Vehicle-Grid Integration Valuation Studies

Funded by GM Energy

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Energy+Environmental Economics

Table of Contents

+ **Overview**
  - Overview of VGI study
  - Preview of key findings and recommendations
+ **Project 1: Grid and Customer Value of V1G and V2G**
  - Grid value results
  - Comparison to previous project
  - Customer value results
+ **Project 2: Customer Value of V1G and V2G by DER Configuration**
  - Customer value of charge management and V2H
  - Customer value of charge management based on V2G pilot program
+ **Conclusions & Key Takeaways**

Study Overview

Project 1

LDV VGI Value

- **This project quantifies the value of different EV load management strategies + V2G to the grid as well as to the customer**
- **Grid Value**
  - In all regions, what is the value of TOU management, V1G, and V2G compared to baseline charging profiles? How does residential ESS value compare?
- **Customer Value**
  - For customers of three select utilities, what are representative customer bill savings when their charging is TOU managed, V1G, and V2G compared to baseline charging profiles?

Project 2

Battery Storage vs. VGI

- **This project compares the value to the customer of different DER configurations paired with EV management and V2G**
- **Customer Value**
  - For customers of a select utility, what is the value to a representative customer of managed and V2G charging alone compared to being paired with storage and solar?

Key Findings

1. **VGI offers substantial system value with a $7B market size by 2030.** V2G provides the highest system value, driven by the ability to respond during high-value grid hours and support reliability needs.
2. **Capacity and T&D deferral make up most of the total grid value**, but these value streams remain difficult for customers to access under current programs.
3. **Energy arbitrage value varies widely by region**, with solar-rich and constrained markets offering the strongest and most predictable opportunities.
4. **Regulatory and program design barriers limit monetization today** - retail export structures and pilot rules prevent customers and utilities from capturing the full V2G value.
5. **Customer benefits depend heavily on rate design and export compensation**, with managed charging delivering consistent savings while V2G economics vary by utility.
6. **Stacked DERs amplify value**, with home storage providing the most consistent bill reductions and EV flexibility offering additional, but availability-constrained, benefits.

Conclusions and Recommendations

+ Cost is a barrier to implementing V2G at scale

- Many V1G/V2G programs are in pilot program phase and may be overpaying customers relative to realized grid benefits. Much larger scale is necessary to justify high setup and enabling technology investment.

+ Program design is another barrier

- Paying retail rates for exports perpetuates NEM cost-shift
- Charging at retail and discharging at wholesale is not economic for customers

+ Potential future program design

- Customers remain on retail TOU rate for consumption behind the meter
- Utility dispatch V2G provides additional grid value – shared benefits between utility and customer
- Via monthly incentive or hourly adder

Project 1:

US-wide Grid and Customer Value of V1G and V2G

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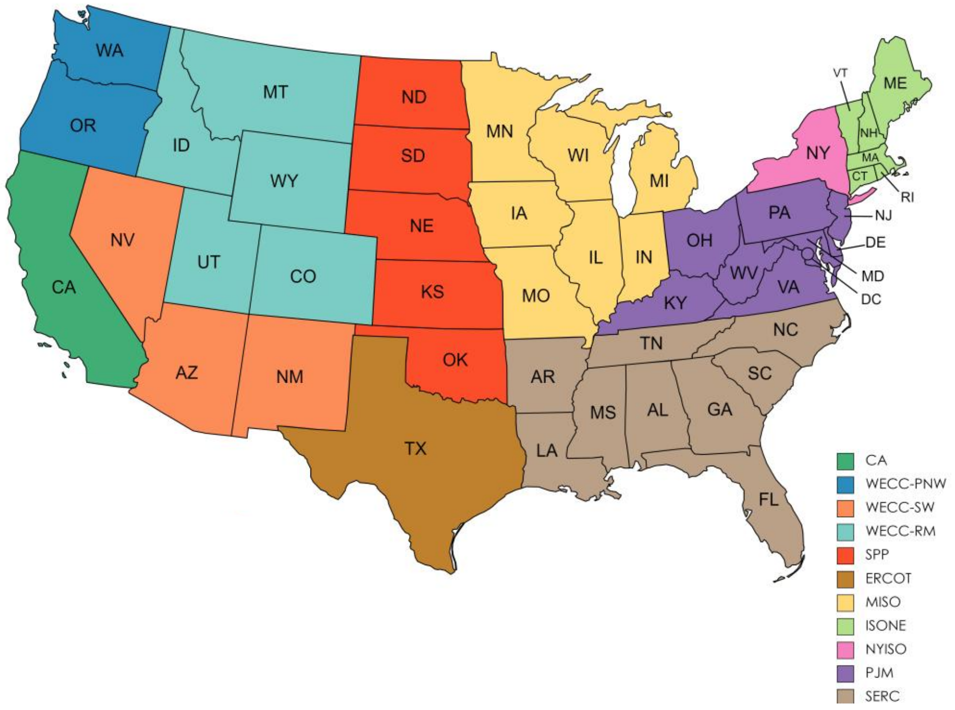
Regional Analysis Objectives

- **Goal: Evaluate V1G and V2G grid and customer value across US markets.**

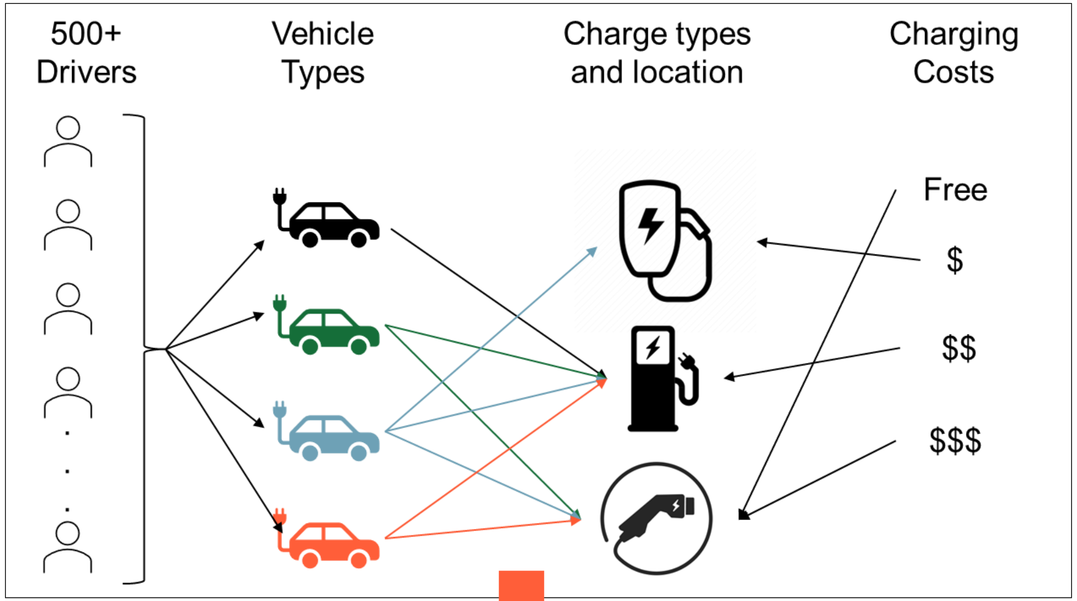
- E3 used our in-house **RESHAPE-EV** model to develop baseline charging shapes and VGI shapes to evaluate the potential load response of vehicles to market signals in each region.
- E3 used our in-house regional **market price forecasts** for energy, capacity, and transmission and distribution (T&D) for 2030.
- The per vehicle grid value of VGI in each region was combined with a regional adoption forecast from E3's **PATHWAYS** model to estimate the total national market size.

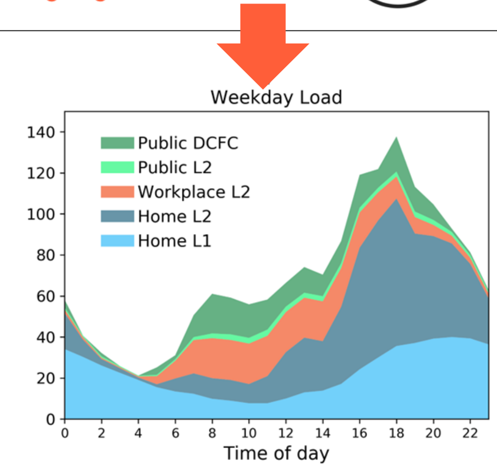
Regions modeled



Creating Custom EV Charging Load Shapes

E3's RESHAPE-EV model generates **diversified** EV charging load shapes based on the **driving patterns of thousands of drivers** and characteristics of the driver population, including **charger access**, **vehicle types**, and **cost** to charge vehicles in various locations.





E3's tool is leveraged to model custom scenarios of EV charging load shapes:

- **Unmanaged charging** load shapes are created based on drivers' travel needs and access to different charger types
- **Managed charging** load shapes are then developed by optimizing load in response to price signals from time-of-use rates
- **V1G** load shapes are optimized against wholesale energy prices
- **V2G** load shapes are optimized against wholesale energy prices and allow vehicle discharge to the grid

Project 1: Grid Value

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Model inputs and methodology

Input	Description
Driving Profile Data	When and where vehicles travel + charging availability.
Demographics	Mix of vehicle types and home/work/public charging access.
Charger and EV Attributes	Range, efficiencies, charger power.
Driver Facing Charging Costs	Drivers shift away from higher-cost charging, when possible, with managed charging behavior.
Energy, RA, and T&D Prices	Market prices for grid services ($/MWh)

[VGI Charging Profile
–
Baseline Charging Profile]

x

Energy, RA, T&D Prices

= VGI Value

Key Inputs

Charger Parameters

Charger	Charger Power (kW)
Home L2 – Low	11.5
Home L2 – High	19.2
Workplace L2	7.2
Public L2	7.2
Public DCFC	200

Vehicle Parameters Reflecting GM EVs

	Battery Size	Consumption	DC rating	Population Split
	kWh	kWh/mile	kW	%
Electric LDV: Crossover	100	0.34	180	60%
Electric LDV: Large Vehicle/Truck	200	0.55	350	40%

Management Assumptions for Per-Driver Results

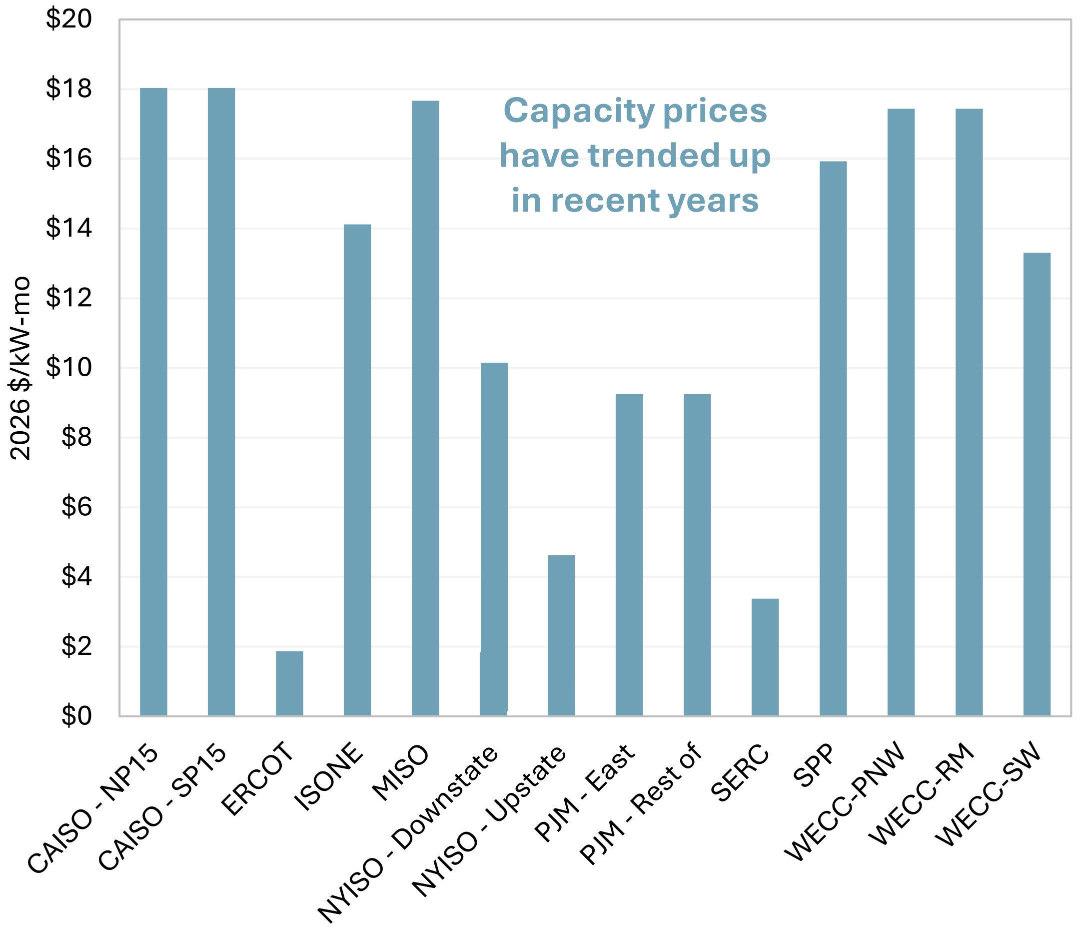
Per Driver Charging Behavior	
Baseline	Blend of 50% unmanaged, 50% managed to TOU rates
V1G	Charging managed against wholesale prices, within driving constraints
V2G	V2G against wholesale prices, within driving constraints

Management Assumptions for Market Analysis

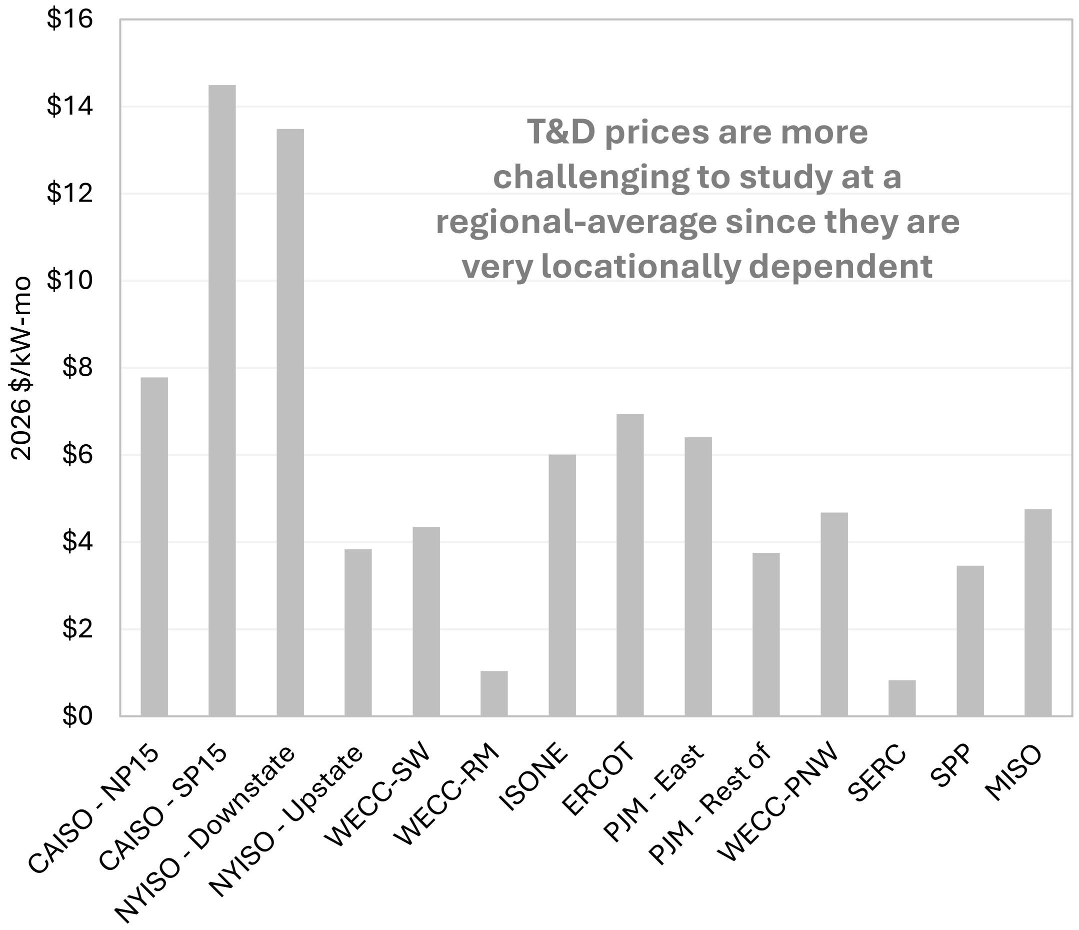
Share of BEVs by Charging Behavior	
% Unmanaged	23%
% TOU	23%
% V1G	30%
% V2G	25%

Capacity and T&D Prices – E3 Market Price Forecasts

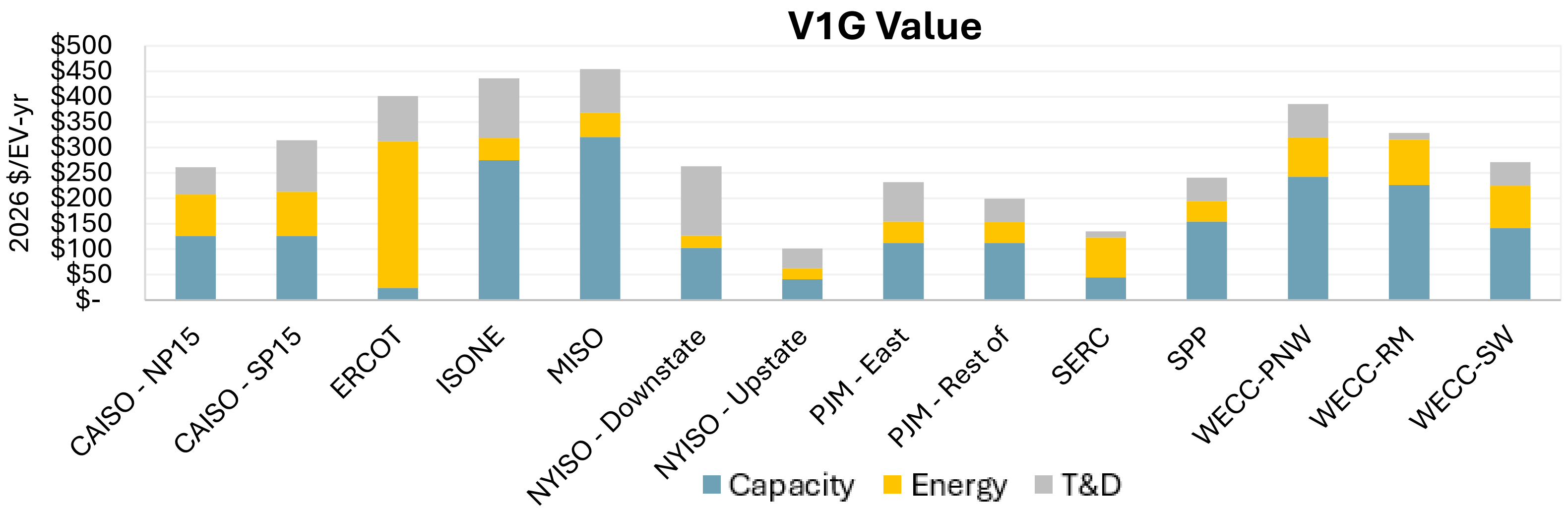
2030 Capacity Prices (2026 $/kW-month)

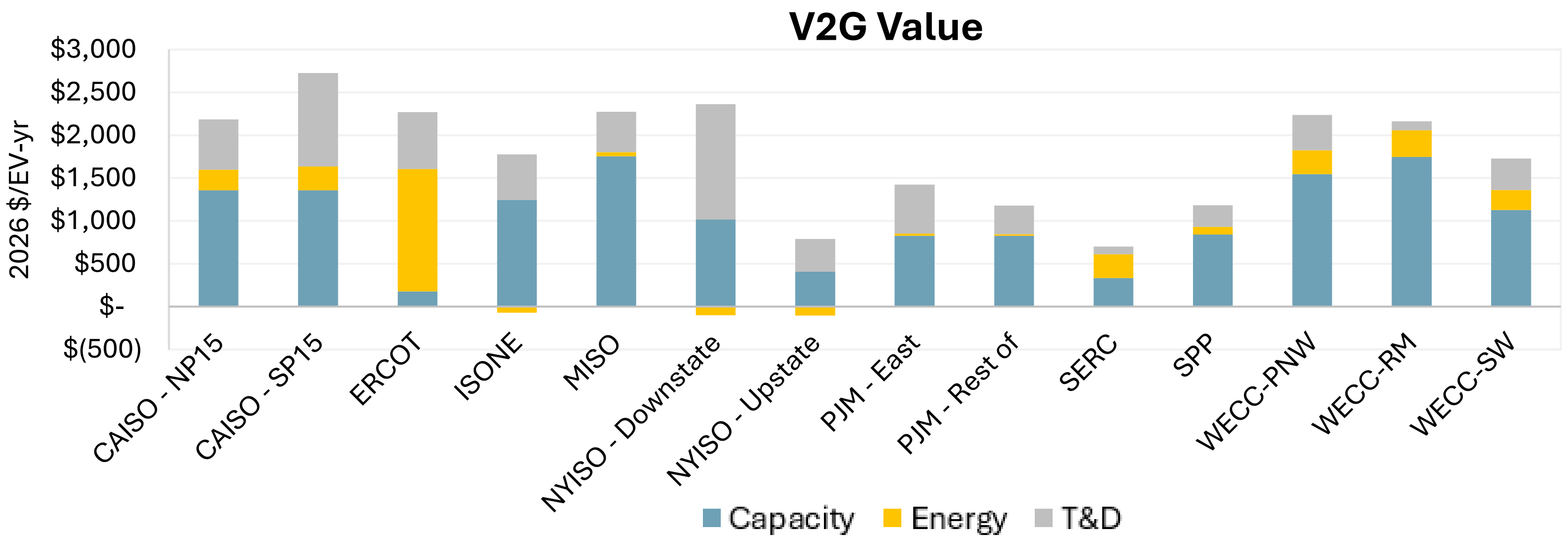


2030 T&D Prices (2026 $/kW-month)



Per Vehicle Grid Value by Region in 2030





+ **V1G value ranges from $100/vehicle-year to $450/vehicle-year in 2030 relative to baseline EV charging.**

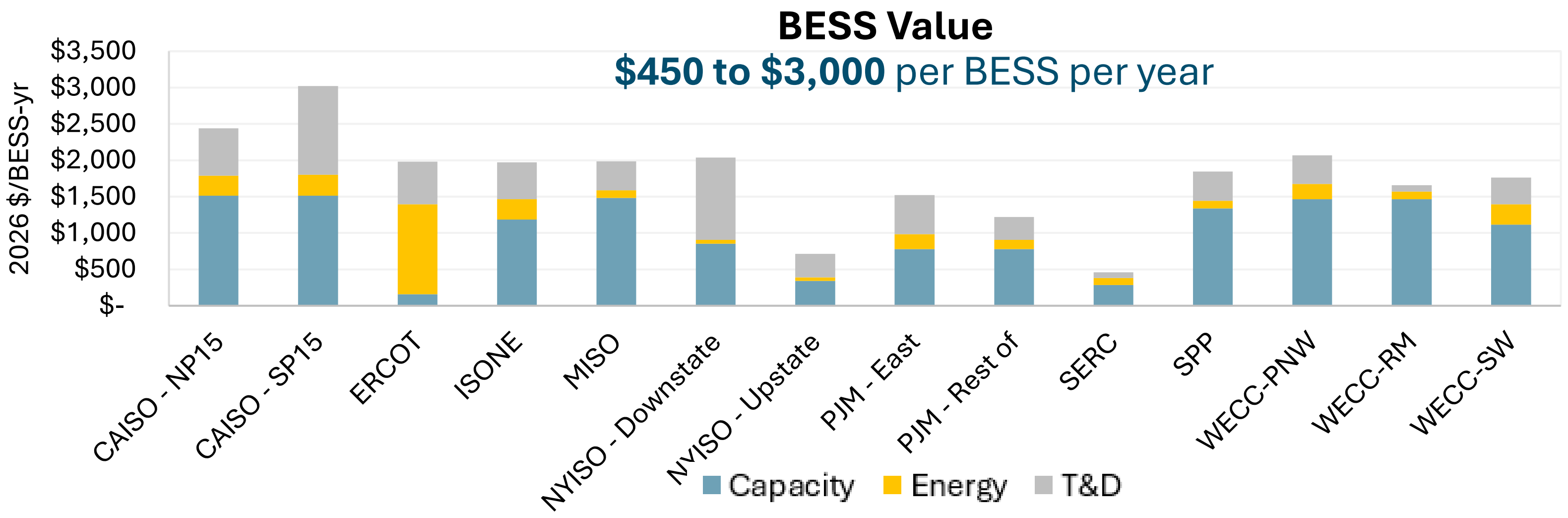
+ **V2G value ranges from $680/vehicle-year to $2,750/vehicle-year relative to baseline EV charging.**
  - The greater V2G value is driven by the ability to increase load response during high value hours.

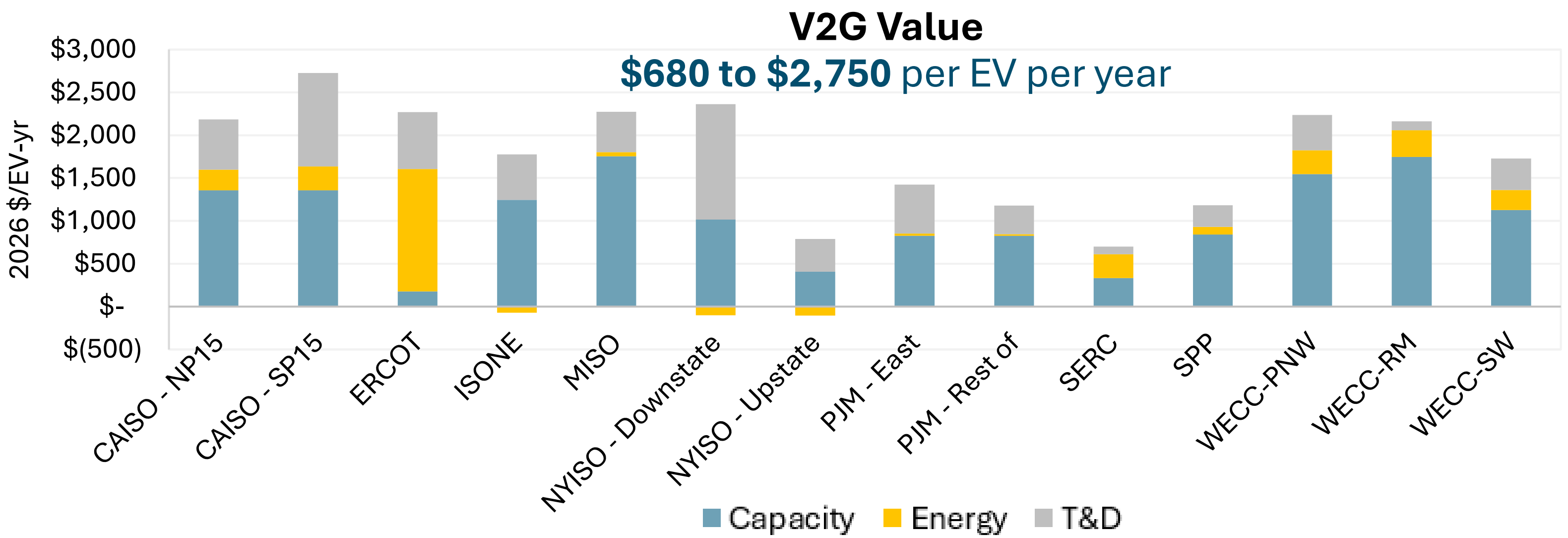
Comparing V2G and Storage

+ **The following key inputs are used to compare the grid value of residential BESS to V2G**

	Storage system	EV
Model	**Tesla Powerwall**	**GM EV models**
Battery size (kWh)	13.5 kWh	140 kWh *Weighted average of GM EVs (100 kWh and 200 kWh)*
Power (kW)	7 kW	15 kW *Weighted average of low and high powered L2 (11.5 kW and 19.2 kW)*

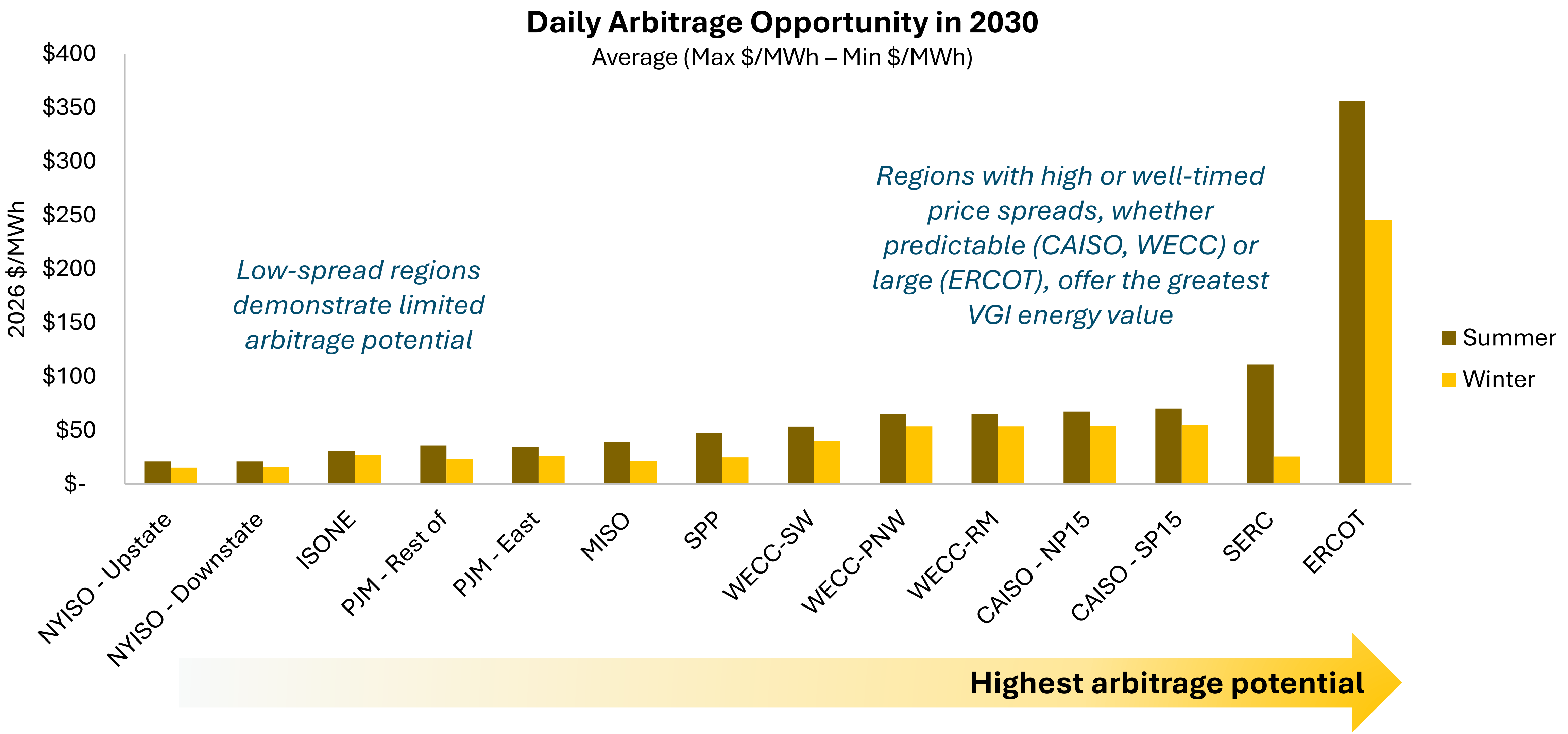
Comparing V2G and Storage by Region in 2030



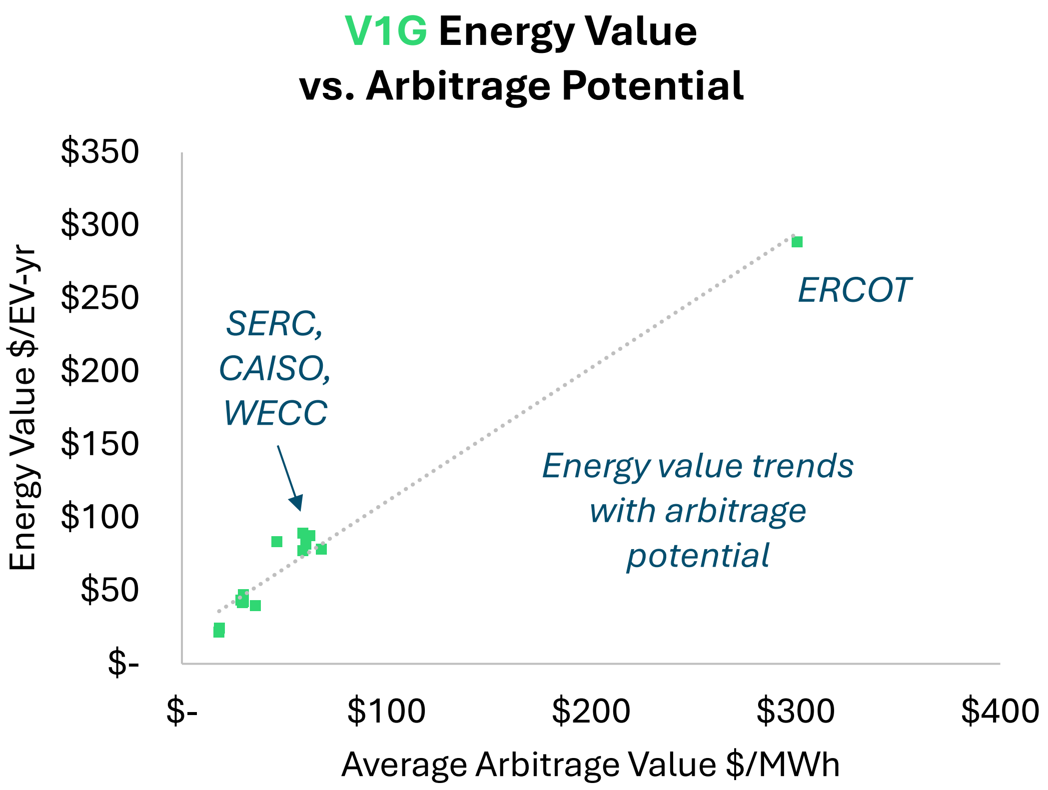


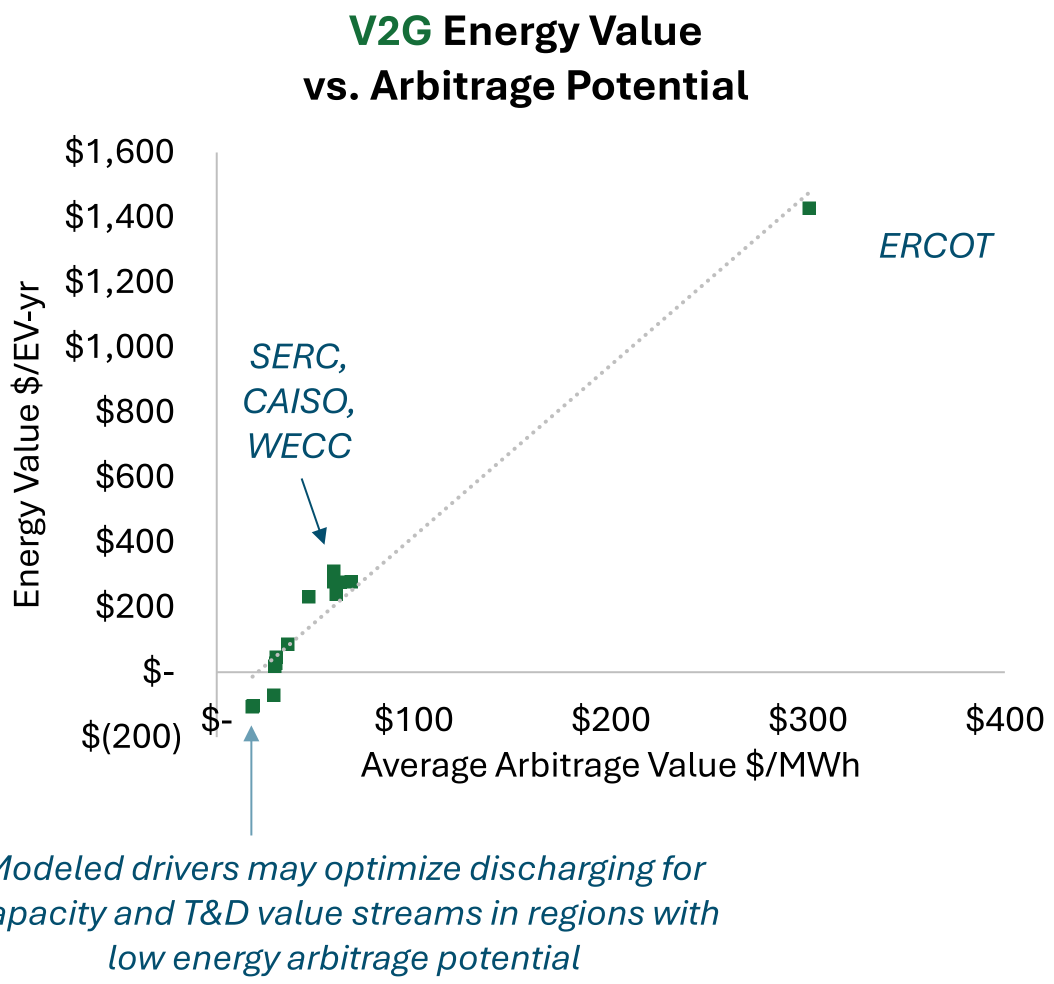
+ **Residential storage and V2G have comparable grid value across regions in the US**
  - V2G has slightly lower value because of driving needs, whereas the storage system is always there to maximize grid value
  - However, the customer purchases the EV for driving needs - the grid value is an added benefit

Energy value is driven by arbitrage opportunity



Energy value correlates with daily arbitrage opportunity

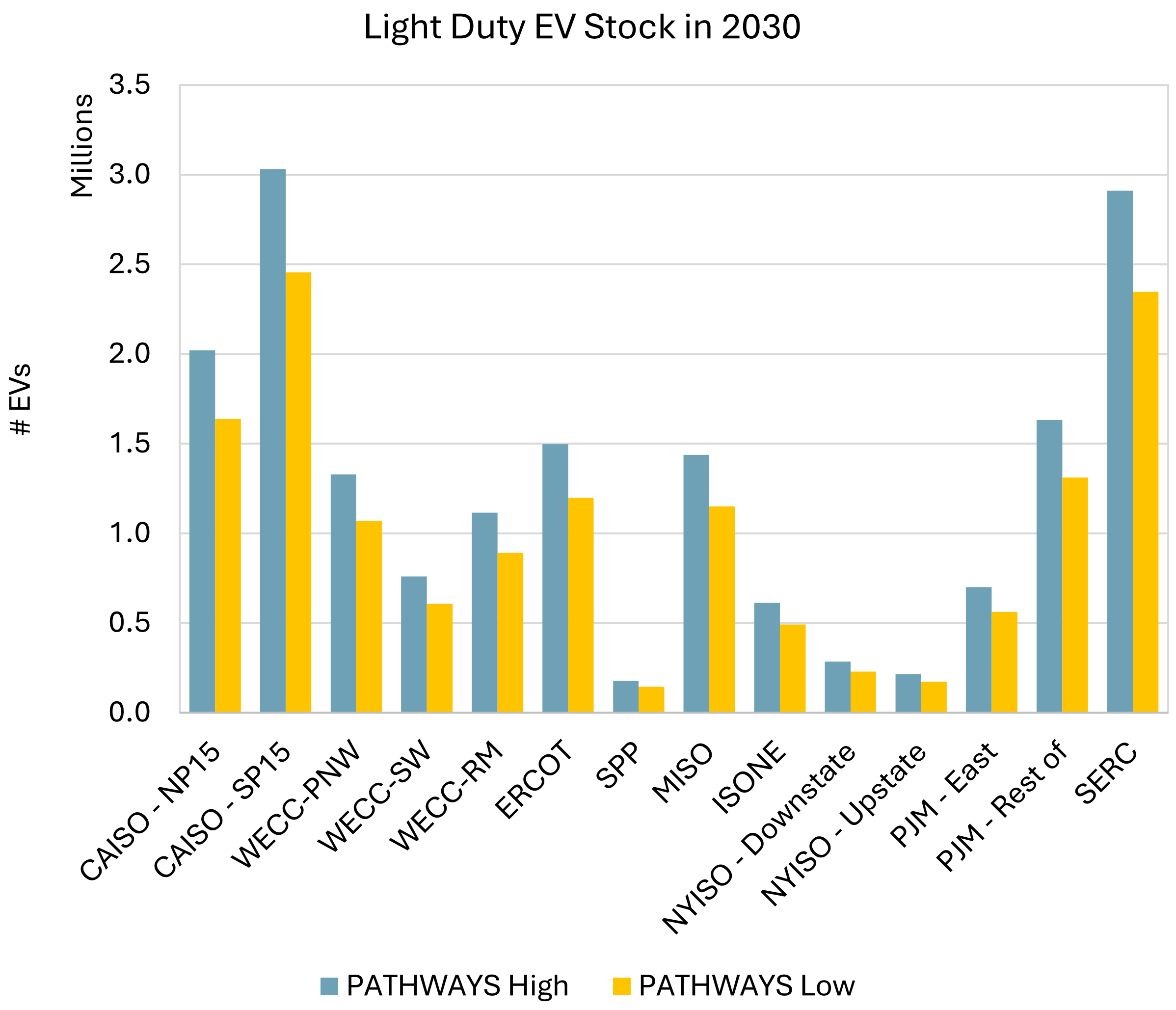




Adoption forecast used to calculate regional grid value

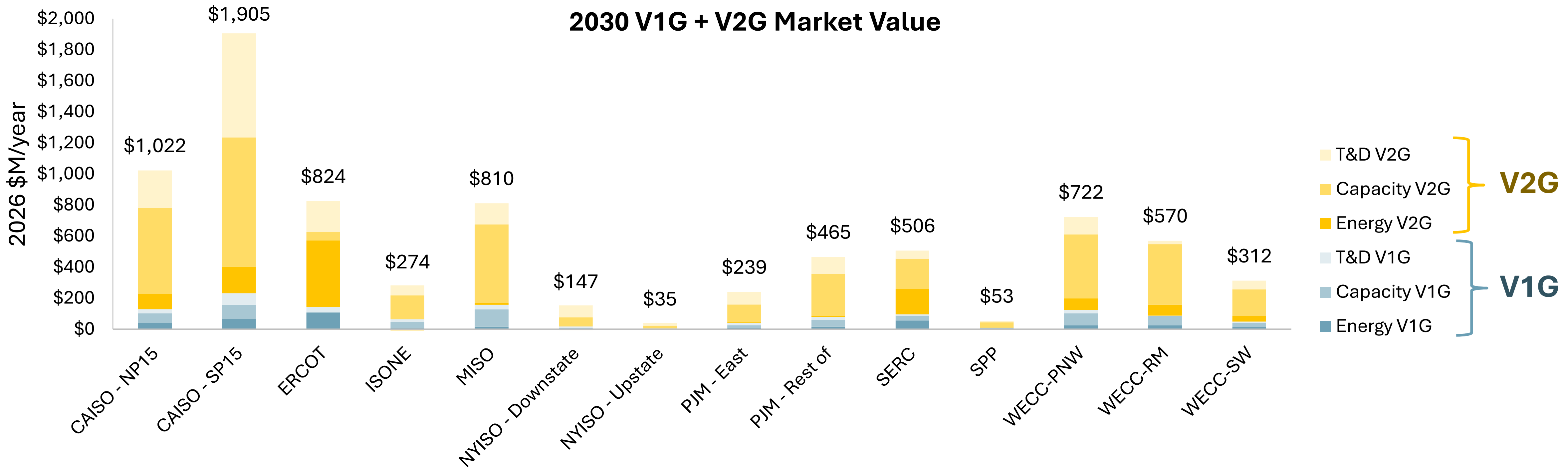
+ **To calculate total US grid value in 2030, E3 used our latest PATHWAYS BEV adoption forecast**
  - High: EV adoption aligned with BNEF EVO 2025 at the national level; state level adoption varies based on historical trends
  - Low: EV adoption based on continuation of historical trends from 2019-2024 by state

+ **Both high and low forecasts were analyzed in the model, but we use the PATHWAYS Low forecast for reporting results here**



National VGI market value is estimated to reach $7B in 2030

- **Most value is in resource adequacy and T&D deferral**, as storage saturates key markets and scarcity in peak hours increases system needs
  - T&D deferral is not monetizable under today's programs
- **Significant portions of VGI value, especially V2G, still lack clear revenue pathways today**
  - Regulatory evolution is required to enable both customers + utilities to access the full potential of VGI



Regional Variations in VGI Value

Grid Value	Key Drivers & Indicators	Current Leaders	Potential Followers
Energy	• Midday solar → deep low-price hours • Evening scarcity → predictable high-value windows • Price volatility (esp. energy-only markets)	**ERCOT** CAISO WECC-RM WECC-PNW	MISO SPP SERC WECC-SW
Capacity	• Peak-hour scarcity • Retiring thermal capacity • Urban load pockets and local constraints • Limited import capability / Tx bottlenecks	**MISO** WECC-RM WECC-PNW CAISO ISO-NE	PJM NYISO Downstate SPP
T&D deferral	• Local peak contribution during distribution-constrained hours • High load growth + electrification • Urban feeders with limited upgrade headroom • Regions with NWA pathways	**NYISO Downstate** CAISO PJM East ERCOT	MISO SERC WECC regions (select utilities)

Ancillary services and environmental values are also potential grid values but were not analyzed in this study.

V2G Investment Priorities by Market Structure

Market Type	Regions	Structural Feature	Avg V2G Value / Vehicle	Monetization Stability
Constrained ISO w/ Capacity Market	CAISO (SP15/NP15), MISO, NYISO Downstate, PJM East	Capacity + Local Deliverability + T&D programs	**$2,200–$2,750**	High
Energy-Only Market	ERCOT	Scarcity pricing, no capacity market	**~$2,270**	Medium (volatile)
Hybrid / Bilateral Adequacy	WECC-PNW, WECC-RM, WECC-SW	Utility capacity contracting, adequacy tightening	**$1,700–$2,200**	Medium
Vertically Integrated (No ISO Capacity Market)	SERC	Cost-of-service utility planning	**~$700**	Program-dependent

Largest **total market** opportunity likely in:

- **CAISO**
- **ERCOT**
- **PJM**
- **MISO**

High per-vehicle but smaller BEV base:

- NYISO Downstate
- WECC-RM
- WECC-PNW

Project 1: Grid Value Conclusions (2030 Outlook)

+ **VGI represents an estimated ~$7B total U.S. market opportunity in 2030.**
  - V2G delivers 5–15x more per-vehicle value than V1G, driven by the ability to discharge during high-value reliability and congestion hours.
+ **Highest per-vehicle value occurs in markets that explicitly price reliability and face local constraints.**
  - Constrained ISO markets (CAISO, MISO, NYISO Downstate, PJM East) show the strongest stacked revenue potential.
  - Capacity (resource adequacy) and T&D deferral drive most of the value in these regions.
  - Energy-only markets (e.g., ERCOT) deliver high volatility-driven upside, but revenue is less structured and more variable than capacity-based markets.
  - Vertically integrated regions (e.g., SERC) show lower and more program-dependent value, absent formal market mechanisms.
+ **Total opportunity concentrates where high per-vehicle value intersects with large projected BEV adoption, particularly: CAISO, ERCOT, PJM, MISO**
+ **Monetization & Policy Implications**
  - Most 2030 value comes from capacity and T&D deferral, not energy arbitrage alone.
  - Monetization pathways, especially for T&D deferral, remain constrained and will require regulatory evolution, standardized aggregation rules, utility program development

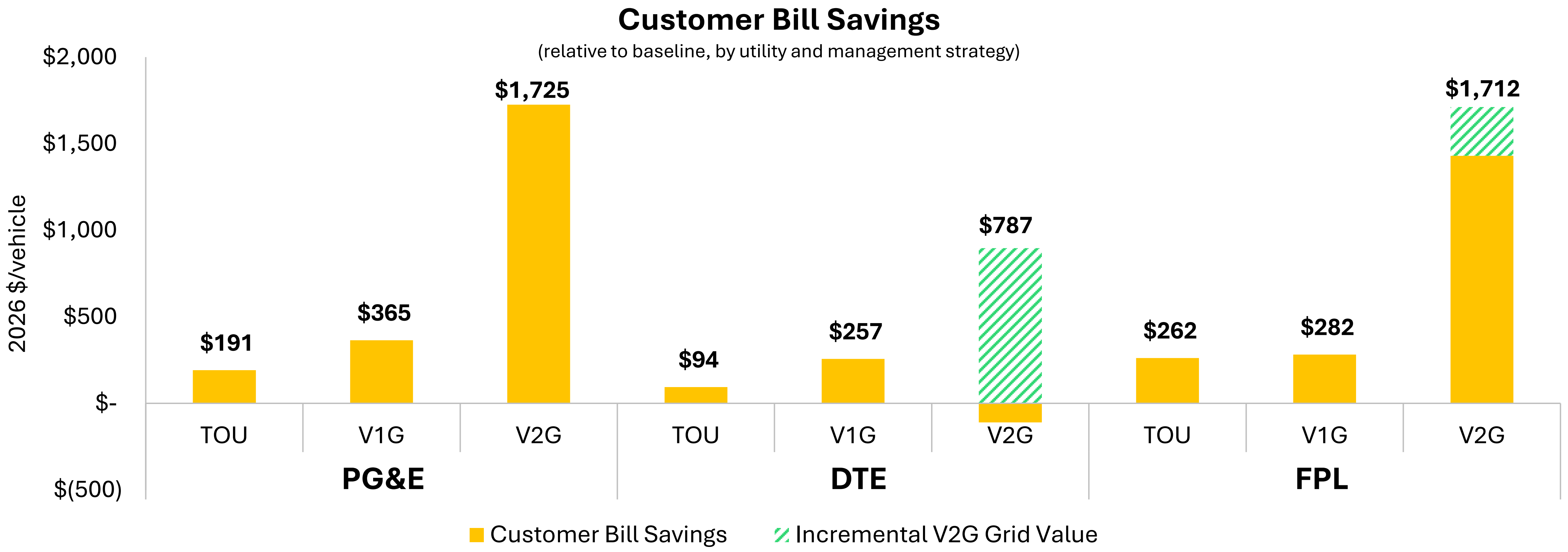
Project 1: Customer Value

Project 1 Customer Bill Savings for 3 Selected Utilities

	Pacific Gas & Electric (PG&E)	DTE	Florida Power & Light (FPL)
Utility V2G programs	Ongoing residential V2G pilot program	Ongoing residential V2G pilot program, only for Ford	No current V2G pilots offered by FPL
Charging cost & V2G compensation	PG&E Hourly Flex Pricing *This varies by feeder, so we averaged the prices to make it more representative*	DTE EV Plan (D1.9) *Assuming that vehicle dispatch is used to shift home load to avoid the retail rate*	Florida RTR-1 TOU *Assuming that vehicle dispatch is used to shift home load to avoid the retail rate*
Incremental grid value	N/A, modeling pilot program	In absence of a pilot program, we calculate the incremental energy, capacity, and T&D grid value to the utility for V2G dispatch compared to V1G. This will be split between the customer + utility to represent a potential future program design	

Customer Value Results

- Managed charging consistently reduces customer bills across all three utilities, providing a reliable and accessible source of value.
- V2G outcomes vary widely by utility because rate design and existing pilot programs differ significantly.



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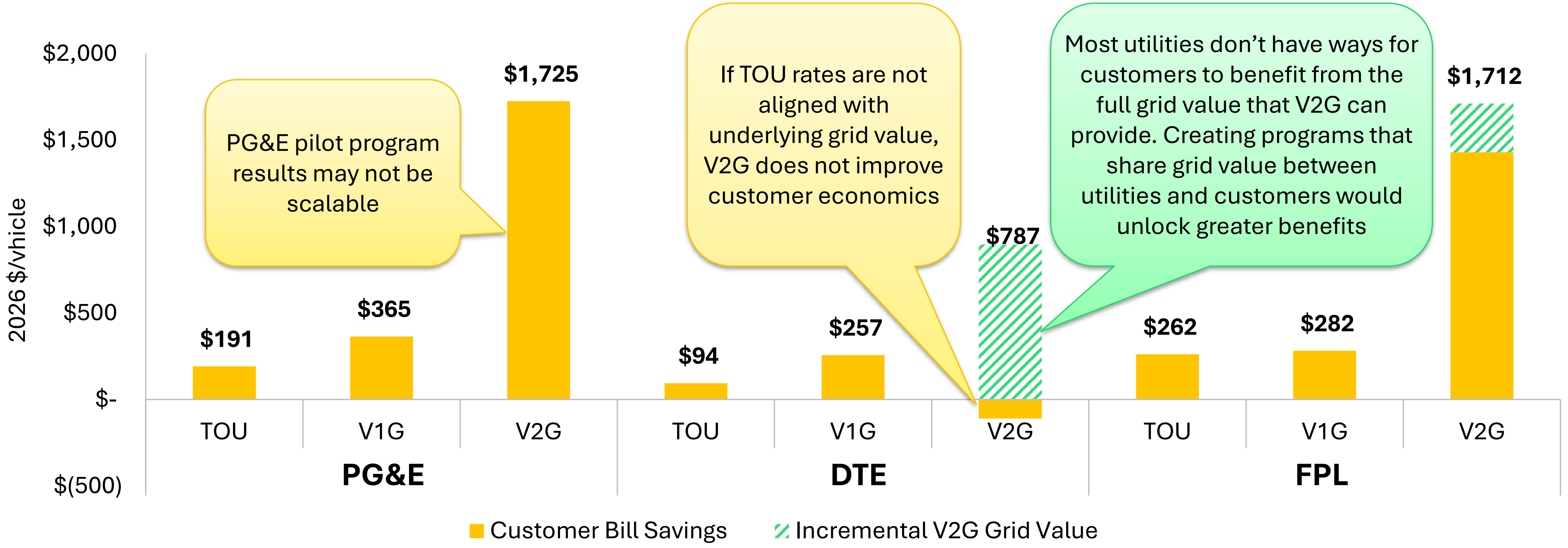
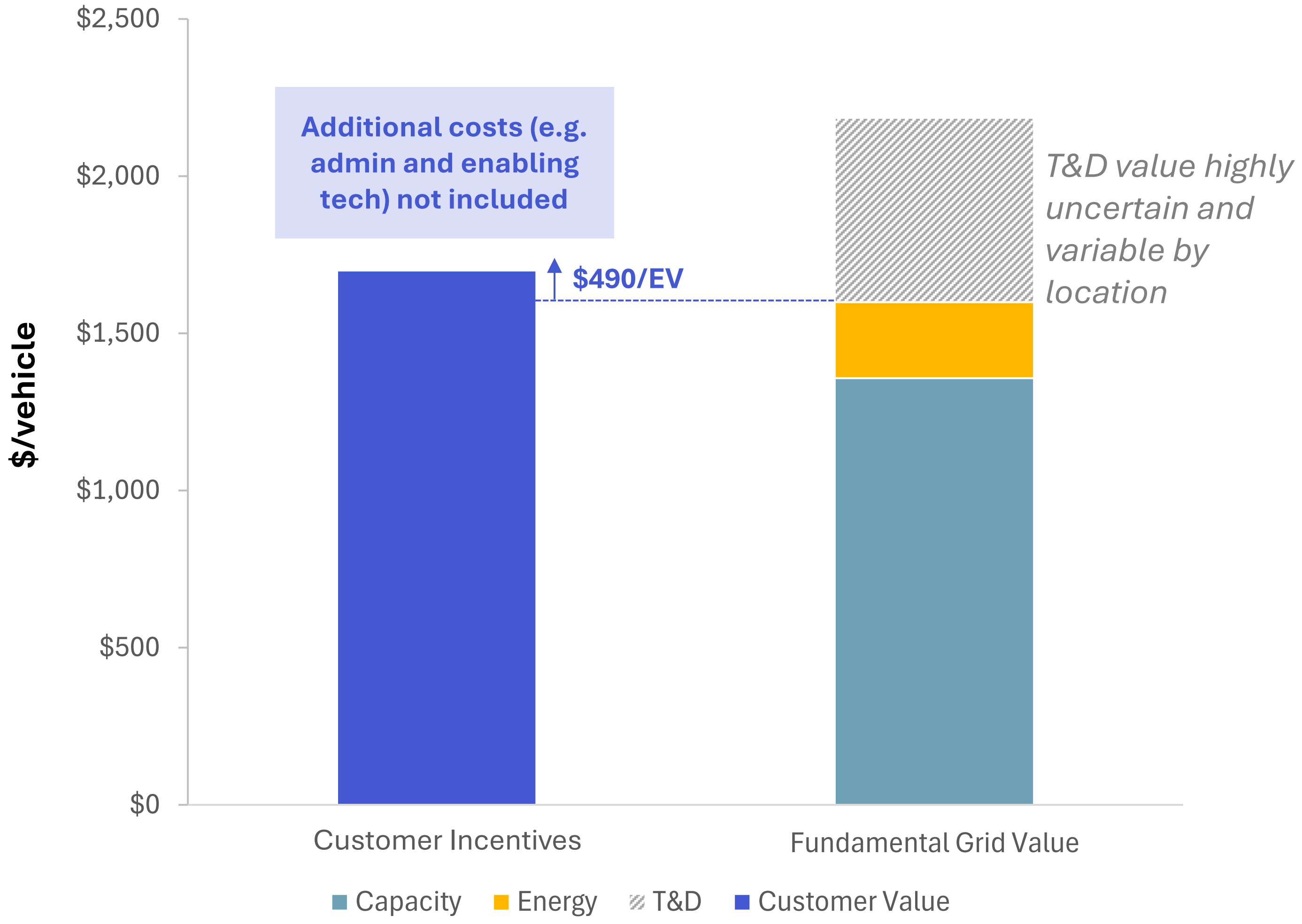


VGI program compensation must be aligned with grid value provided to maintain ratepayer benefits

Customer Bill Savings on PG&E's Hourly Flex Pricing Program vs. Corresponding V2G Grid Value



- E3's analysis of PG&E's V2G pilot[1] showed net benefits if T&D value can be realized by the utility, but T&D value will not be universally high and available across the service territory
- As VGI programs scale, it will be critical to set incentive levels such that the utility does not overpay the customer while also encouraging participation.

1. Customer incentives were calculated based on the average of 3 feeder's prices for using published prices for two summer weeks and two winter weeks.

Project 1: Customer Value Conclusions (2030 Outlook)

- Managed charging reliably reduces customer bills across all utilities.
- V2G customer value varies widely depending on rate design, export rules, and availability of pilot programs.
- Most utilities do not currently offer pathways for customers to access the full grid value created by V2G.
- Customer economics improve significantly in programs that share avoided-cost grid value between utilities and customers.
- V2G benefits are strongest where export compensation reflects underlying system value; without this alignment, V2G may not improve customer bills.
- Clear regulatory frameworks and updated rate structures are needed to unlock broader customer participation and value.

Project 2:

Customer Value of V1G and V2G by DER Configuration

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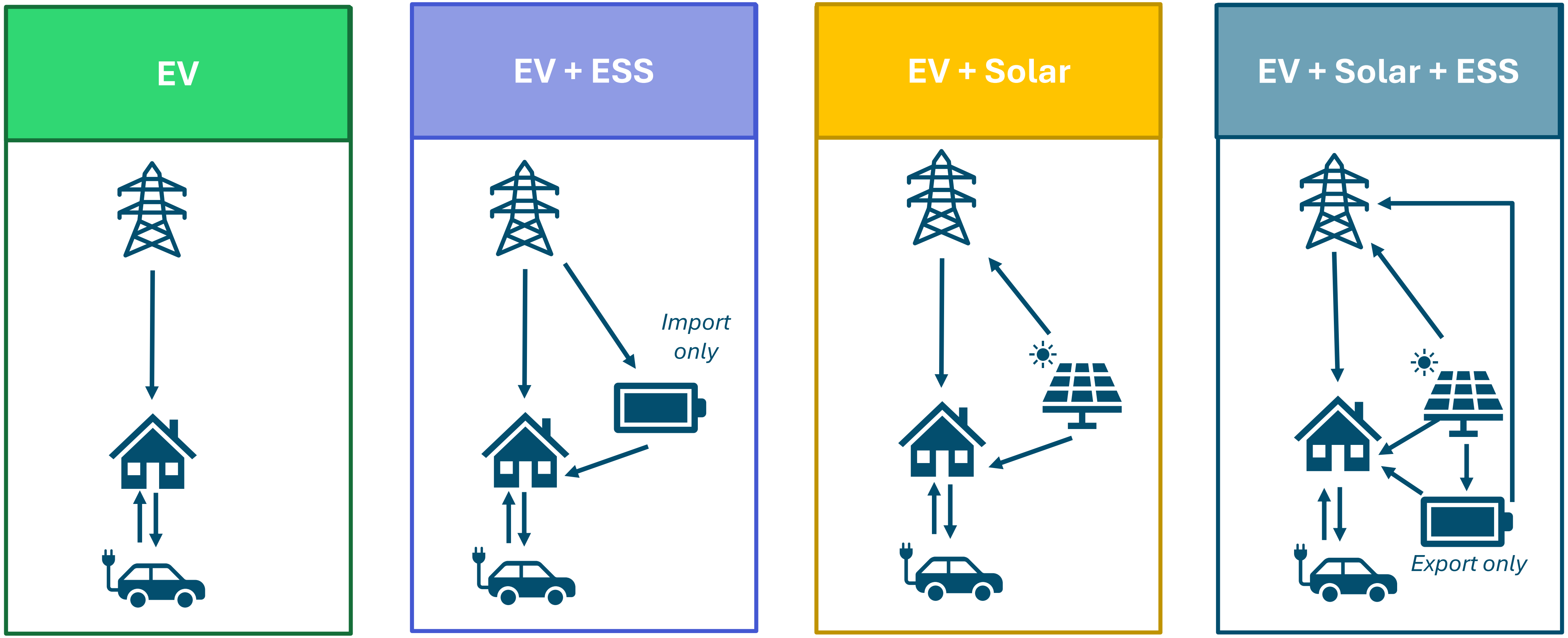
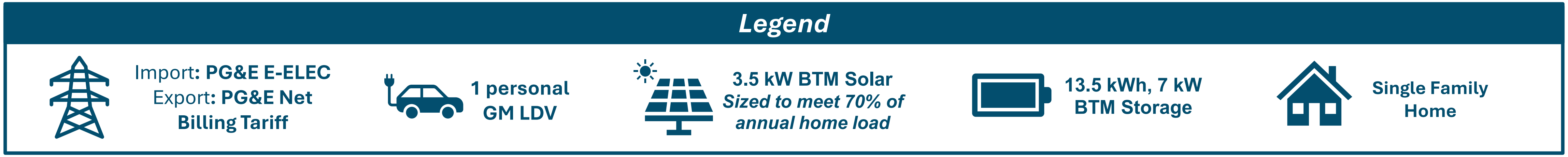
Project 2 Overview: Customer Value of V1G & V2G Using RESTORE

- **Project 2 evaluates the customer economics of EV managed charging, V2H/V2G, and DER configurations (solar + storage)**
- **To quantify these impacts, we use RESTORE, E3's behind-the-meter storage and distributed energy resource (DER) dispatch model**
  - RESTORE optimizes the hourly operation of DERs, including EV charging, behind-the-meter storage, and rooftop solar, to minimize customer bills.
  - It simulates how customers shift charging, discharge storage, or export solar depending on time-varying prices, Net Billing Tariff rules, and technology constraints.
- **How RESTORE Is Used in Project 2**
  - Models a single-family PG&E customer with EV, ESS, and solar in various combinations
  - Applies current CA rules: NBT export rates, import-only ESS behavior, and V2H (not grid export) for EVs
  - Models PG&E V2G pilot program
  - Compares unmanaged, managed, and V2H/V2G-enabled operation
  - Quantifies bill savings attributable to EV flexibility vs. storage and solar
  - Evaluates how DER pairing shifts the value proposition of V1G and V2G

Charge and Discharge by Technology and Scenario





Vehicle-to-grid in California is currently in pilots only, so we also model a V2G sensitivity

Current CA Market Rules

- NEM 3.0 (aka Net Billing Tariff (NBT)) took effect in April 2023
- Unlike traditional net metering that credited solar exports at retail rates, NEM 3.0 compensates homeowners based on “avoided costs” – essentially what utilities would pay for electricity elsewhere.

	NEM 2.0	NEM 3.0 / Net Billing Tariff (NBT)
Export rate basis	Retail rates (~$0.30/kWh)	Avoided costs (~$0.08/kWh on average)
Typical payback period	4-6 years	8-10 years (solar only), 6-8 years (solar + ESS)

- Implications for our RESTORE modeling:
  - For EV + ESS, since there is no solar installation, the ESS system is "import only," meaning it can charge from the grid during low priced hours and discharge to the home load in high priced hours, but it cannot export to the grid beyond the home load.
  - For ESS + solar, the ESS is "export only" meaning that it can only charge from solar (not from the grid) but then it can export to the grid
  - For EVs, we model V2H in most cases, and added a V2G sensitivity using PG&E’s pilot program for compensation

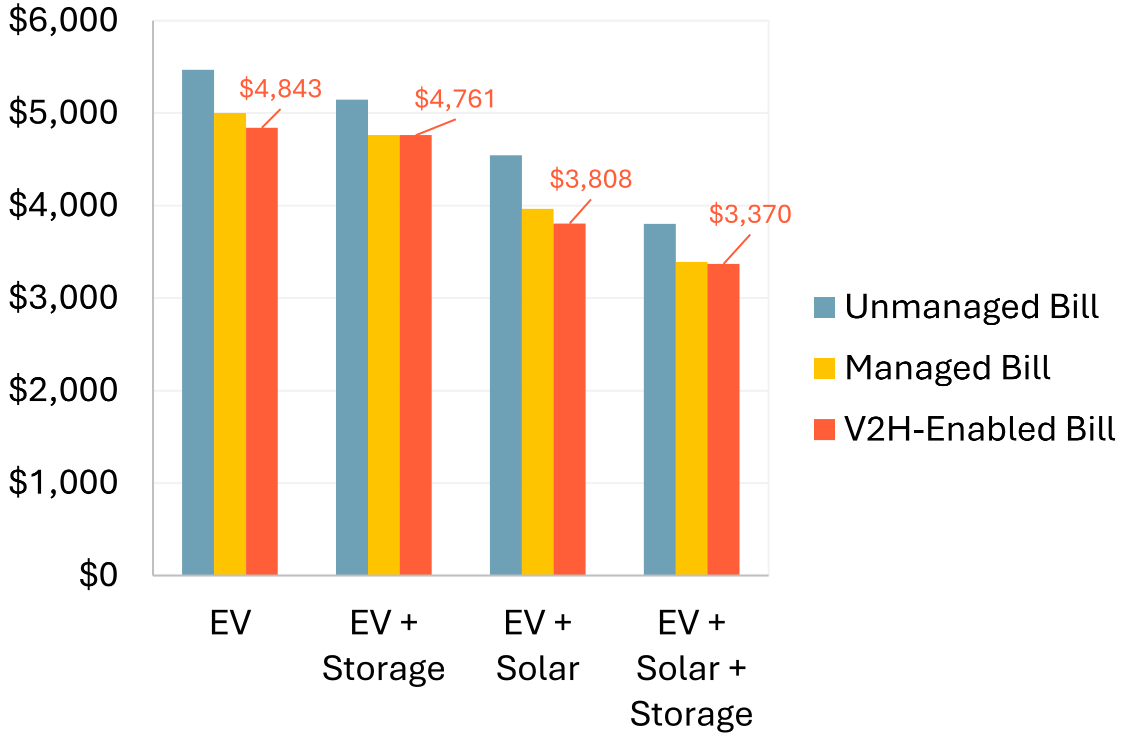
RESTORE Configurations (PG&E)

Configuration	CA Market Rules			V2G sensitivity
	Unmanaged	Managed	V2H	V2G
EV	Import: TOU rate Export: N/A, no grid export			Import and export: PG&E hourly flex pricing
ESS + EV	Import: TOU rate Export: N/A, no grid export			No sensitivity
Solar + EV	Import: TOU rate Export: NBT			Import and export: PG&E hourly flex pricing
Solar + ESS + EV	Import: TOU rate Export: NBT			Import and export: PG&E hourly flex pricing

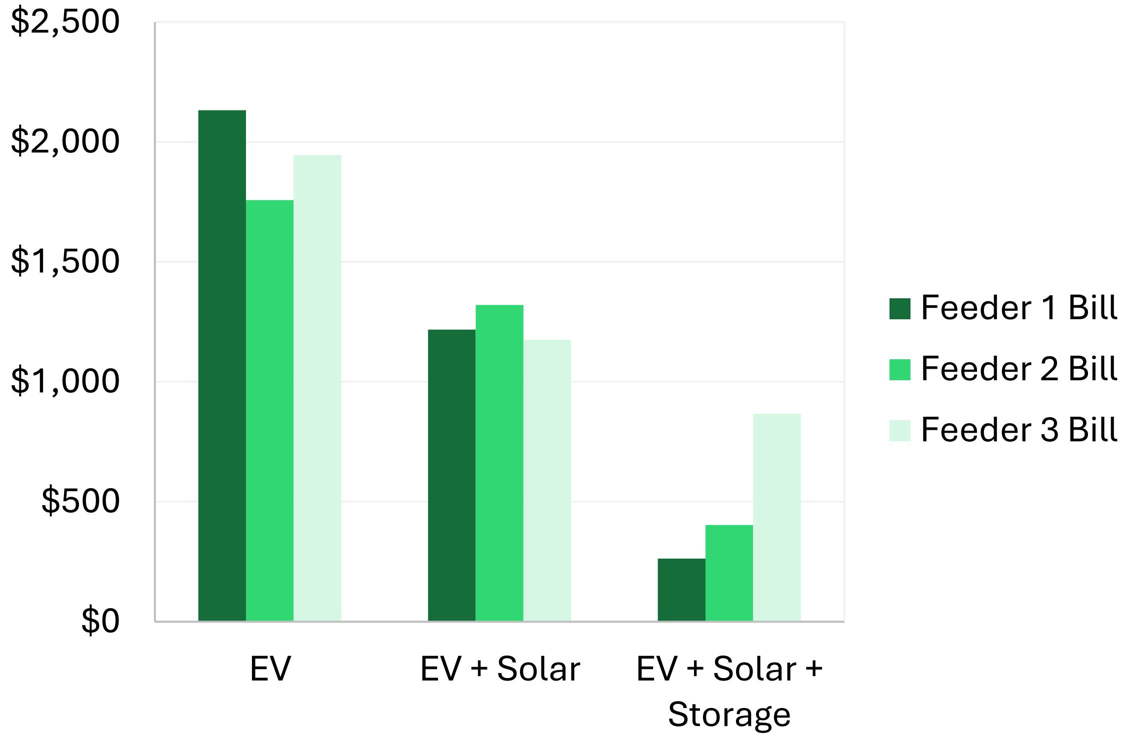
Stacked DERs deliver the largest customer bill savings

- Pairing **EV + Solar + Storage** yields the **lowest total bill** across all feeders due to stacked bill-saving mechanisms (solar self-consumption + load shifting + peak shaving).
- **Managed charging reduces costs across all cases**, while **V2H adds modest incremental savings** compared to solar and storage.

Customer Bills with **V2H-Enabled** Configurations

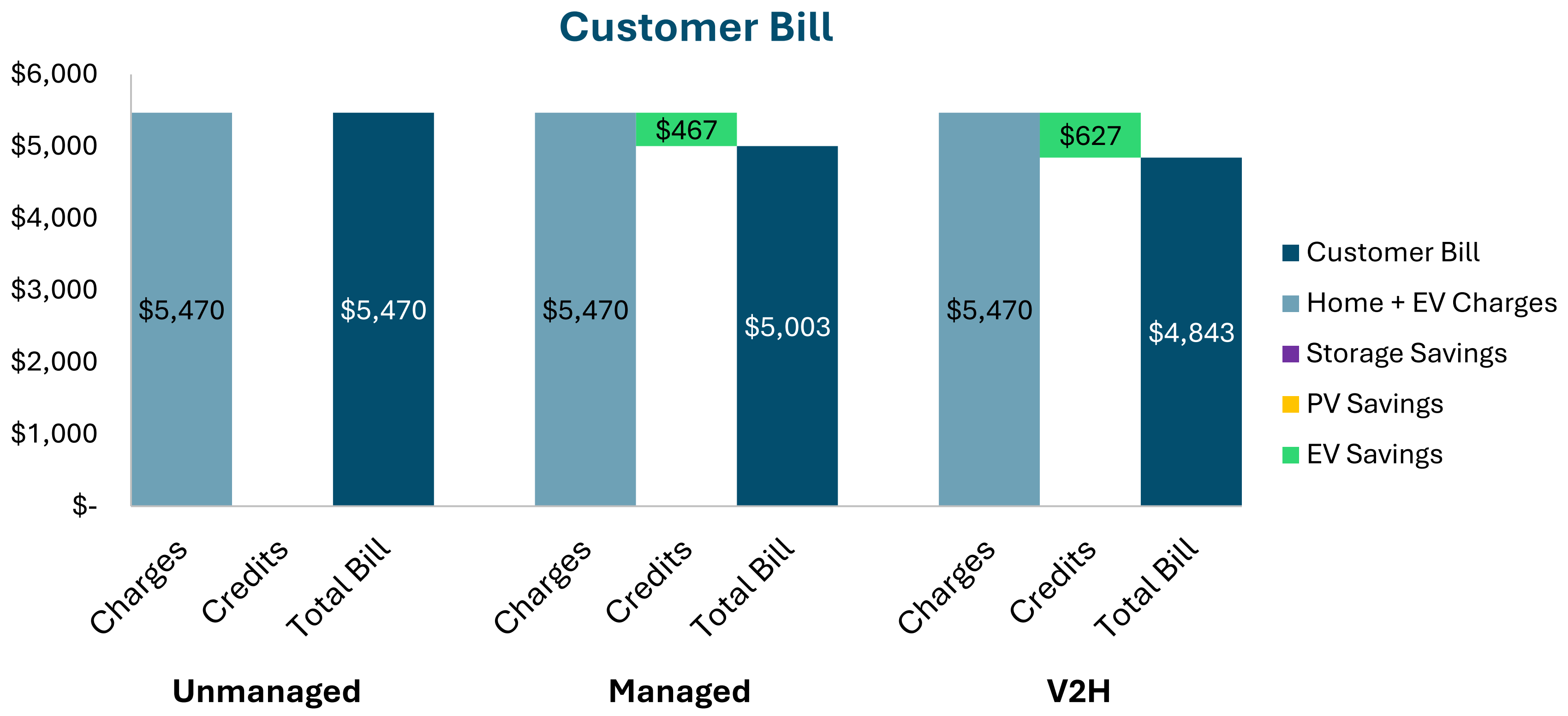


Customer Bills with **V2G-Enabled** Configurations



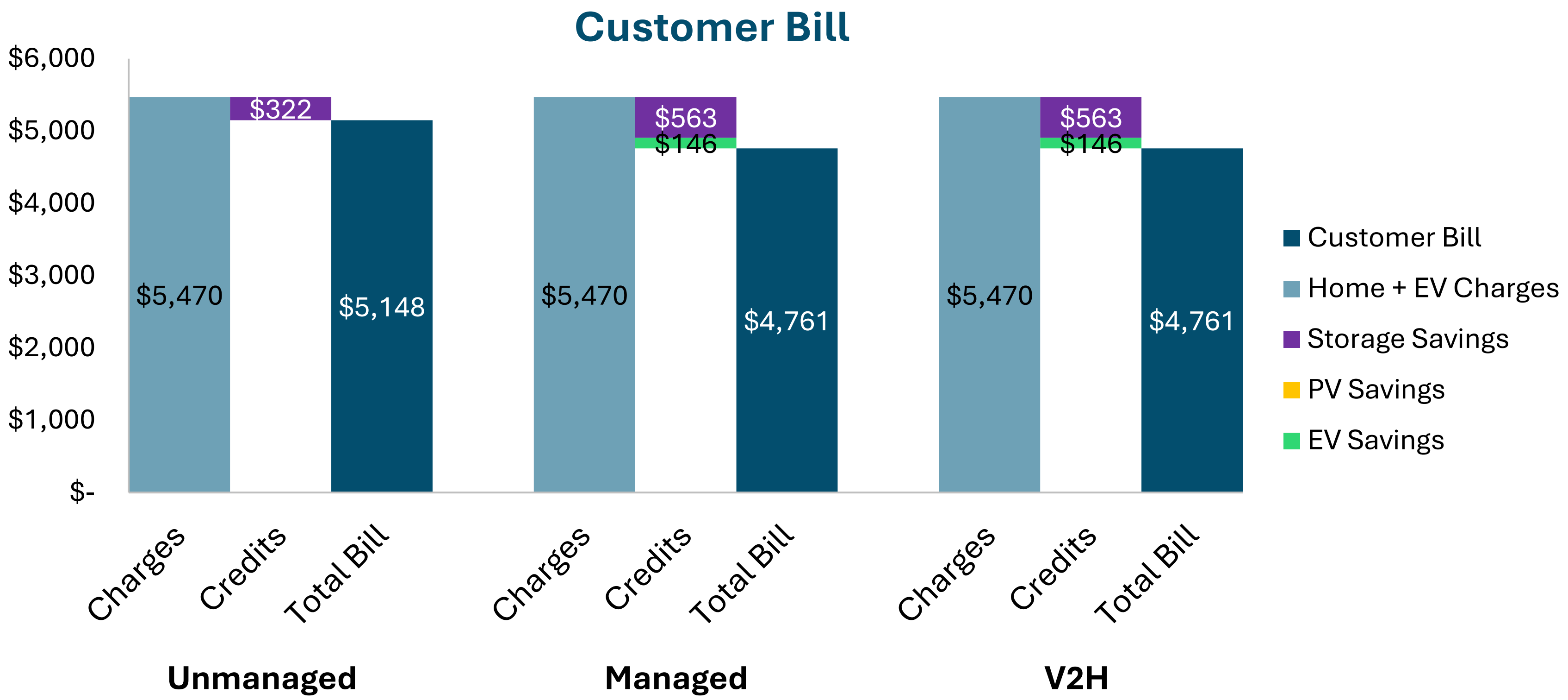
EV Only

- Managed charging provides meaningful savings, reducing the annual customer bill by $467 compared to unmanaged charging.
- V2H adds value, providing ~$160/year in further bill reductions on top of managed charging.
- Overall, EV-only V2H offers modest but valuable incremental benefits.



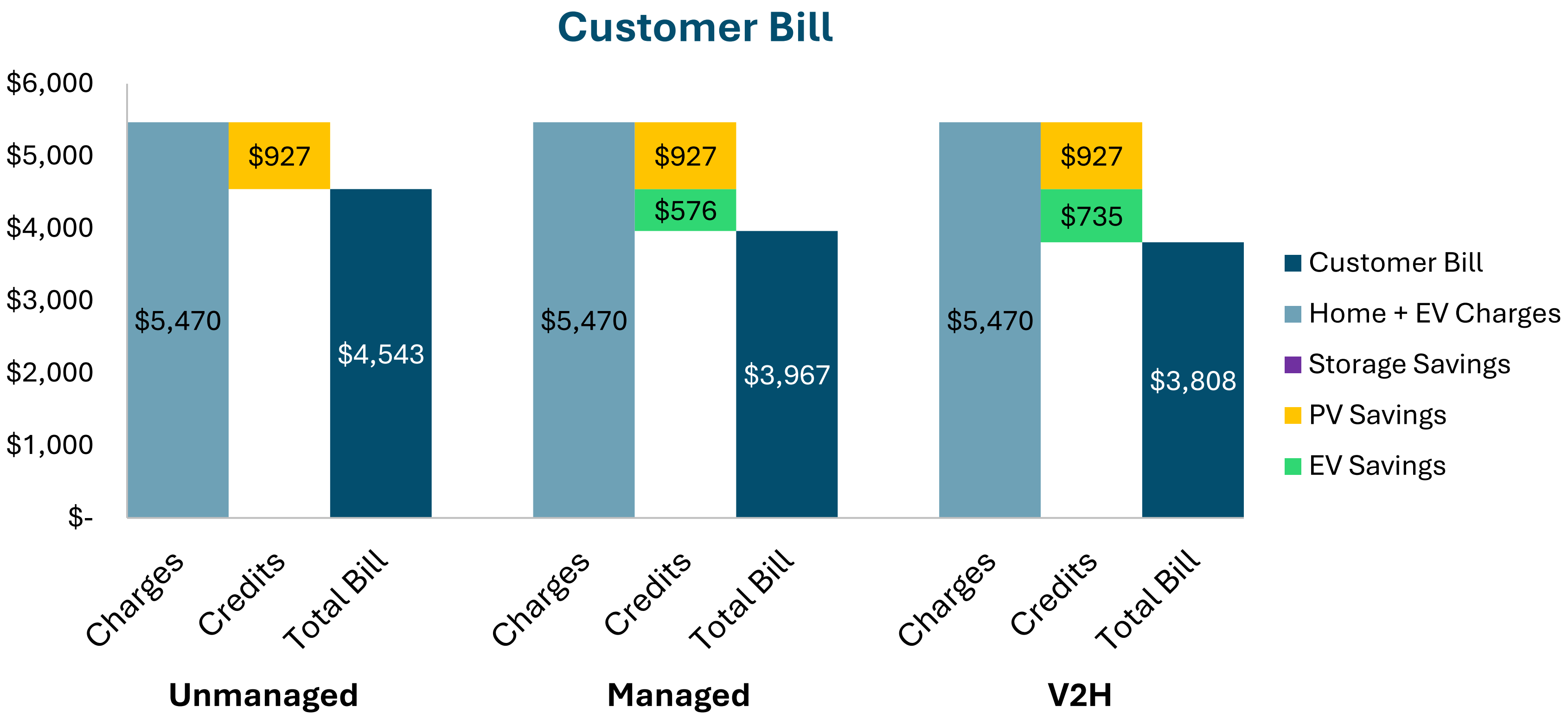
EV + Storage

- Storage is the primary source of savings in this configuration.
- Managed charging offers additional but modest savings.
- V2H does not add extra value in this configuration because the behind-the-meter battery already meets most high-value discharge needs.
- Overall, pairing an EV with storage yields ~$700/year in total savings compared to unmanaged charging.



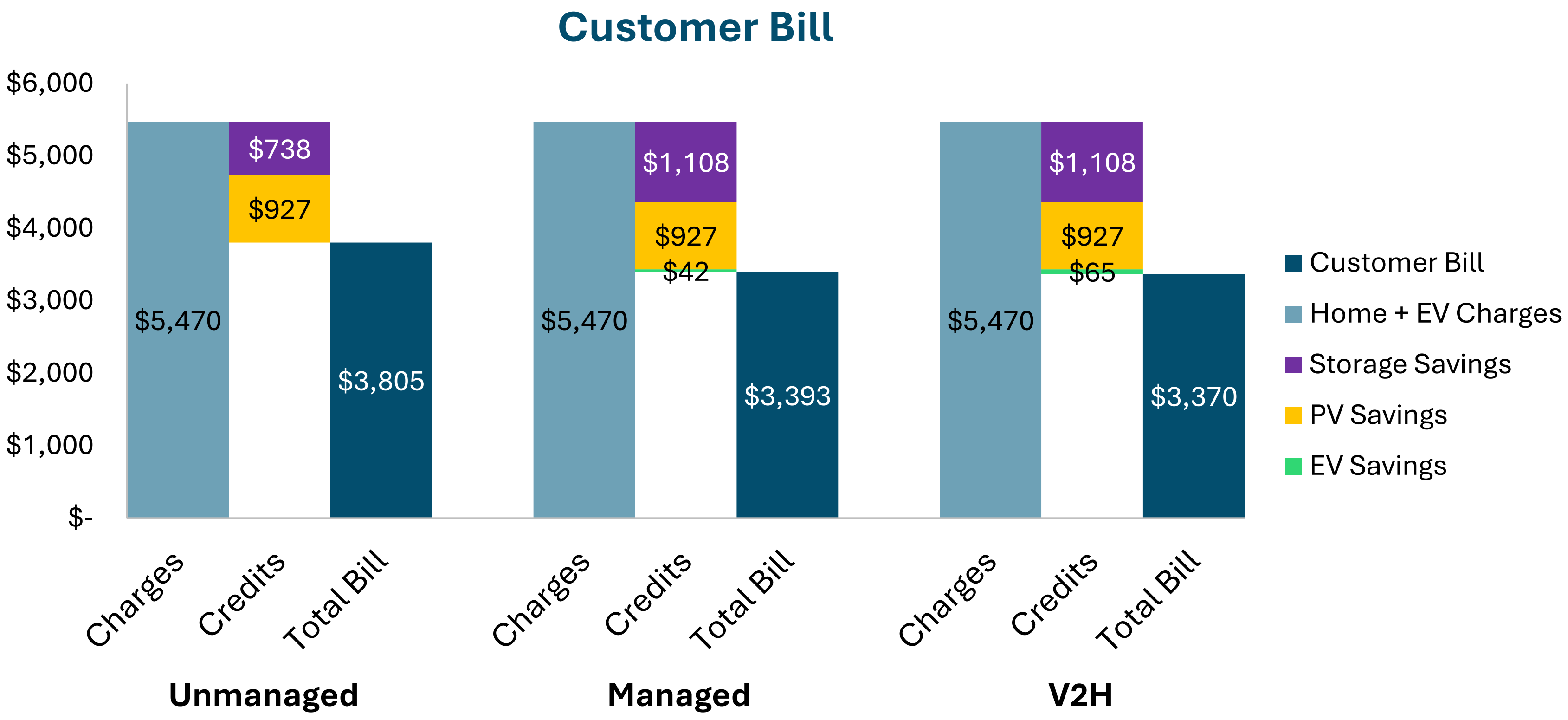
EV + Solar

- Solar is the largest driver of savings
- Managed charging adds meaningful value, reducing bills by $576/year relative to unmanaged charging.
- V2H provides additional incremental benefit, contributing ~$160/year on top of solar and managed charging savings.
- Total customer bill decreases substantially, with V2H delivering the lowest overall bill.



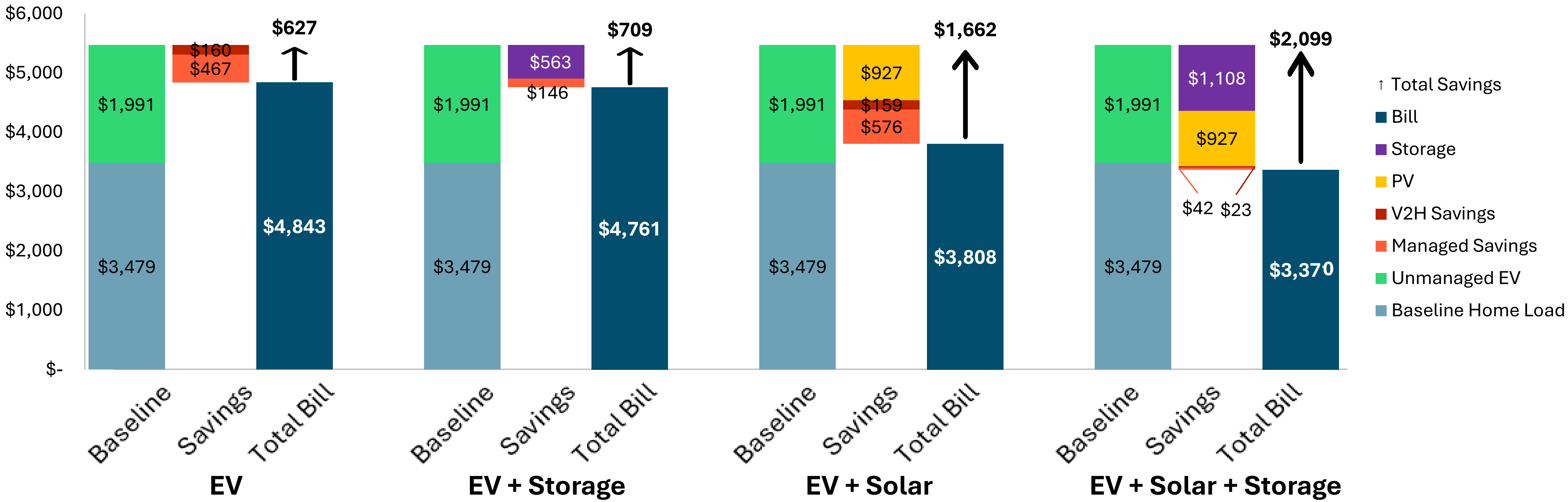
EV + Solar + Storage

- **Solar and storage drive the highest bill reduction.**
- **Storage delivers the highest individual savings, contributing $700–$1,100/year depending on scenario.**
- **Solar adds another ~$900/year in bill reductions.**
- **EV flexibility adds limited savings because 1) storage discharge prioritized due to higher efficiency; 2) limited availability of EV for discharging**
  - Managed charging adds only ~$42/year
  - V2H adds ~$23/year



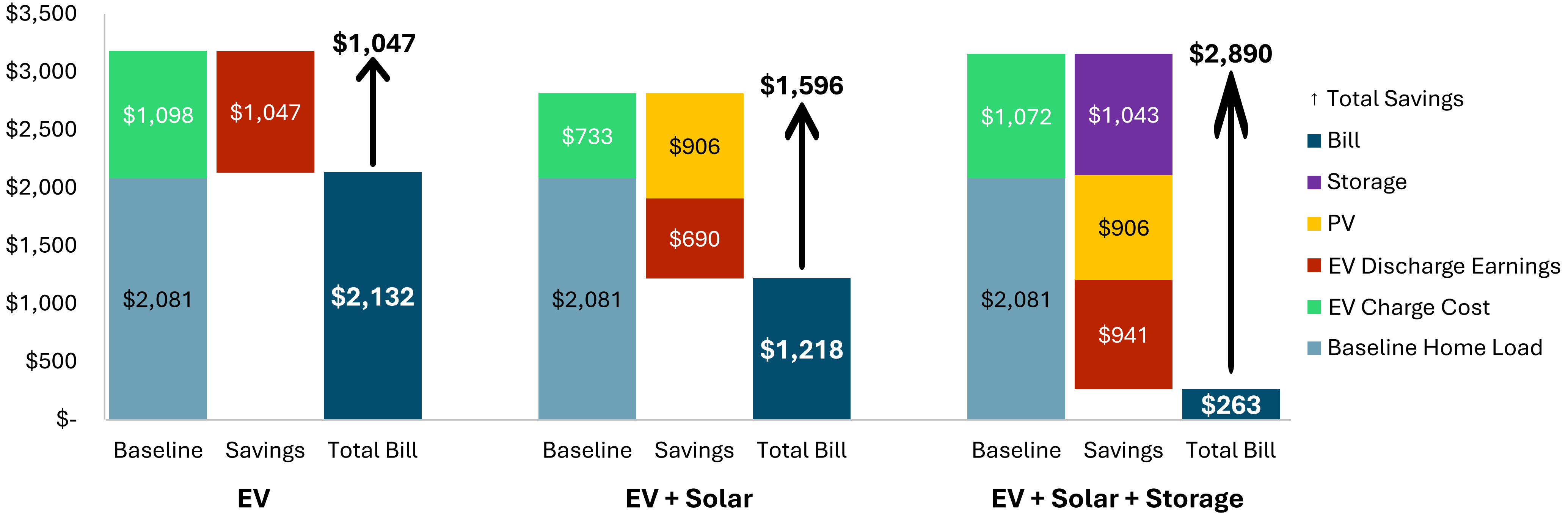
V2H-Enabled Cases Compared

- **Stacking DERs** (solar + storage + EV flexibility + V2H) **provides the largest bill reductions.**
- Storage delivers consistent value because it cycles daily, while V2H is limited by whether the vehicle is home and available during high-value hours, leading to smaller incremental savings.



V2G-Enabled Cases Compared

- Stacking DERs produces the strongest overall customer economics
- EV-only V2G adds value, reducing the net EV bill to only $50
- Solar + storage drives significant savings, with storage adding strong daily cycling value
- Storage delivers greater value than EV flexibility, since it has a higher RTE, and operates every day regardless of driving and therefore can charge from solar during the day



We tested three feeder prices – shown here is Feeder 1

Project 2 Conclusion

- Pairing **EV + Solar + Storage** yields the **lowest total bill** across all feeders due to stacked bill-saving mechanisms (solar self-consumption + load shifting + peak shaving).
- **Managed charging** consistently lowers bills relative to unmanaged charging by shifting EV load to lower-cost hours.
- **V2H-enabled** operation provides incremental savings but is modest compared to solar and storage impacts.
  - The value of V2H is context-dependent - largest where peak-to-off-peak spreads are high.
- **V2G-enabled** results may not be scalable since they are based on a pilot program; value is highest when paired with on-site generation.
- When paired with solar or storage, the EV contributes **additional flexibility**, reducing grid imports and improving utilization of onsite generation.
- **Comparison of value: EV vs. ESS**
  - ESS delivers larger bill reductions than EV flexibility because storage can respond every day, independent of driving patterns, and the Tesla PowerWall efficiency is better than current EV batteries
  - EV flexibility adds value but is limited by vehicle availability, while storage operates continuously. However, customers purchase an EV for driving purposes, so the flexibility and bill savings potential are an added bonus.

Thank You

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