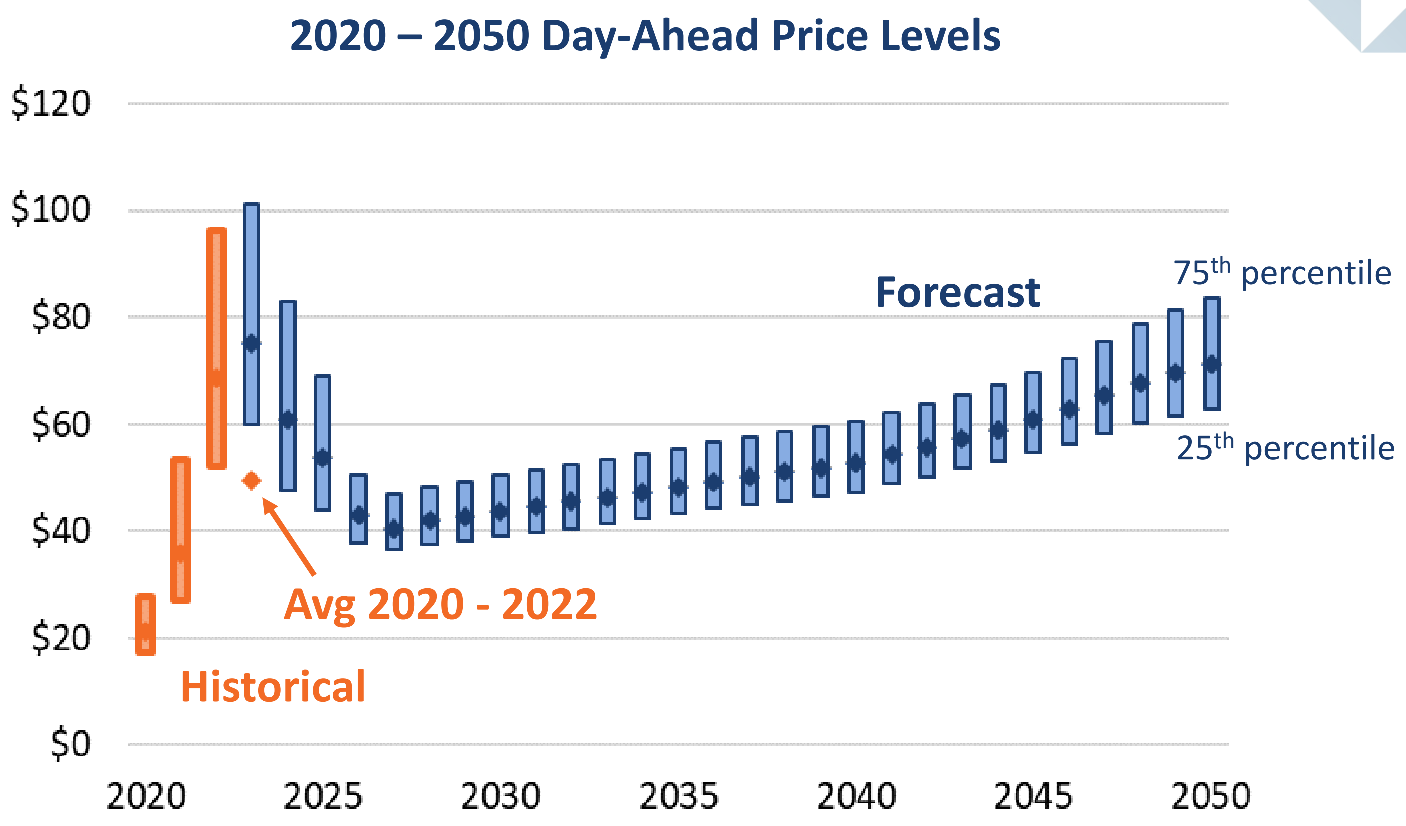
Distribution benefits are included in the Annual V2G revenues in the BCA

- Assume system-wide avoided distribution costs of $30/kW-year (based on prior BGE work); expect the value to be 2-3x higher if buses located on feeders that would require upgrades
- Assume 60 kW charger per bus
- De-rate capacity by 50% to account for portion of system peaking in the summer
- Assume limited impact on other V2G benefits as the resource will be called upon infrequently to avoid peak demand

Increases NPV of V2G revenues by **$2.5 million**

Historical Price Comparison

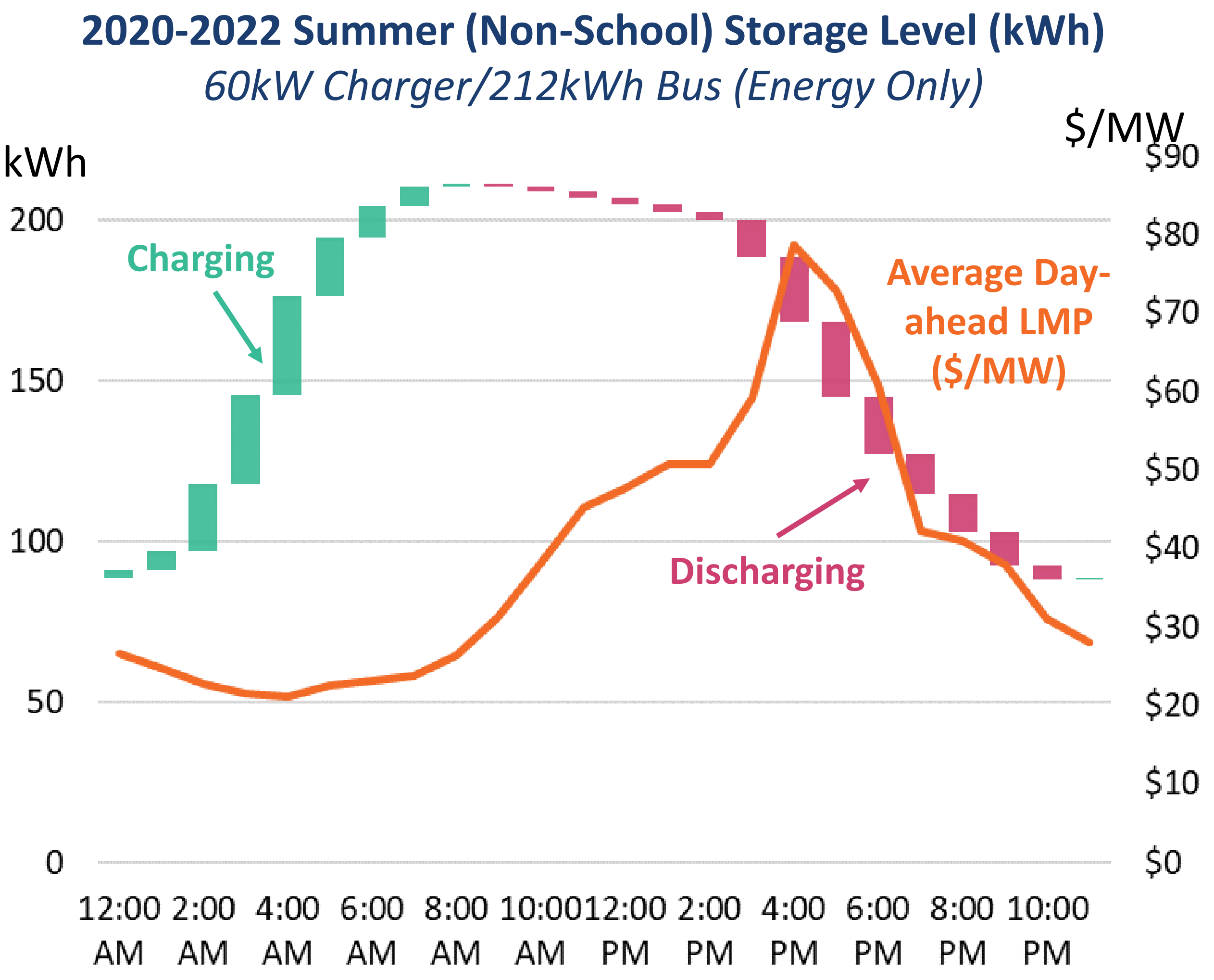
- Price forecasts suggest that near-term prices will more closely resemble prices in 2022 and longer term forecasts remain at or above price levels seen in 2021
  - Future battery revenues may trend more towards higher revenues seen in 2021 and 2022
  - While volatility is lower in later forecast years, volatility is frequently muted in price forecasts



Note: Forecasts are Cambium prices blended with forward energy prices. Inflation is assumed to be 2.5%

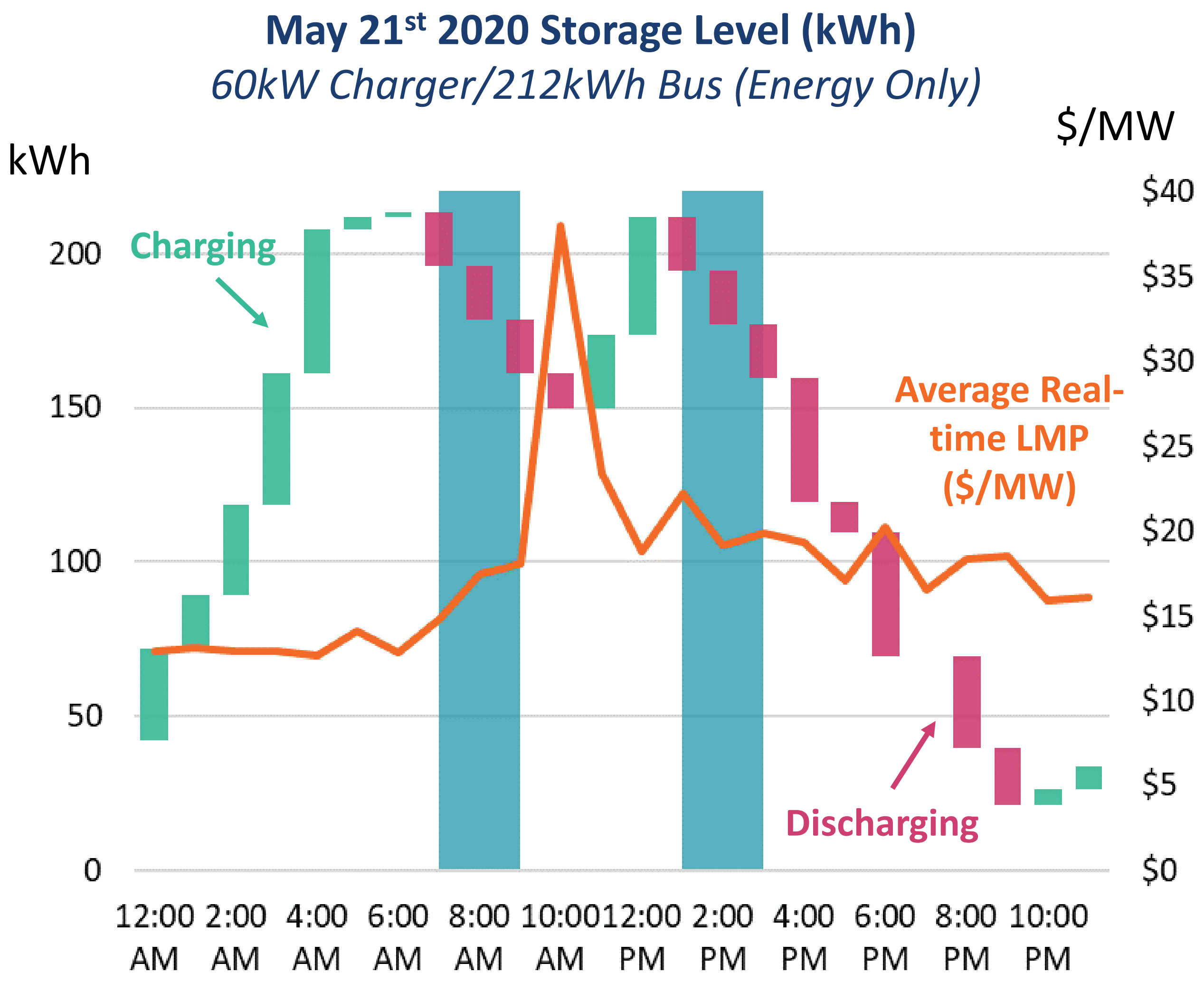
Appendix

2020-2022 Summer (Non-School) Storage Level (kWh)

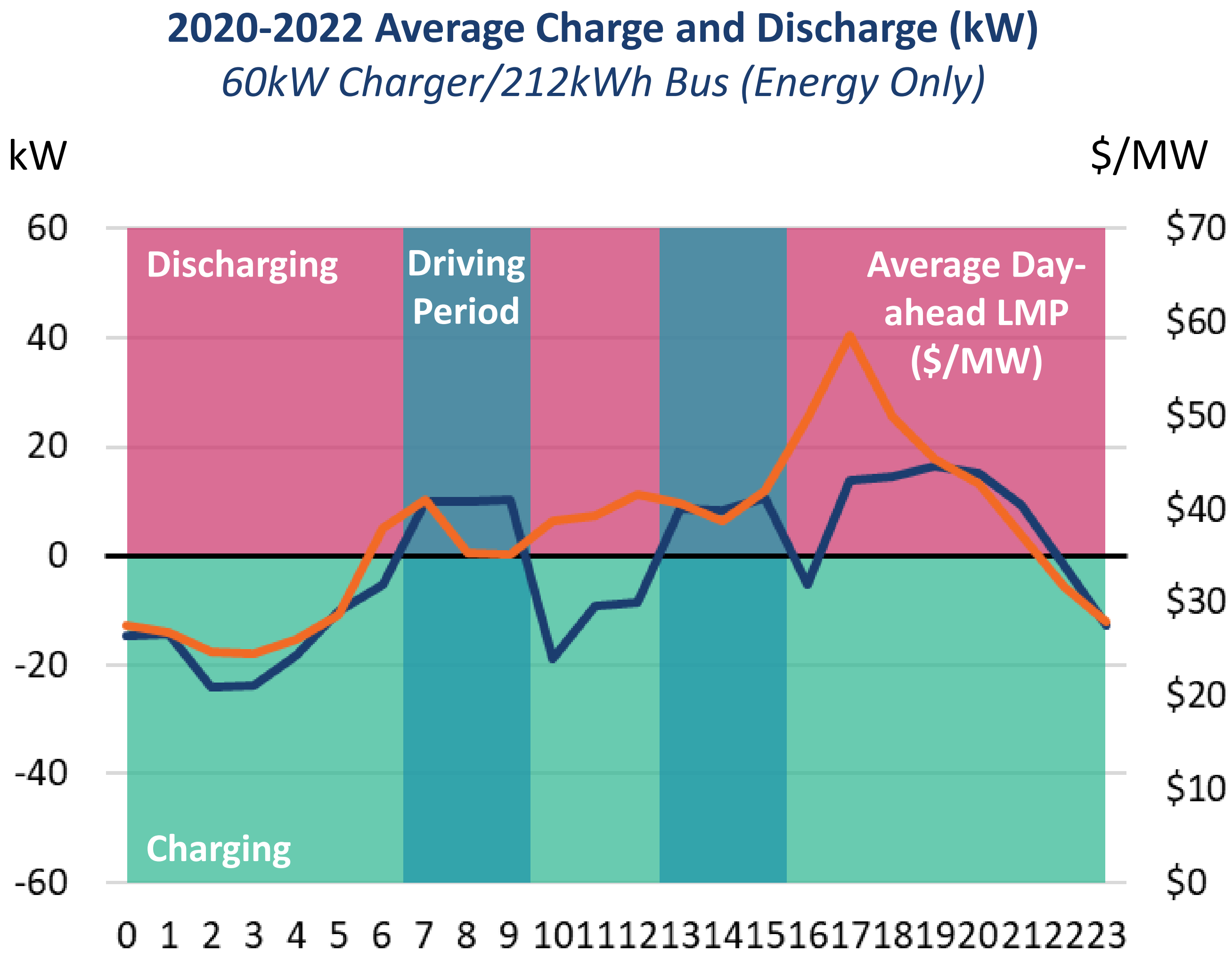


APPENDIX

Illustrative Day (May 21st 2020) Storage Level (kWh)



2020-2022 Average Charge and Discharge (kW)



Energy and Capacity Price Assumptions

We rely on NREL's 2021 Cambium data – a publicly-available long-term forecast tool that assembles simulated hourly costs, emissions and operations by balancing areas across the U.S. electric sector

NREL Cambium data sets are the most comprehensive and granular set of forecasts that are relevant to our analysis, which allows for internal consistency across the various value streams that are considered in the analysis. They have also been validated by other researchers.

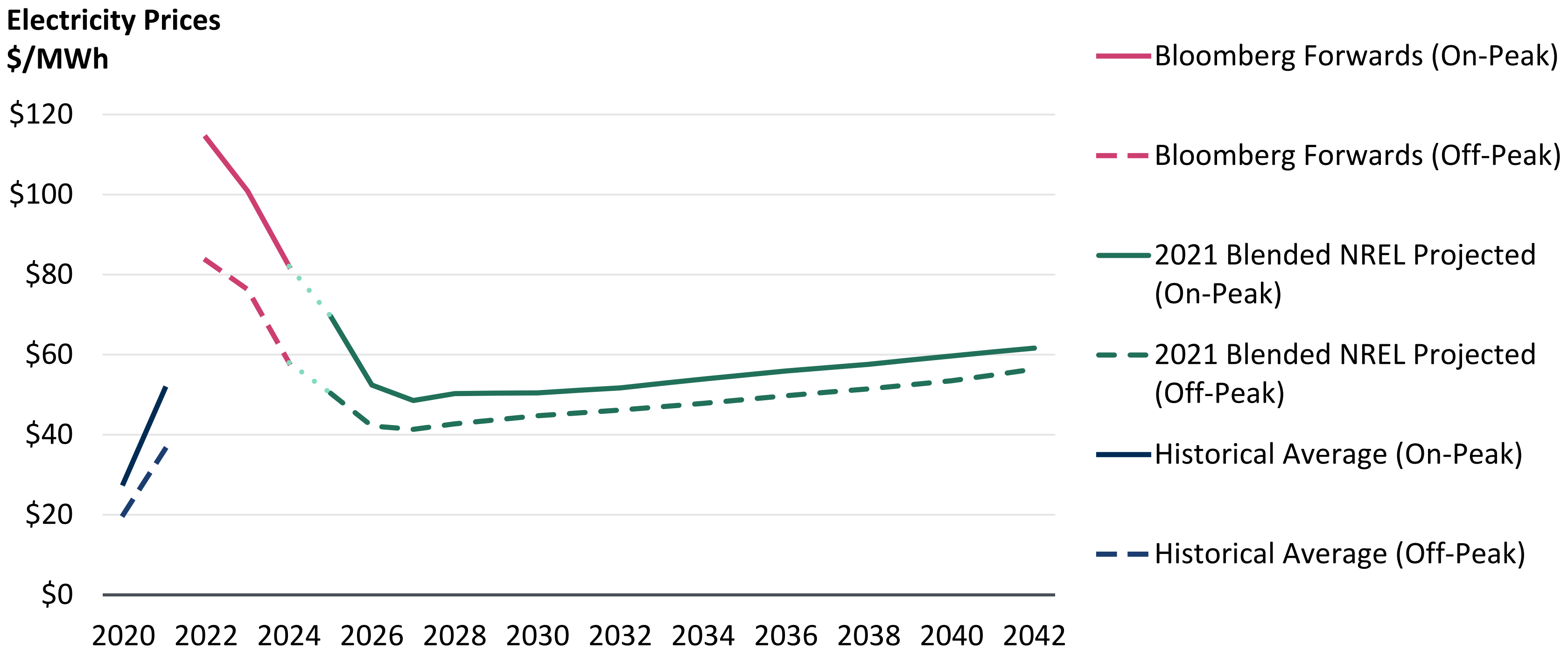
We use NREL's Mid-Case as the basis for our assumptions. The Cambium Mid-Case is a reference forecast, with NREL's default assumptions for load growth, resource mix, fuel costs, etc. They use existing carbon polices to forecast renewable penetration in future years.

NREL Cambium Updates – Energy Prices

We blend in Cambium data with Bloomberg PJM BGE Zone forward prices to develop final energy price projections. We rely on Bloomberg data through 2024, blend Cambium and Bloomberg data in a 25/75 split for 2025, a 75/25 split for 2026, and rely on Cambium forecasts thereafter.

To the blended Bloomberg data, we make the following adjustments to reflect prices in the BGE Zone:

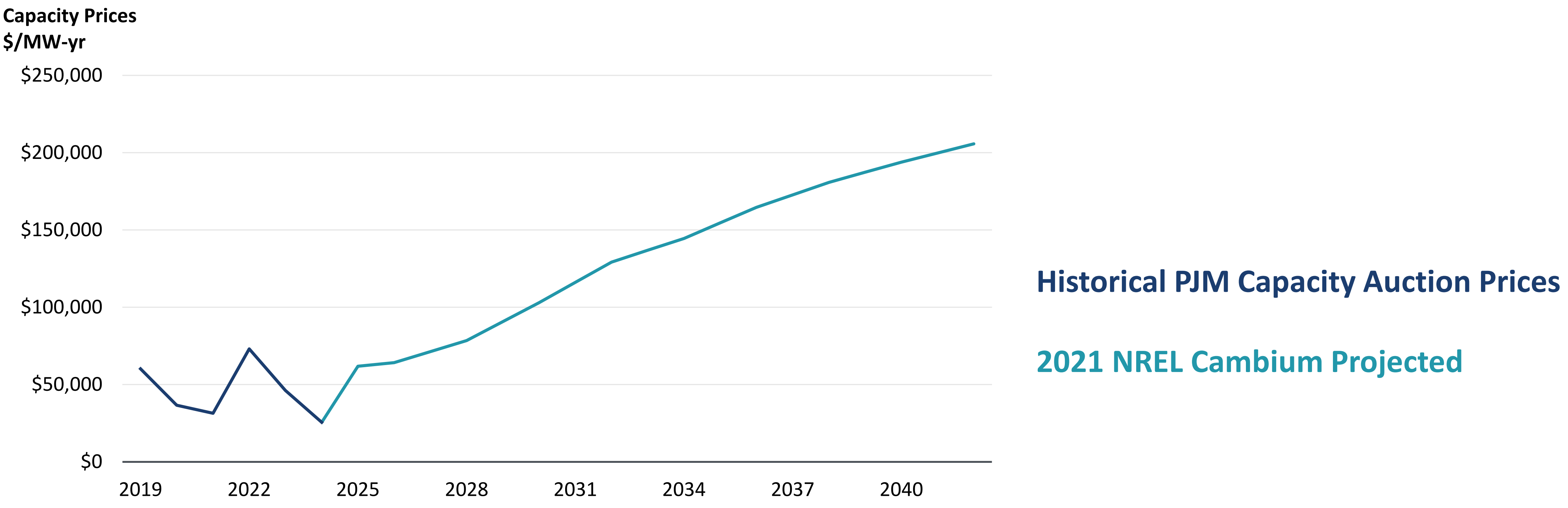
1) **Risk Factor** (10% applied to total price)
2) **Load shaping factor** (1.06 applied to energy)
3) **Ancillary services adder** (2021 value of $1.24/MWh inflated for future years)



NREL Cambium Updates – Capacity Prices

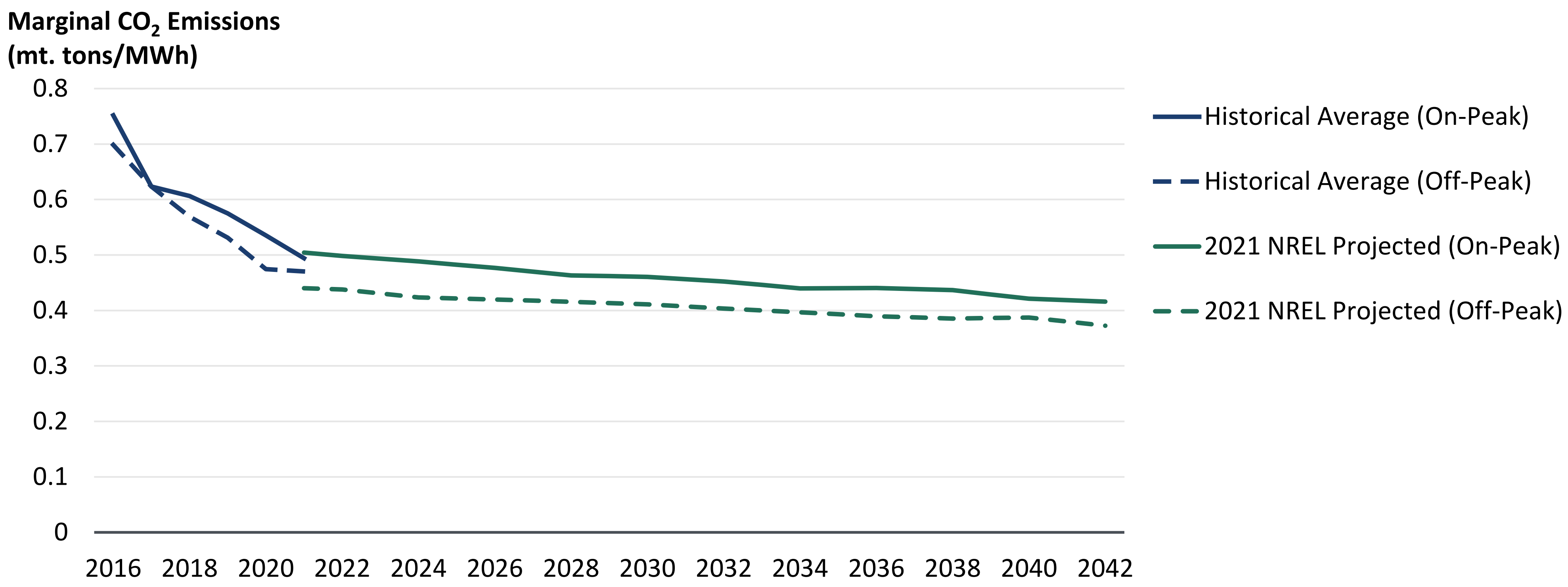
We used the most recent PJM BRA results for short-term capacity prices (through 2024), then relied on NREL Cambium's projected prices thereafter

- We attribute the increase in NREL's projected prices to their considering a greater swathe of new generating resources in their modelling – including nuclear SMR, CCS, etc.



Cambium Updates – Marginal Emission Rates (MERs)

The marginal CO2 emissions rate benchmarks trends from NREL's Cambium against recent historical PJM emissions in 2021. Emissions trend downward slightly as fossil generation retires and renewable generation increases.

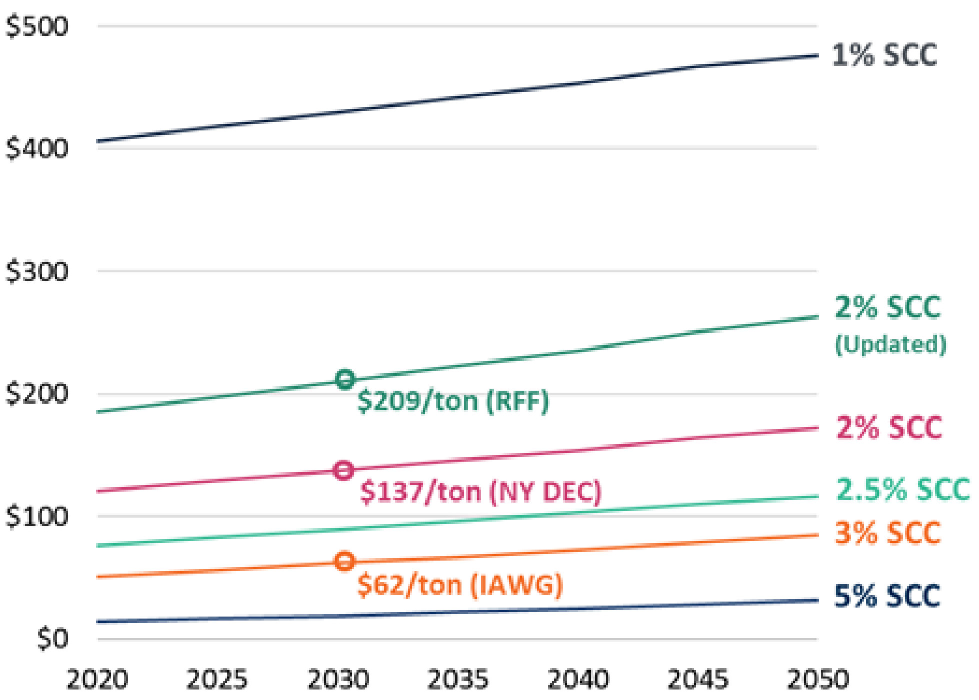


Social Cost of Carbon

We use the SCC associated with a 2% discount rate, based on the "Establishing A Value of Carbon" study by NYS DEC

- This decision is supported by recent RFF studies, which are supportive of the 2% discount rate based on updated analysis of available market data
- The SCC value associated with 2% discount rate was recently adopted by the New York Department of Environmental Conservation (NY DEC) for estimating the costs of changes in GHG emissions
- We test a sensitivity on the SCC using updated guidance from RFF as of 2023.

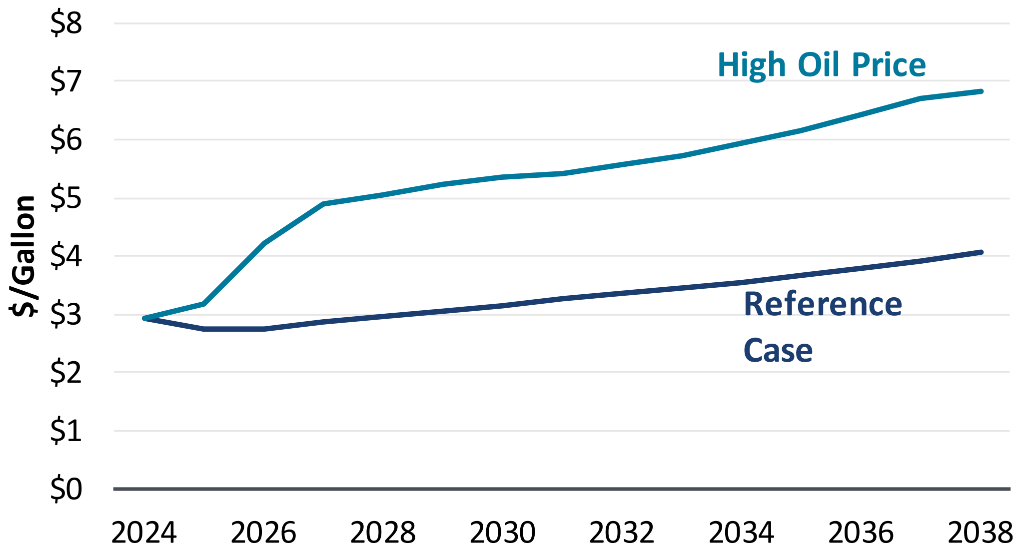
Social Cost of Carbon (2020$/metric ton)



Source: Brattle 2022; New York State (NYS) Department of Environmental Conservation (DEC), "Establishing a Value of Carbon" (2021)

Diesel Prices

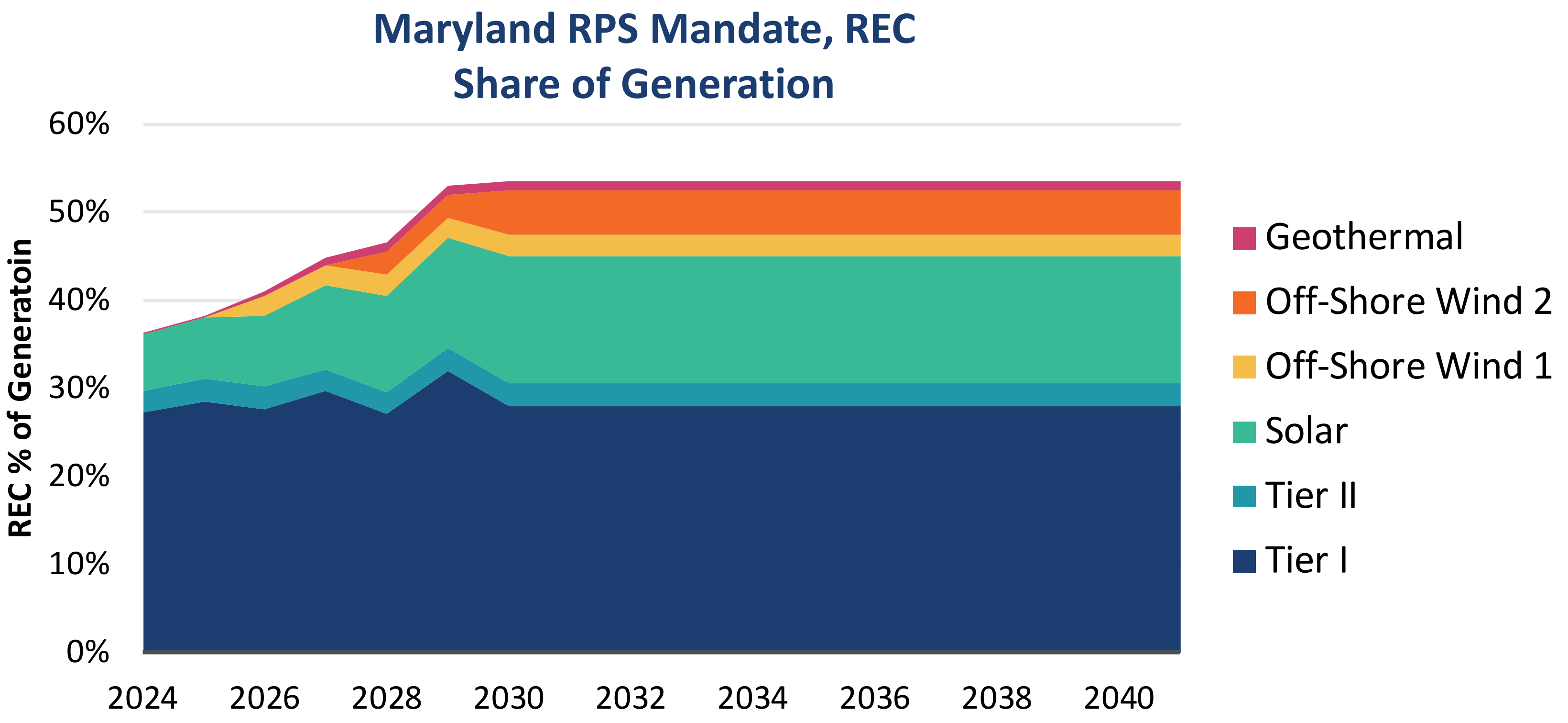
- We utilize near-term futures and blend into long-term EIA Annual Energy Outlook wholesale fuel price forecasts.
- For 2024, we rely solely on NY Harbor Ultra-Low Sulfur Diesel (ULSD) futures. In 2025 and 2026, we blend the near-term futures and long-term EIA forecasts using a 75%/25% and 25%/75% split, respectively. We rely on EIA projections 2027 and onward.
- We test a sensitivity using the AEO High Oil Price scenario as well with fuel prices that are
- In both cases, we add the applicable Federal Tax series to our prices.



Maryland RPS Mandate

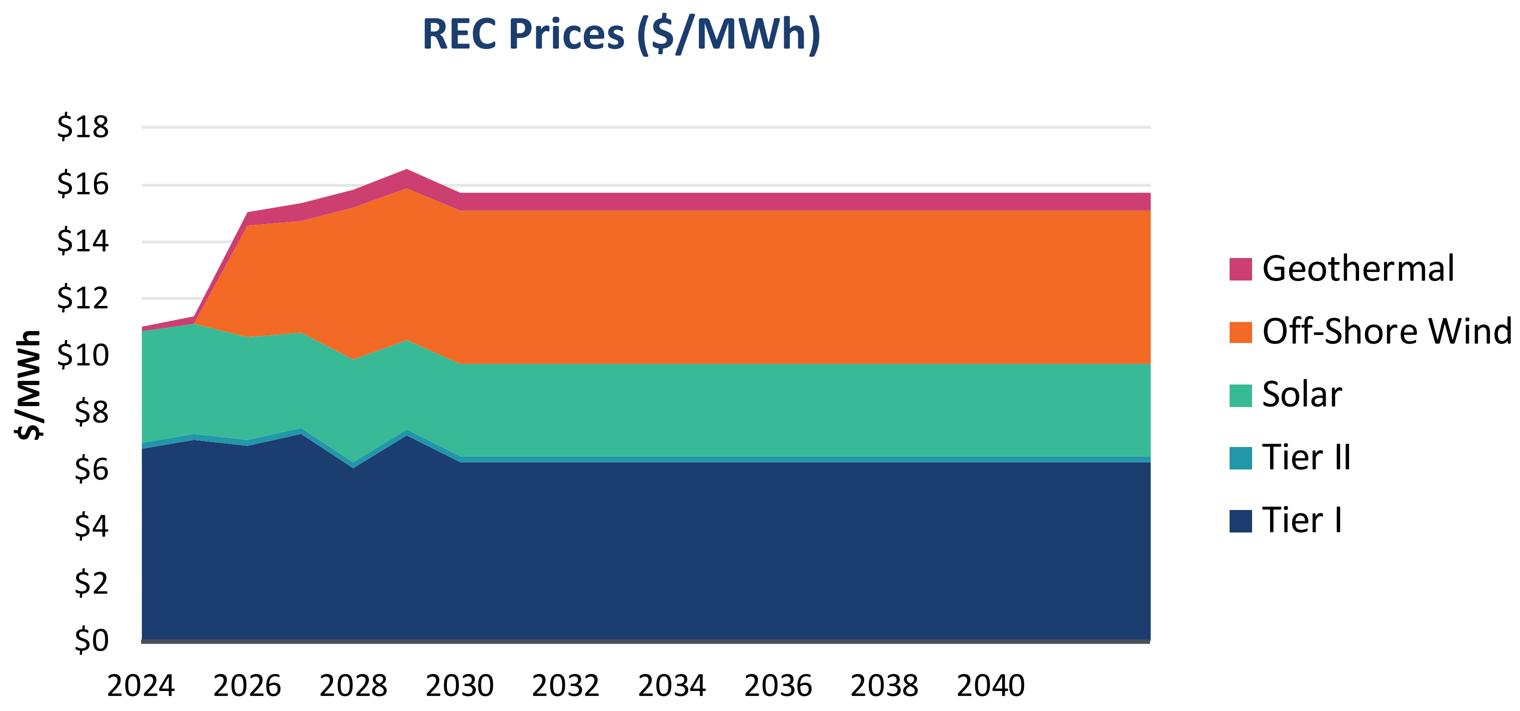
We rely on the MD RPS Mandate for our assumption regarding the share of future generation that will be met by non-emitting resources in BGE's service territory

- BGE provided data through 2030; we assume these values remain constant in the subsequent years



REC Prices

REC price forecasts are provided by the BGE team. RECPrices are used to quantify the added cost of procuring non-emitting resources to meet the RPS requirements detailed on the previous slide.



REC Profiles

Although the MD RPS mandate calls for generation from several types of non-emitting resources in the future, most of this requirement is currently being met through solar and wind generation.

- Extract solar and wind generation profiles from NREL's Cambium dataset to create an average annual REC profile.
- Assume a 60/40 blend of solar to wind in each hour to create a weighted generation profile