



Energy+Environmental Economics

California Framework for Grid Value of Vehicle Grid Integration (VGI)

Presentation to VGI Working Group

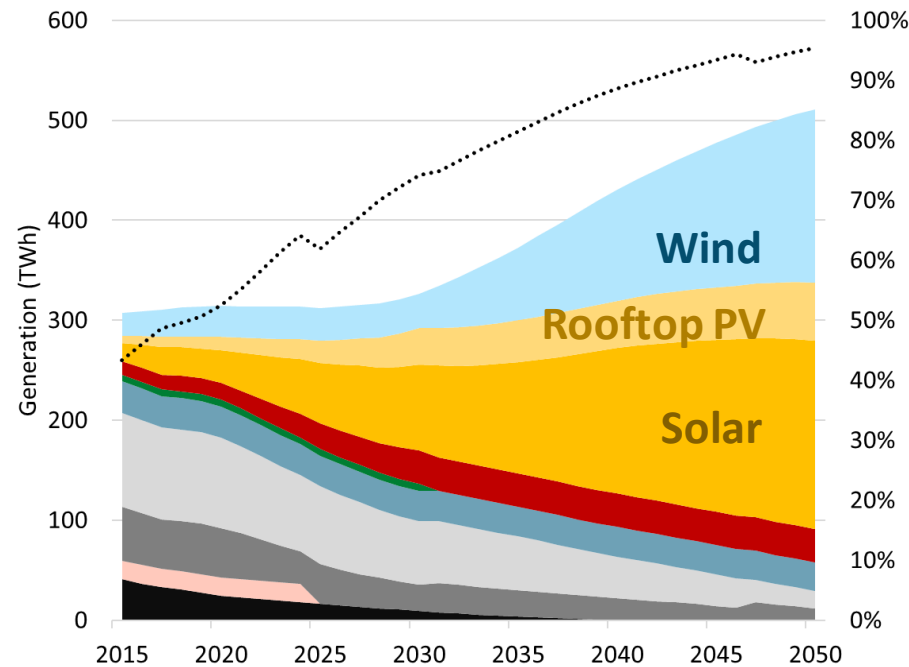
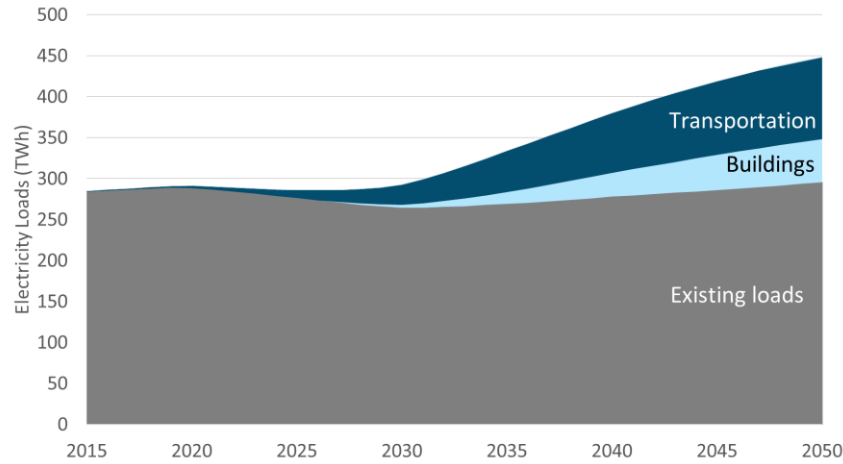
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VGI is crucial for low carbon pathways

California PATHWAYS
High Electrification with No Hydrogen Scenario



Transportation is first, new flexible load in pathways portfolio...



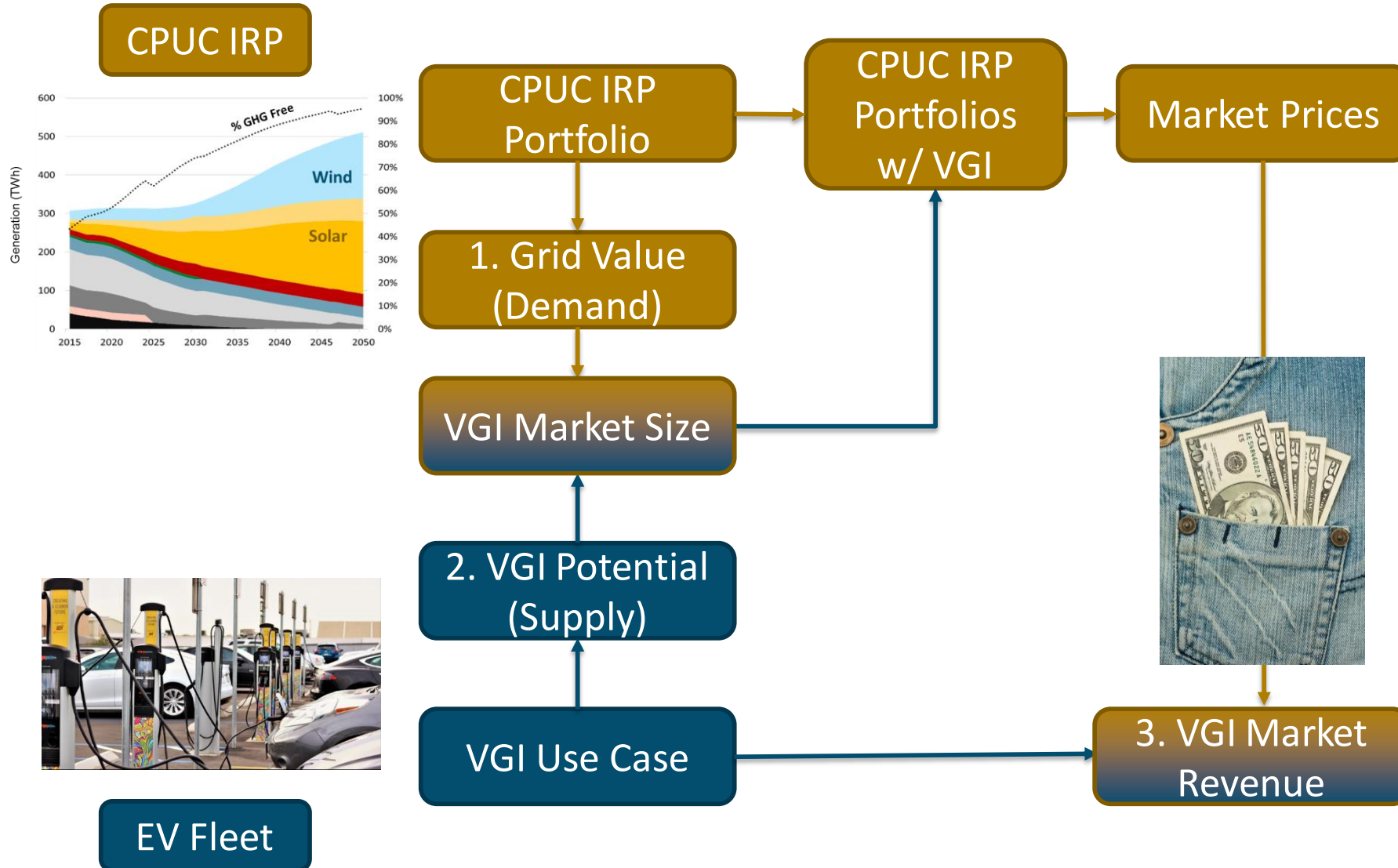
...establishing business models for flexible building loads to follow...



...enabling increase in low carbon electricity



California VGI Grid Value Framework





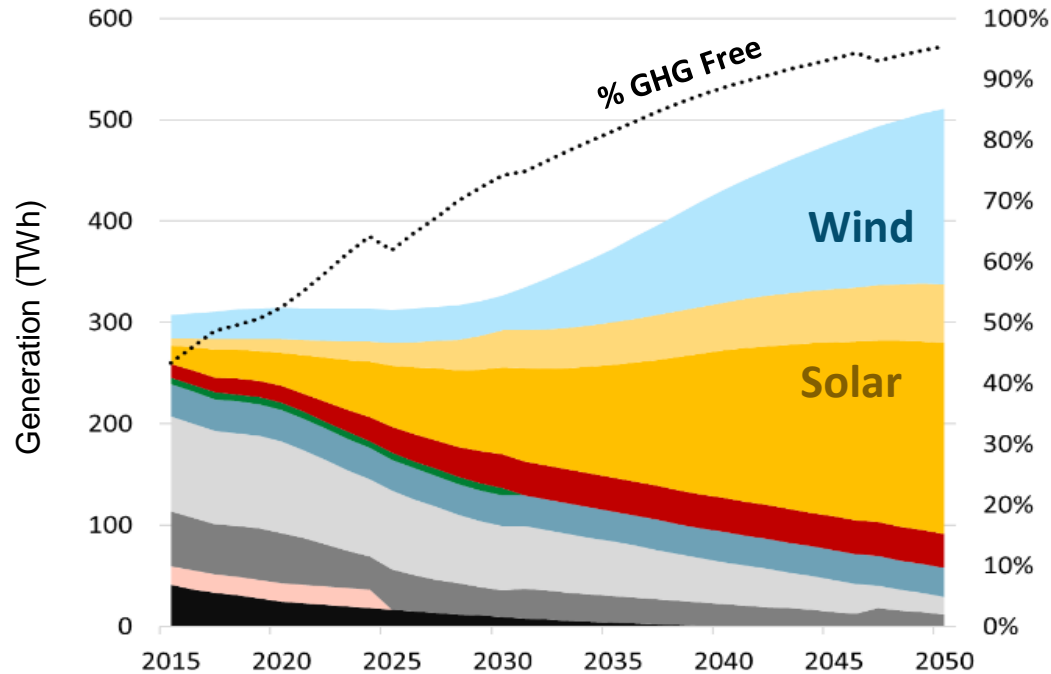
1. Grid Value (Demand)



Start with CPUC Integrated Resource Plan

California PATHWAYS
High Electrification with No Hydrogen Scenario

Least-Cost Planning Scenarios to meet GHG target



Utility Scale Solar



Energy Storage

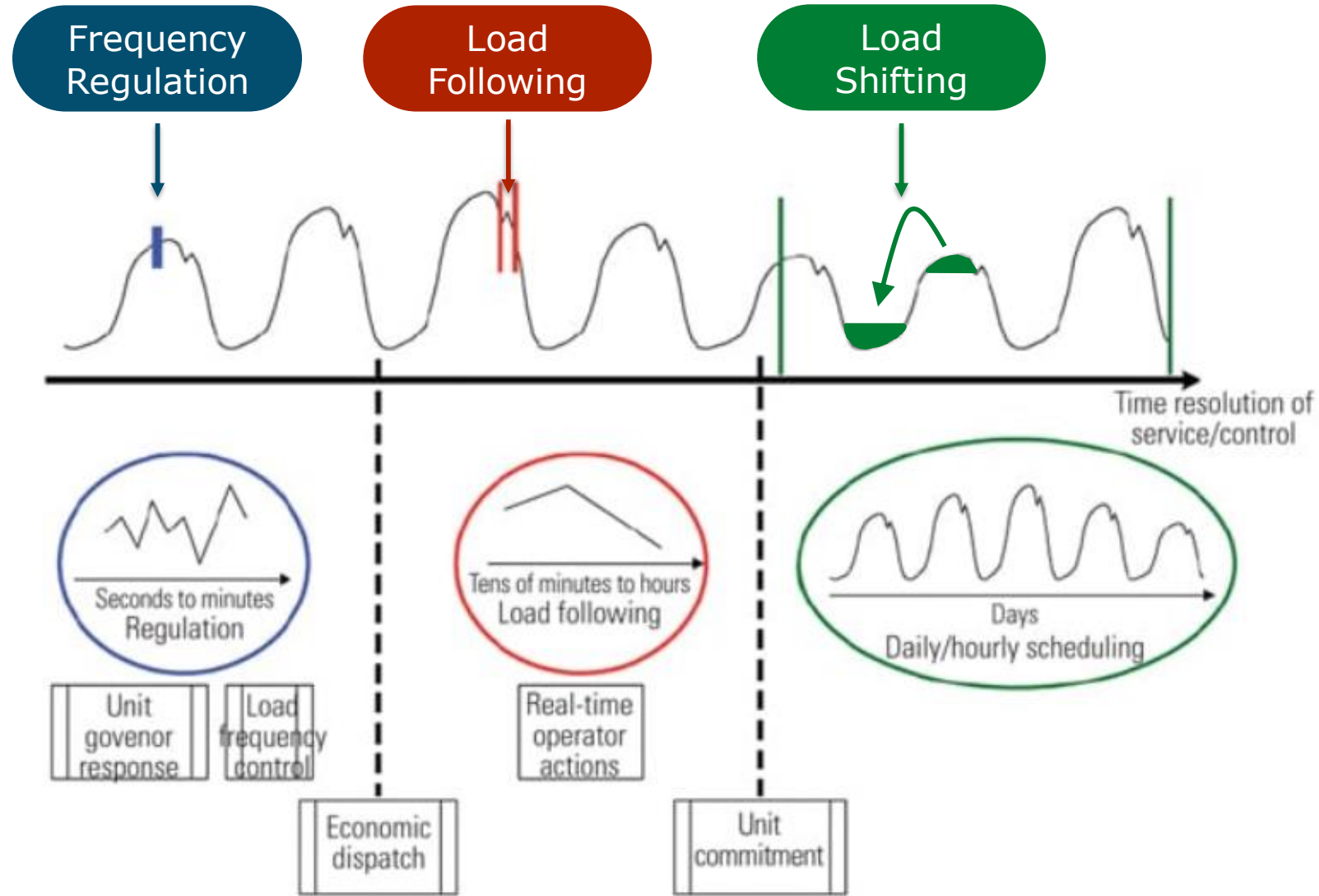


Regionalization and EIM

Baseline System Cost (2016 \$M)	Baseline Storage Build (MW)	Baseline Curtailment (%)
\$5,332	2,679	5.4%



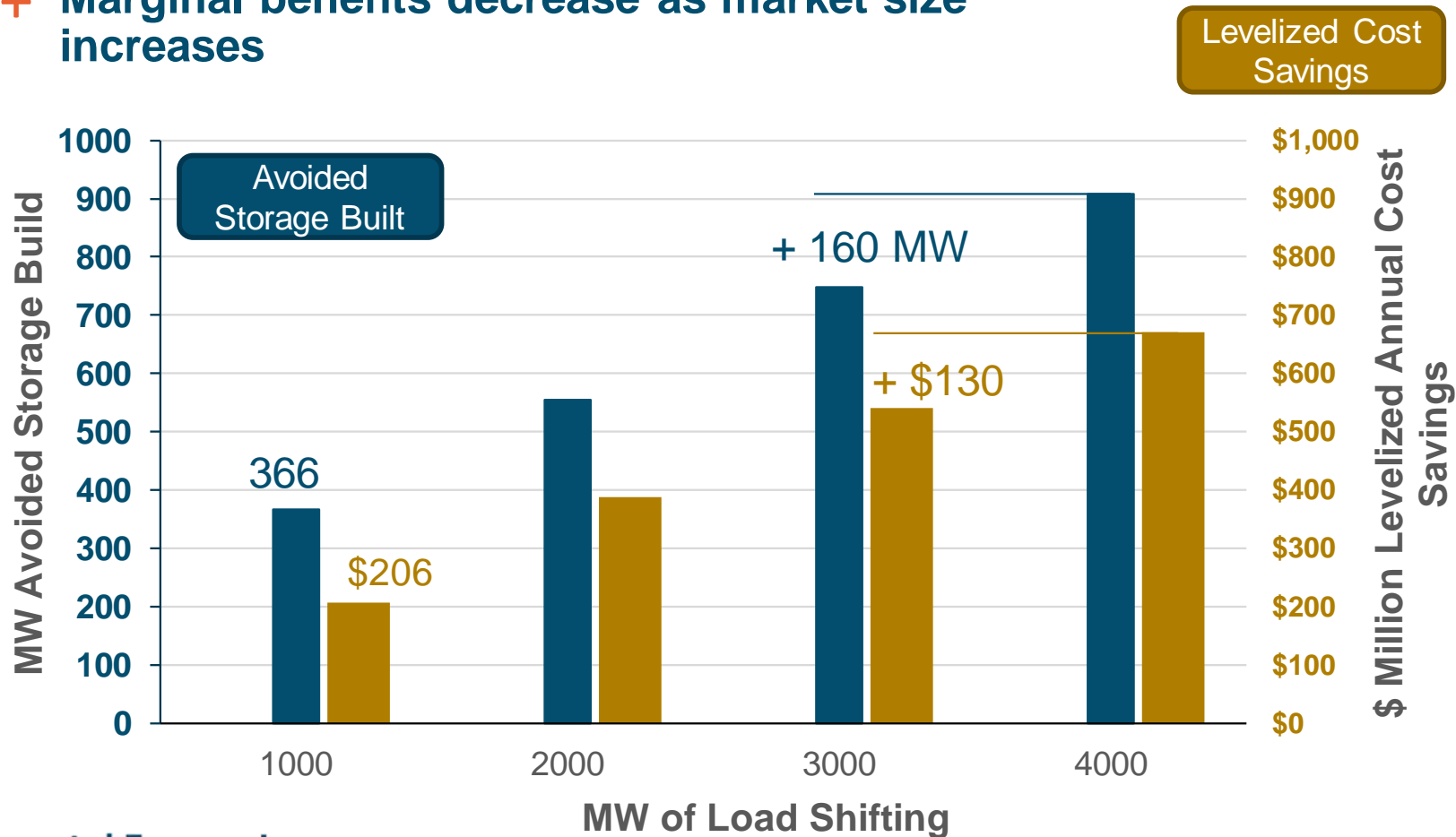
Three Illustrative VGI Grid Services





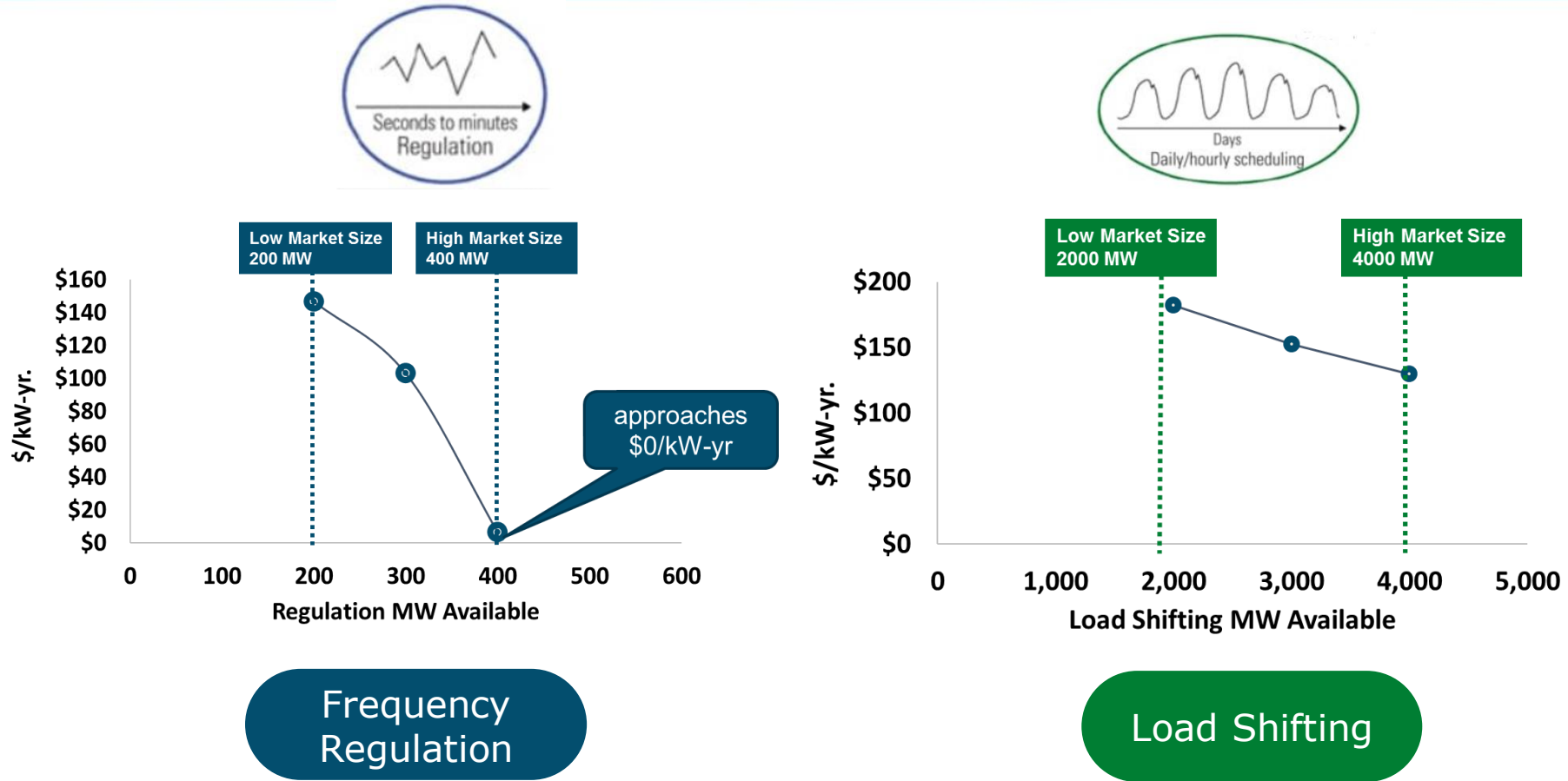
Grid Benefits (Load Shifting)

- + Load shifting reduces both grid capital investment and operating costs by reducing the amount of storage built, and PV curtailment
- + Marginal benefits decrease as market size increases





Declining Marginal Value with Increasing Supply



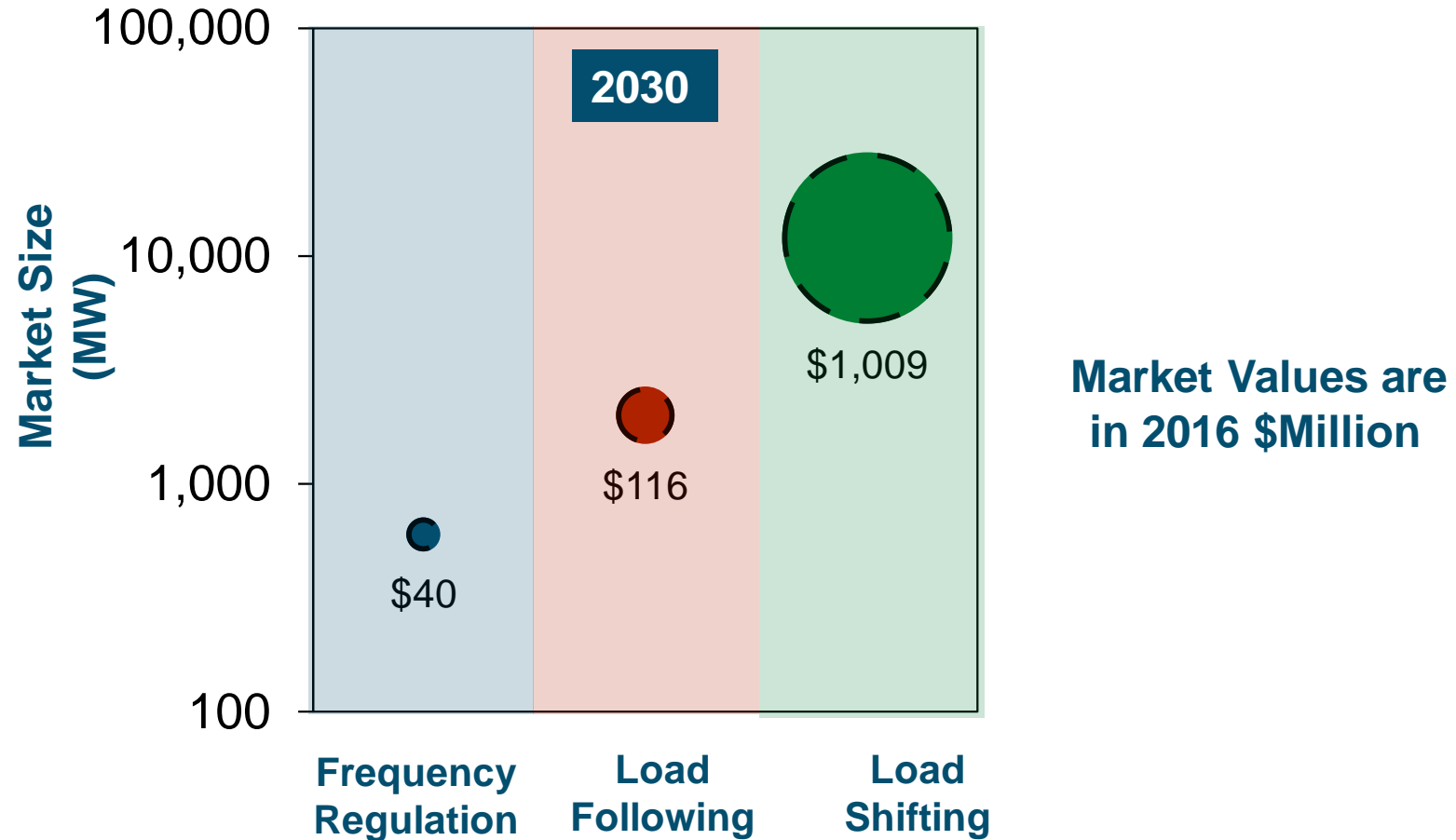
- + Small market for Frequency Regulation is easily saturated
- + Larger market for Load Shifting

2018 42MMT Case in 2016 \$/kW-yr. (CA 2018-2030 levelized value)



CA VGI Market Estimation Results

+ Load shifting has highest market size and value potential



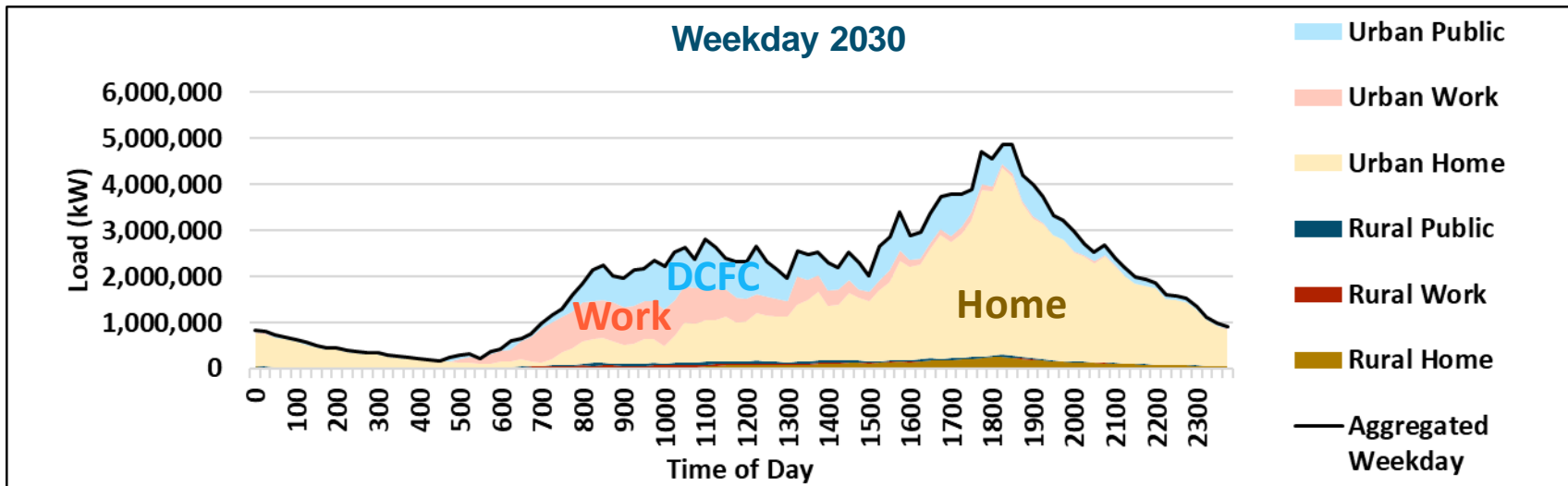
2018 42MMT Case in 2016 \$/kW-yr. (CA 2018-2030 levelized value)



2. VGI Potential (Supply)



Unmanaged EV Charging Load Shape Results – CA 2030



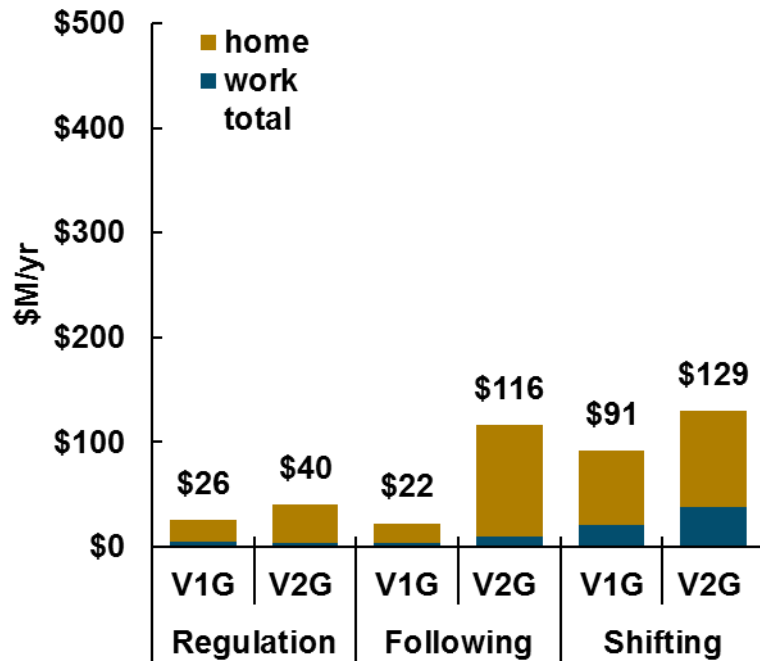
	Average hourly load (GW)	Peak load (GW)	Total Energy (GWh)
Home	1.3	4.3	30.2
Work	0.3	0.9	6.5
Public	0.4	1.0	9.8
Combined	1.9	4.9	46.5

- + VGI potential from EV fleet
- + Based on vehicle types, charging level and location and driving patterns



VGI Market Results Summary (2030)

$$\text{Market Value (\$M)} = \text{Total Market Value (\$M)} \times \frac{\text{VGI Supply for EV (MW)}}{\text{Grid Demand for VGI (MW)}}$$



25% EV Participation

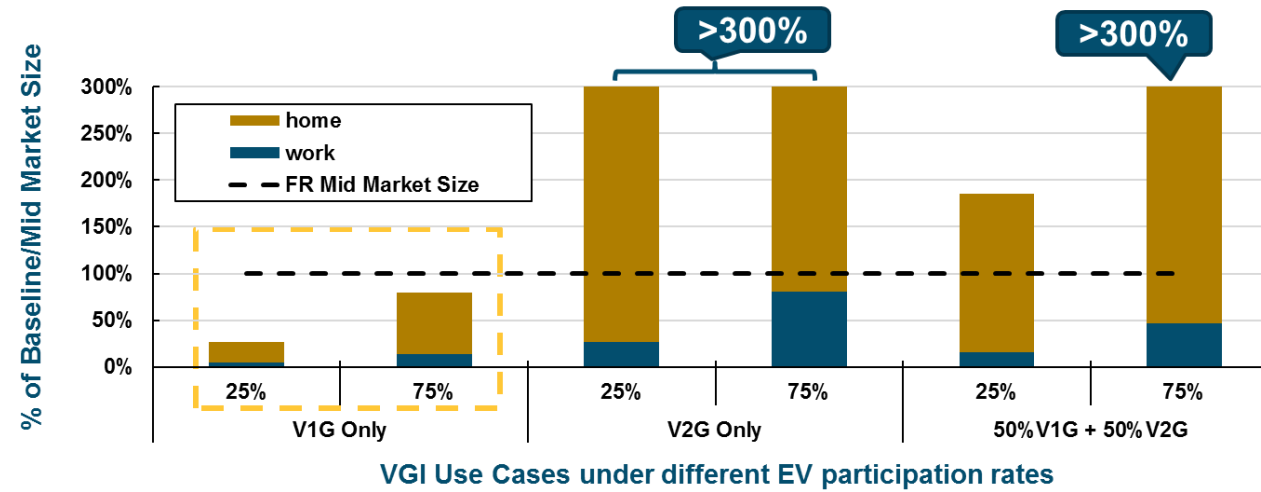
% Market Size	V1G	V2G
Regulation	64%	100%
Following	19%	100%
Shifting	9%	13%

**+ With 25% EV participation and V2G capability
Frequency Regulation and Load Following market is fully saturated by EVs alone**

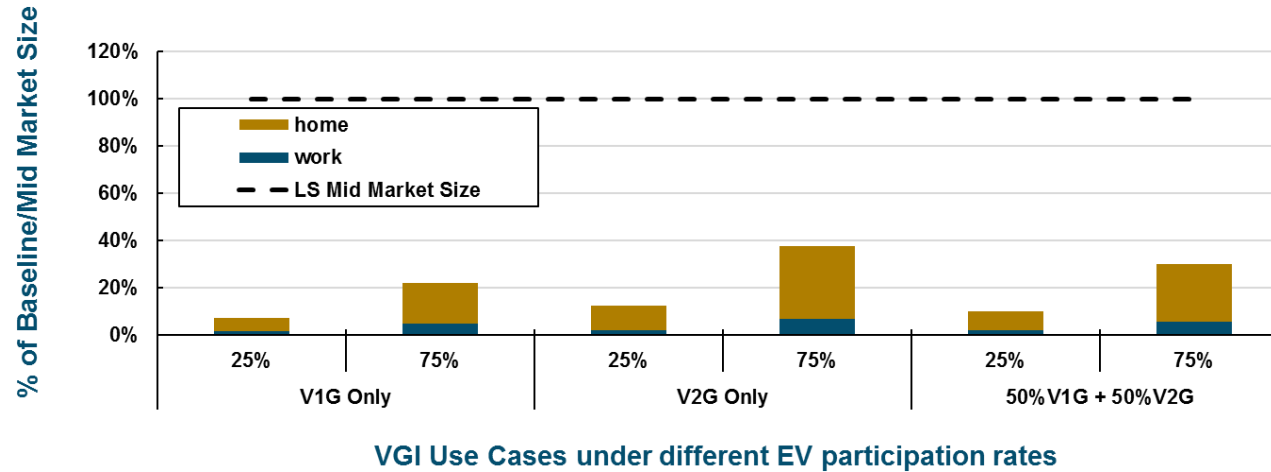


VGI saturates Frequency Regulation but not Load Shifting Market

Frequency Regulation



Load Shifting





3. VGI Market Revenues



Develop Market Prices from CPUC IRP Scenarios



Key Inputs From CPUC IRP Reference Scenarios

- 1 Load Forecast**
(Including Impact of Rooftop Solar, DG Storage, and EV Adoption)
- 2 Resource Buildout**
(To meet policy goals and reliability needs)
- 3 Transmission and Operational Changes**



Hourly Production Simulation and Long-Term Capacity Expansion



Hourly Production Simulation

- Wheeling costs and transactional friction between different zones
- Impacts and pricing from renewable curtailment
- Advanced hydro and storage representation
- Incorporate key energy policies and trends

4

Other Major Drivers:

- Gas Prices
- Carbon Prices



Key Model Outputs

Energy Market Price Forecast

- Hourly day-ahead energy market results by scenario and zone



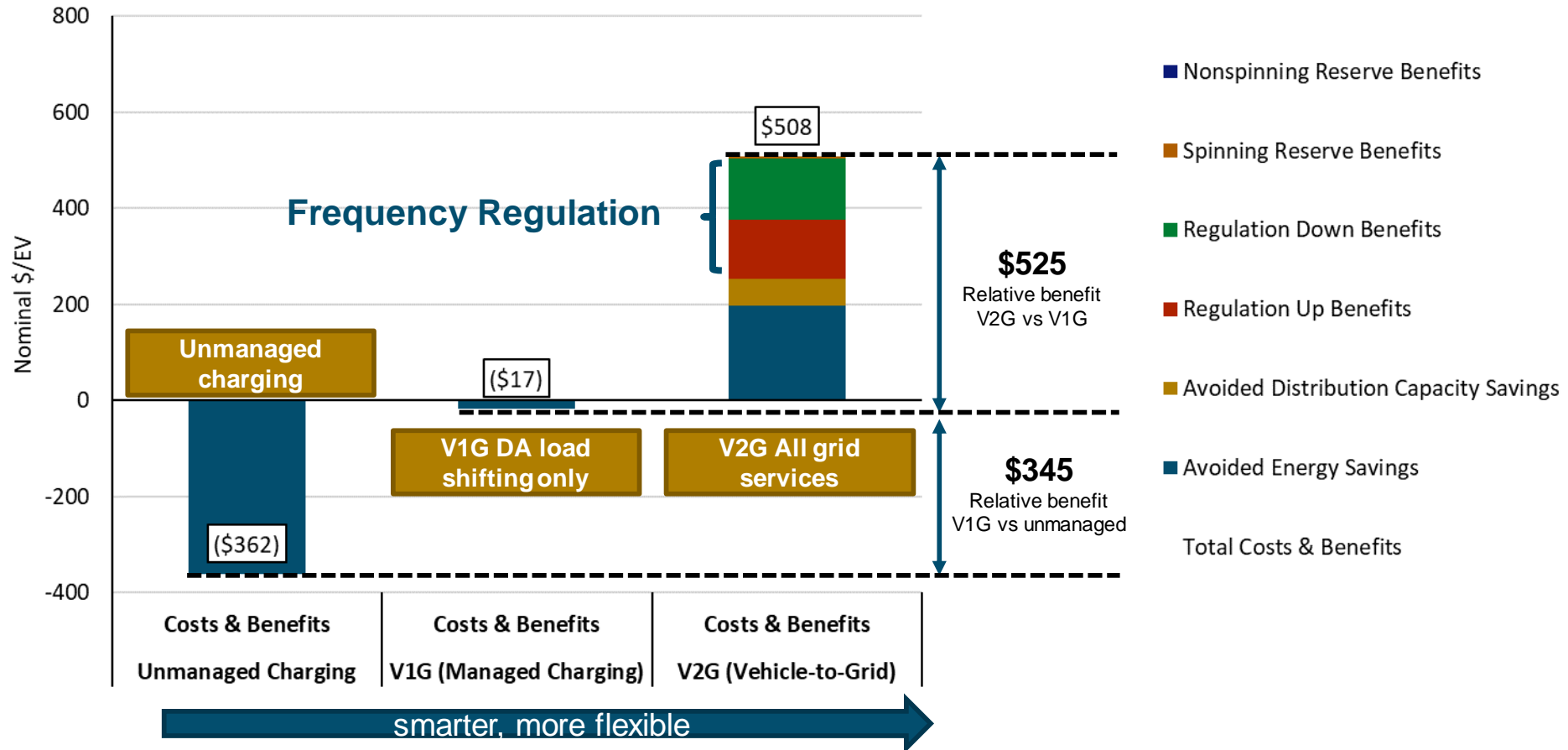
Derivative Outputs

Ancillary Services, Capacity, and Real-Time Energy Forecasts



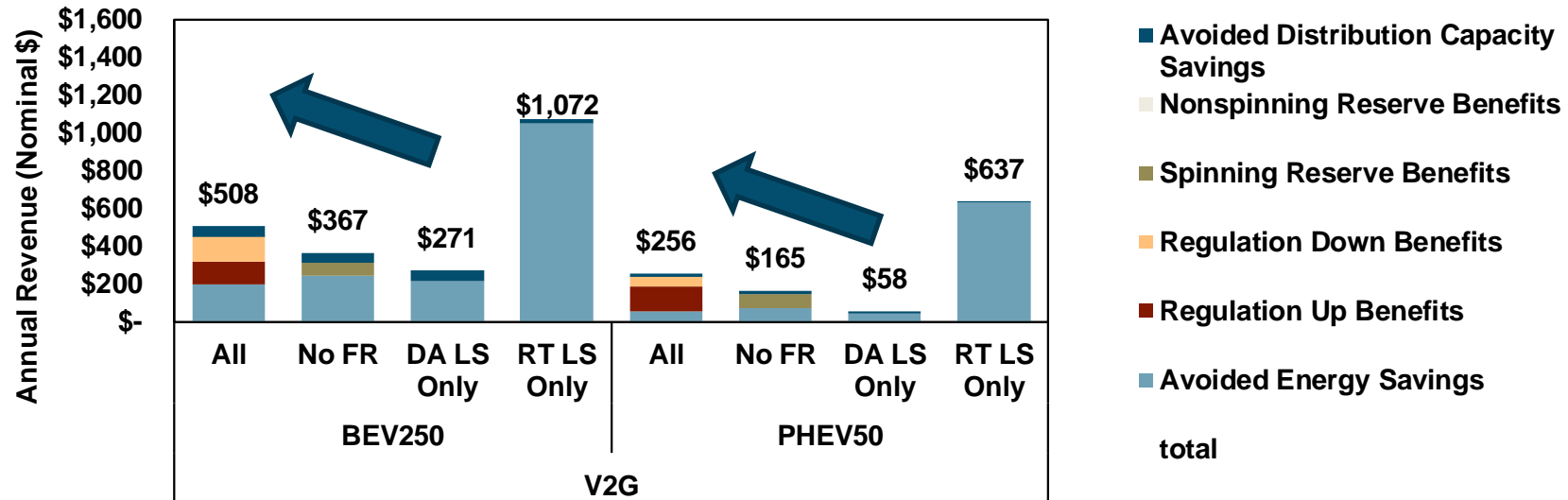
3. VGI Expected Revenue

- + BEV250 in 2025
- + Relative benefit of V2G versus unmanaged charging is \$870/EV-yr. (if Frequency Regulation prices remain high)





V2G Revenue for BEV250 and PHEV50



DA – Day Ahead Energy
RT – Real Time Energy

FR – Frequency Regulation
LS – Load Shifting

- + Increasing revenue potential with additional market services
- + Potentially high revenues in real-time energy market, but harder to forecast and capture

Price taker, perfect foresight co-optimized dispatch with market prices derived from 2018 42MMT Case



Key Drivers



Key Drivers and Uncertainties

IRP

EV Fleet

Quantifiable with Scenario Analysis

- + Renewable penetration
- + Cost of PV & storage
- + Regionalization & EIM

- + EV Adoption & BEV ratio
- + Intra- vs. Inter-session VGI
- + Workplace charging

Fillable Knowledge Gaps

- + Distribution costs of high electrification

- + Driver participation and behavior

Known Unknowns

- + Grid Modernization

- + Automated & shared vehicles (3 Revolutions)



In Conclusion

- + Define key drivers that can be quantified with scenario/sensitivity analysis
- + Quantify grid value with CPUC IRP scenarios (Demand)
 - IRP will enhance representation of distributed resources and EVs in next cycle
- + Estimate resource potential from EV's providing VGI services (Supply)
- + Estimate market size for VGI services
- + Develop market price forecasts from CPUC IRP scenarios
- + Estimate revenues from VGI services

