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When the Rubber Hits the Grid:
Planning for 100% Transit Electrification in Renewable Power Systems

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Agenda

- Background and Motivation
- Electrification with SB100
- Full On-Road Fleet Electrification
- System Impacts and Implications

Background & Motivation

- Past contributor to RE/TX CA planning initiatives (e.g. WREZ, RETI, RPS)
- Originally developed a 100 Percent RE model in 2015
  - Prior to SB100 legislation – 100% Zero Carbon by 2045
  - Used to identify major technical obstacles e.g. seasonal storage
- Present analysis funded by B&V, Growth Accelerator
  - See Transportation Electrification as a major Business Opportunity
  - Largest installer of high voltage charging – 1400 stations to date
  - Major provider of RE engineering and EPC service – 19 GW Solar; 26 GW Wind

Seek to explore possible implications of transportation electrification in the context of SB100 to inform understanding of technical obstacles and future opportunities.

100 Percent RE Model: Examine Tradeoffs between Generation, Curtailment and Energy Storage to Meet Load in 100% RE Scenarios

Forecast future demand

Develop load and generation shapes

Estimate RE capacity build-out compared to potential

Identify storage size (GW/GWh) needed to ensure all load is served by either storage or RE resources

Examine base case and scenarios to assess tradeoffs of RE overbuild, flexible generation, RE mixes, and curtailment versus energy storage.

Purpose is to understand magnitude of renewable development needed, storage requirements, and transmission impacts across scenarios.

Key Questions on 100% Transportation Electrification (TE) Explored in Today's Presentation

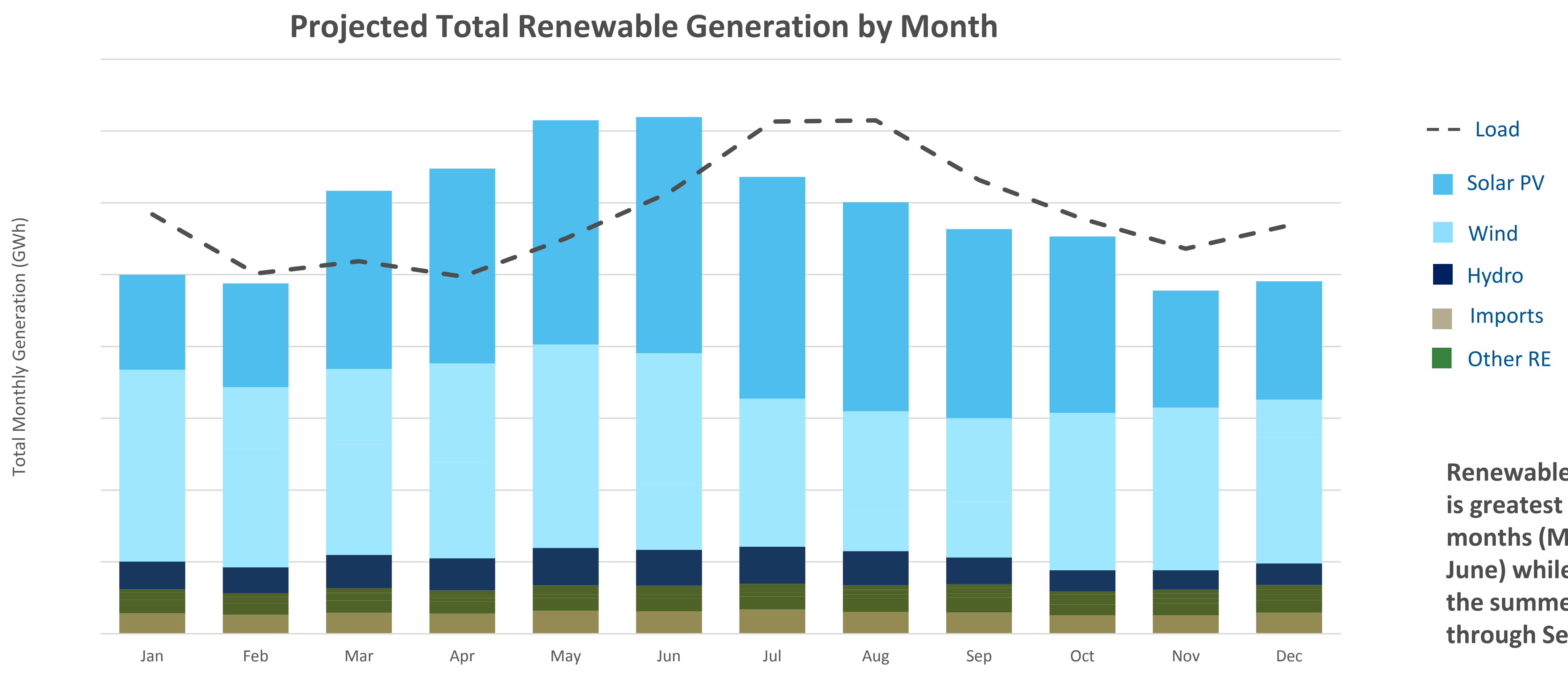
- What are possible opportunities for TE in the context of SB100?
- What are the impacts of 100% TE on statewide electricity consumption?
- How could various charging strategies impact peak load and what are the implications on overall infrastructure build and cost?

Disclaimer: this work is a high-level thought exercise and does not represent Black & Veatch's opinion on the feasibility, economics or desirability of 100% transportation electrification

Electrification with SB100

Seasonal Imbalance in CA between Load & Renewable Energy

Monthly overages and shortfalls require longer term storage solutions

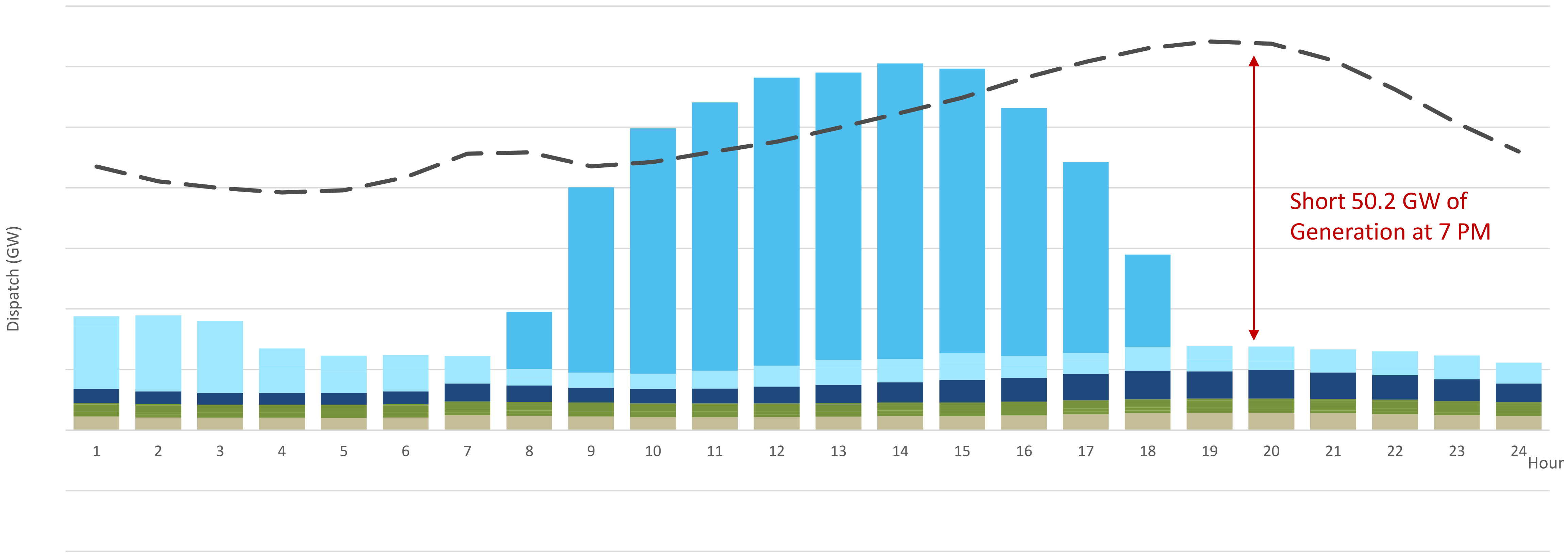


Renewable Energy output is greatest in the spring months (March through June) while load peaks in the summer months (July through September).

Source: Black & Veatch Analysis

Potential Challenges Achieving SB100

Great amount of energy storage discharge capability is needed during periods of higher electric load and renewable generation



Generation & Load Profile: September

Source: Black & Veatch Analysis

Challenges and Strategies to CA's 100% Zero Carbon Goal

Up to 30,000 GWh of storage capacity could be required

Energy Storage

- Longer term storage solutions
- Power to Gas, Flow batteries

Broaden RE Definition

- Include gas & Renewable Energy Credits
- Flexible resources become key

Renewables Overbuild

- Renewables curtailment
- Export capabilities
- Land access and environmental costs

Transmission Build

- Facilitate exports to WECC and beyond
- Significant costs & environmental impacts

Consider Two Strategies to CA's 100% Zero Carbon Goal (No EV)

High Storage Scenario	
Renewable Build	35 GW PV 30 GW Wind
Curtailment	< 0.5%
Storage Req.	40 GW, 20,000 GWh
Cost	Trillions

Curtailment Scenario – 2x RE	
Renewable Build	90 GW PV 70 GW Wind
Curtailment	50%
Storage Req.	40 GW, 300 GWh
Cost	250 Billion

Selected as Baseline for Electrification Analysis.

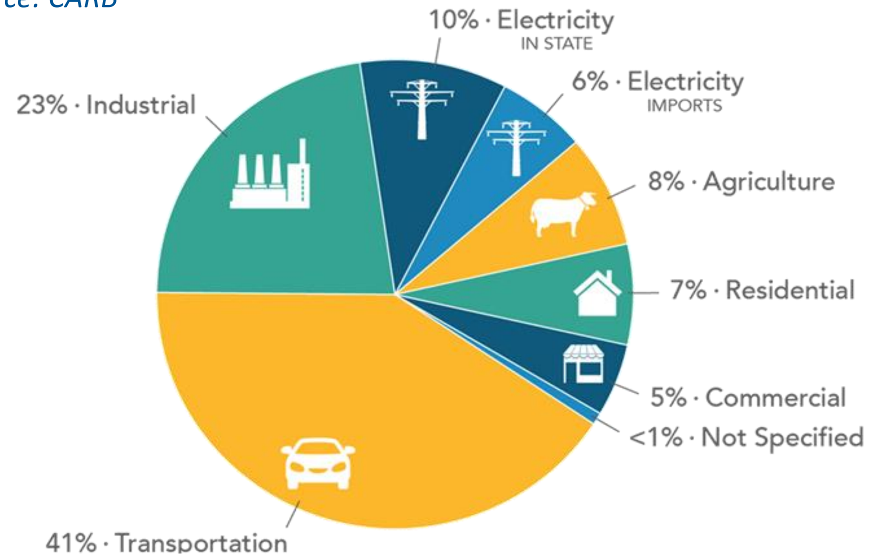
Use excess curtailment for EV charging.

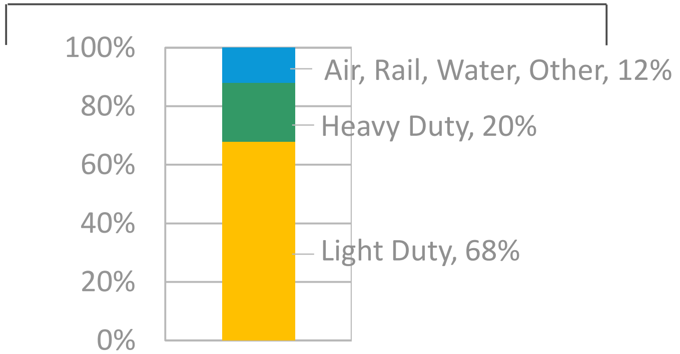
Energy Storage → Broaden RE Definition → Renewables Overbuild → Transmission Build

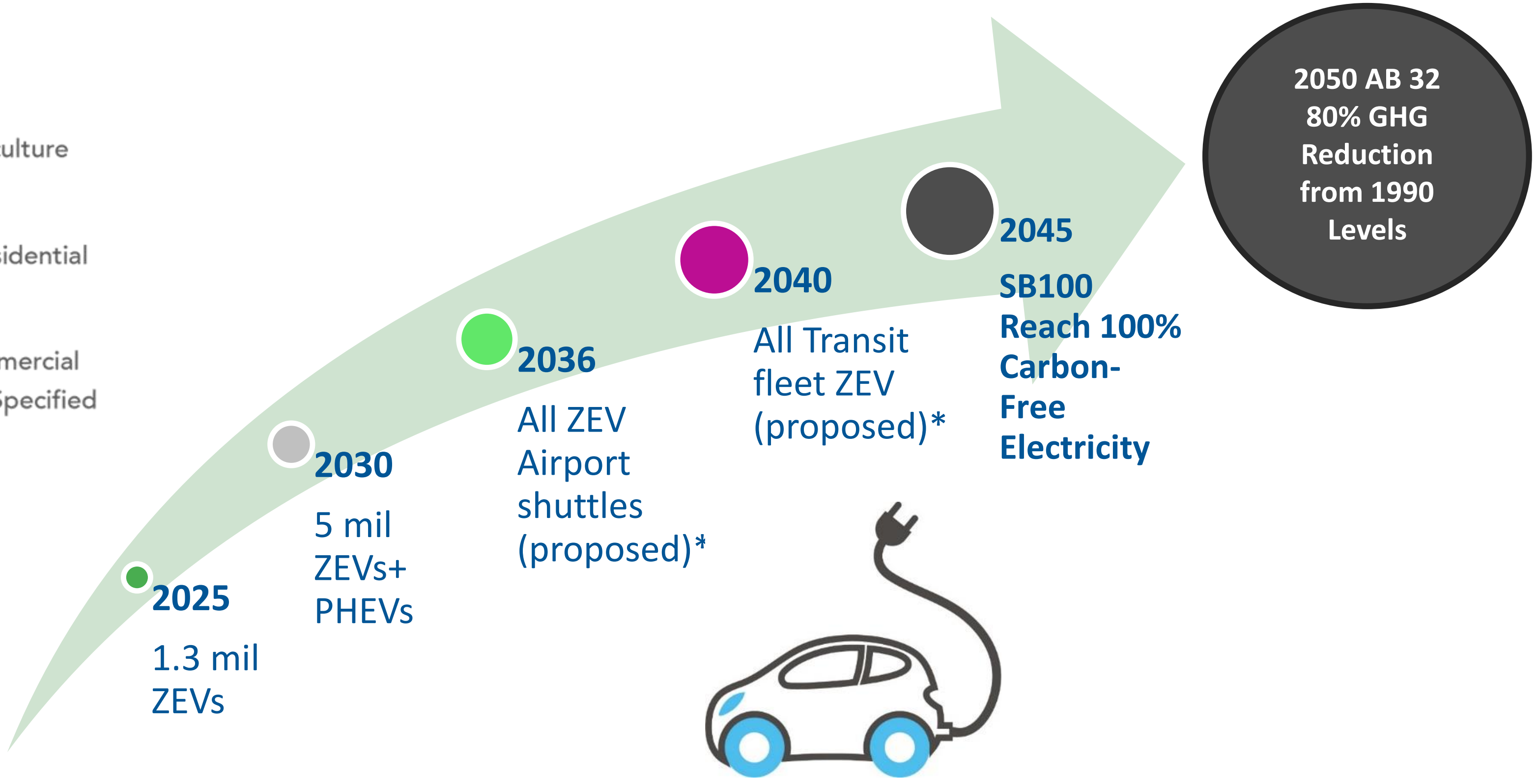
Full On-Road Fleet Electrification

In CA Transportation Sector produces more than 2.5x GHG compared to electricity; CA is On-path to Full De-Carbonization of On-Road Vehicles.

Source: CARB



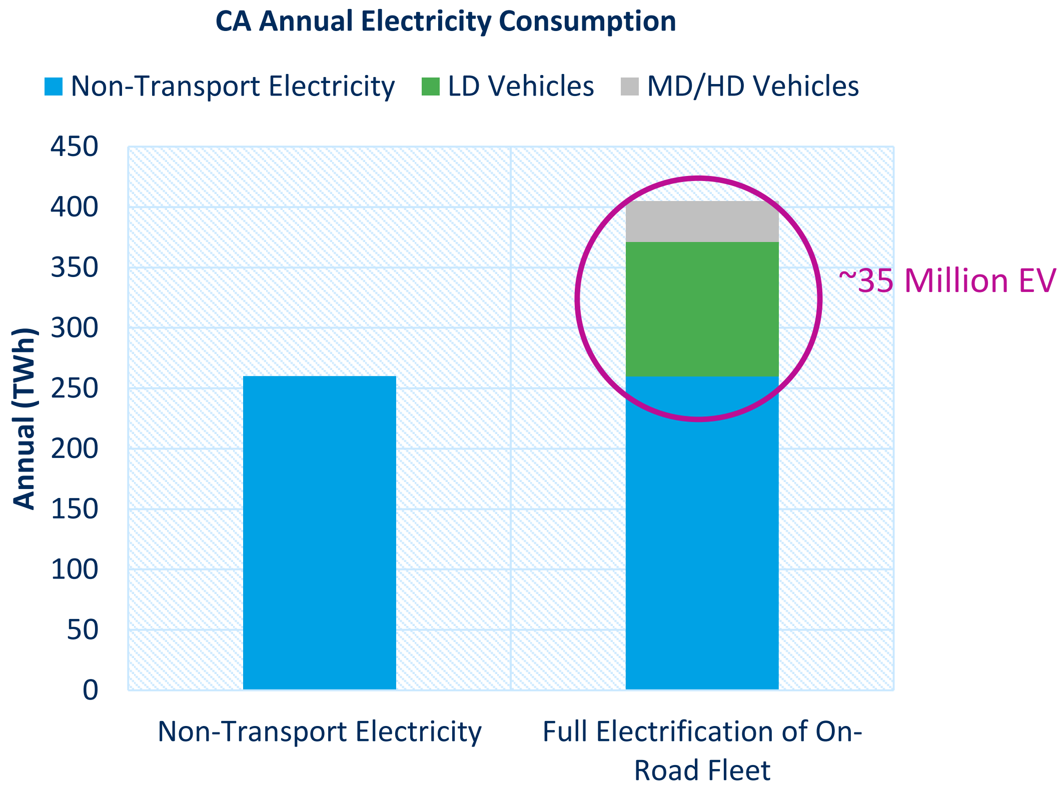




Proposed by CARB Presentation: https://www.arb.ca.gov/msprog/zev_fleet_workshop_presentation_083018.pdf

To get to GHG goals, 100 Percent of New On-road Vehicle Sales Would Need to Be EV by 2050

Full Electrification of On-Road Vehicles Increases CA Annual Electricity Consumption by Over 50 Percent



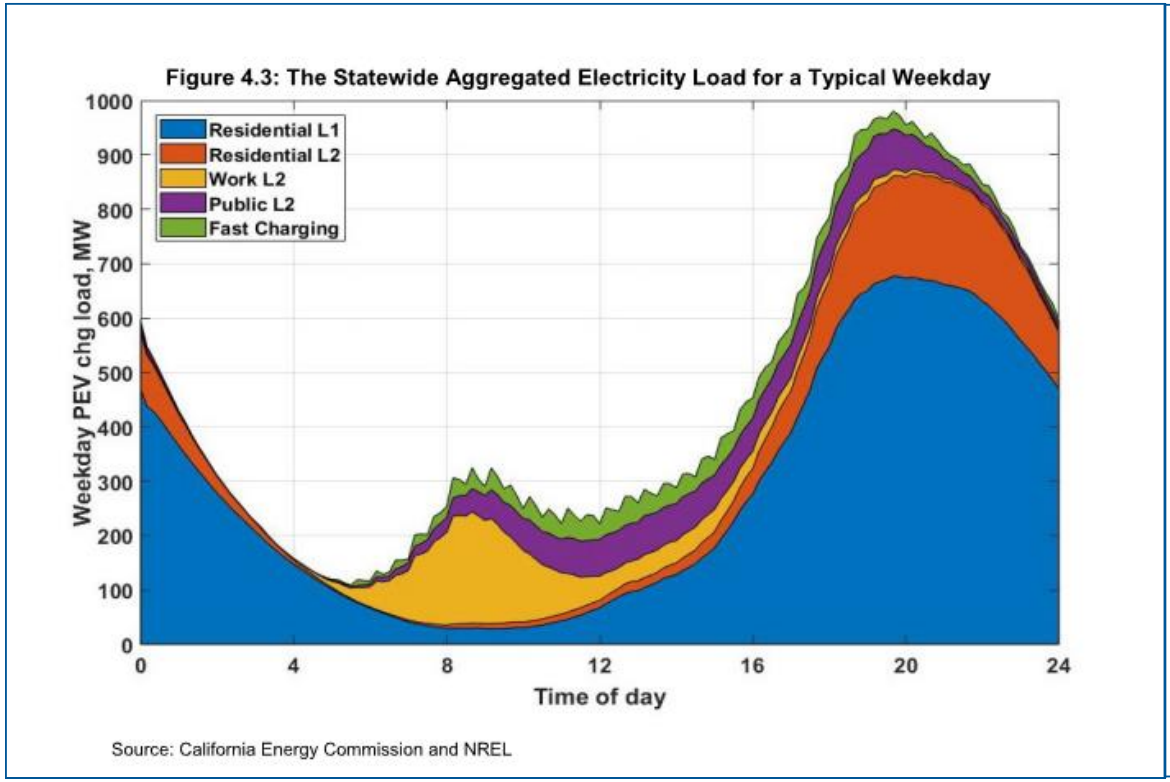
Source: *CARB, CA DMV, EIA, Black & Veatch Analysis*

CARB forecasts 35 million on road vehicles by 2050. The ratio of LDV count to MD/HDV count is about 30:1, but energy consumption is only 4:1.

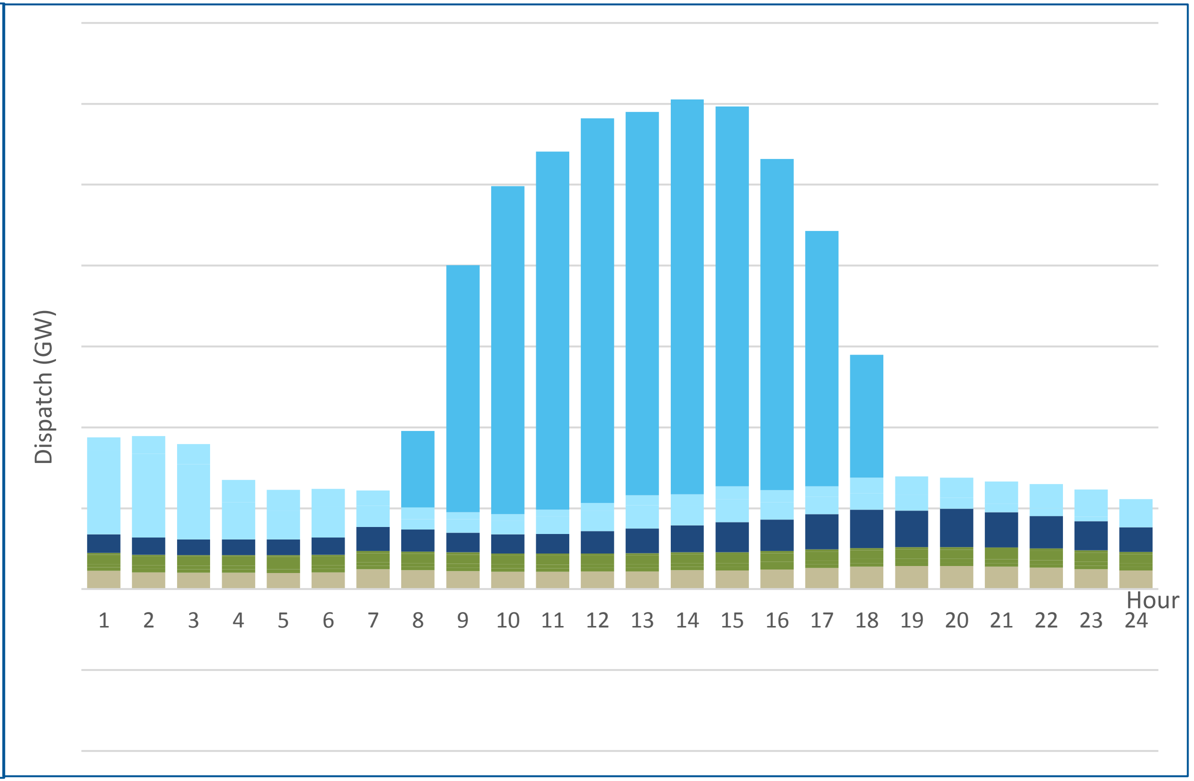
Total Electricity Consumption is based on VMT/efficiency from EIA. Vehicle stock based on CA DMV and CARB projections.

Unmanaged Charging Pattern Will Not Be Compatible with the RE Profile

Typical Unmanaged EV Charging



Renewable Energy



Flexibility is key to reducing the storage needed to use curtailed RE from SB100 scenario.

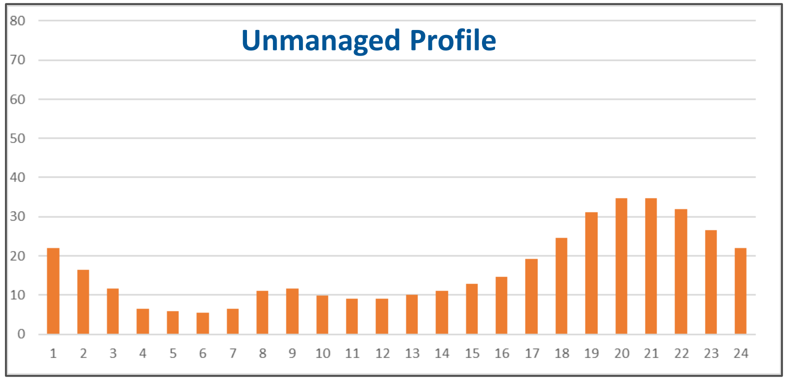
Is it Possible to Charge Full On-Road EV Demand from RE Curtailment?

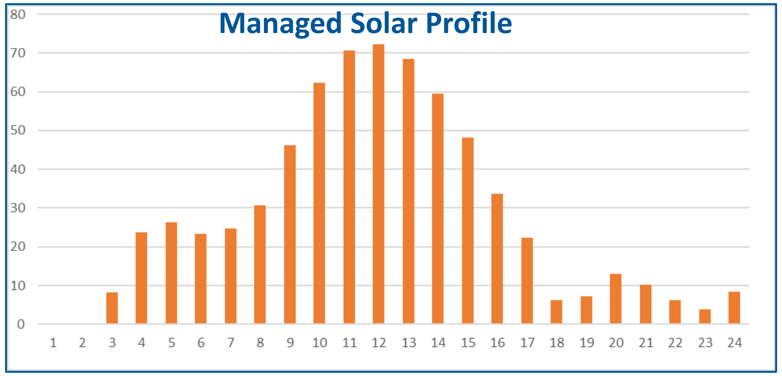
- **If EVs can be managed to charge coincident to RE production (during daytime hours) less large-scale BESS may be needed.**
- **Anticipate coincident EV charging has different requirements from the transmission system, distribution system and location of chargers.**

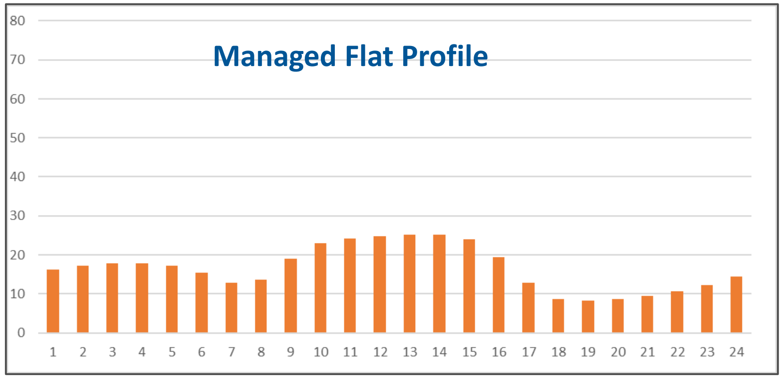
Ultimately, 100% electrification with renewable energy comes with greater infrastructure investments beyond EV charging stations

Modeled Three Scenarios to See How Different Charging Impacts the System

- **Unmanaged Load**
  - Historic EV charging (majority at home)
  - Weekday/Weekend profile from CEC/NREL
- **Managed Load - Solar**
  - Charges during time of curtailment (8760)
  - Eliminate extreme peak charging in critical hours.
- **Managed Load - Flat**
  - Flattens system load using average daily EV load (8760)

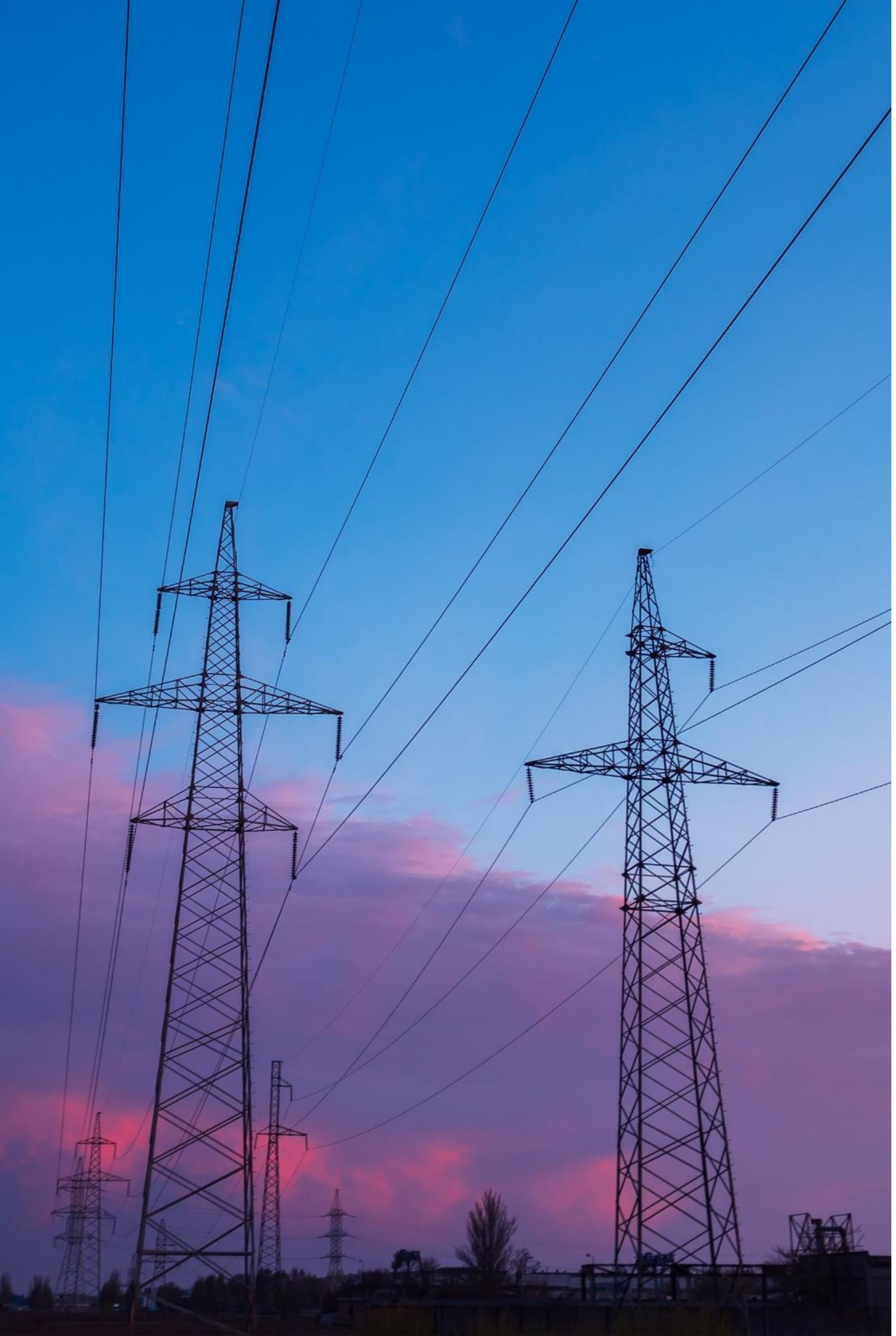






Scenarios not fully optimized! Designed as test cases.

System Impacts



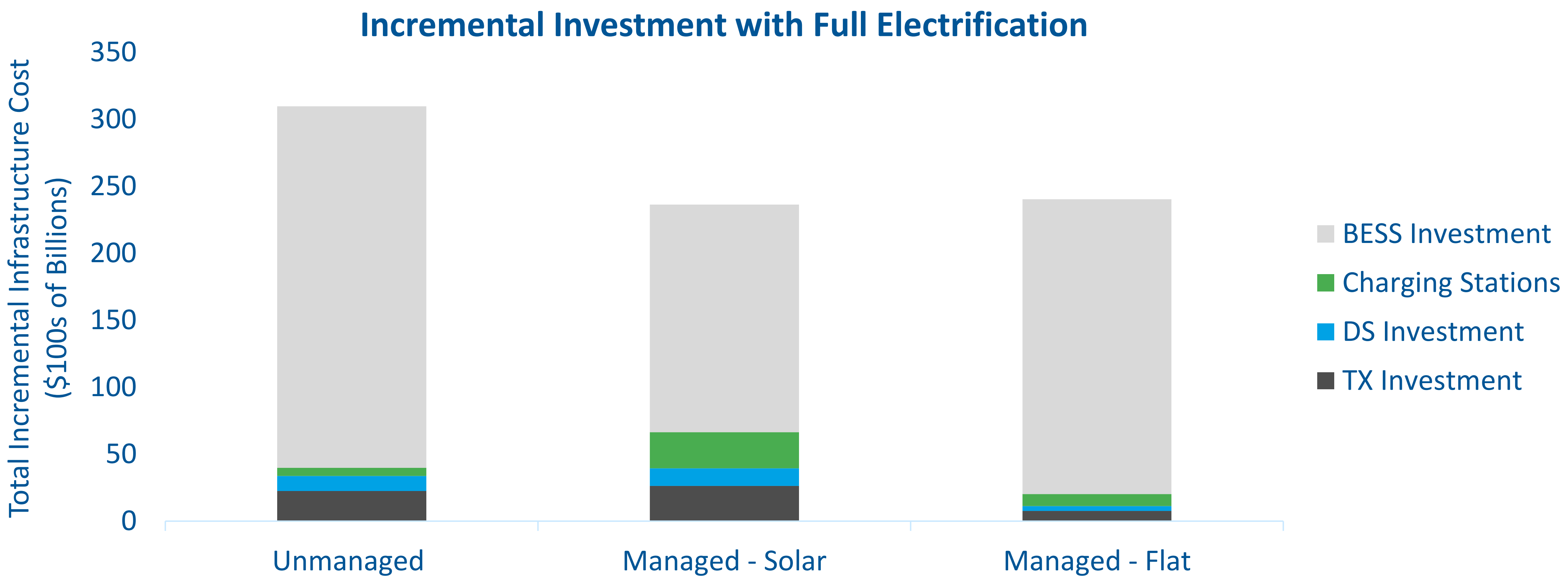
System Impacts with Managed and Unmanaged EVs

Load Scenario	Annual Peak Load (GW)	Incremental T&D	Incremental Storage
No EVs [1]	60 GW	-	-
Unmanaged Load	90 GW	+ 30 GW	+ 20 GW, + 2700 GWh
Managed Load – Solar	95 GW [2]	+ 35 GW	- 10 GW, + 1700 GWh
Managed Load - Flat	70 GW	+ 10 GW	+ 5 GW, + 2200 GWh

- **System peak increases in solar/ unmanaged cases.**
- **Storage need decreases for coincident charging; required storage is from seasonal impacts.**

1. Installed storage in No EV case is *40 GW, 300 GWh (previous slide)*
2. When charging is allowed during all curtailment the peak equals 115 MW; however exceeded 95 GW only 0.2% of the year (24 hours total), thus limited EV charging in these hours as a realistic measure. Scenarios not fully optimized!

Tradeoffs Between BESS and Managed EV Charging



Managed EV charging may improve incremental costs in SB100 future. Increased infrastructure requirements for managed charging outweighed by flexibility cost (storage).

Disclaimer: Assumed costs for equipment are optimistic. TX = $750/kW, DS = $375/kW, BESS = $100/kWh, L2 Charging Stations = $3K. Does not include any managed incentives.

Main Findings

- **100% RE power systems may result in substantial amounts of curtailment as an economic alternative to seasonal storage.**
- **High-penetration EV can take advantage of a large portion of otherwise curtailed electricity through workplace and public charging.**
- **There is a trade-off in infrastructure cost (e.g. chargers, T&D) for managed charging vs. increased system flexibility requirements for unmanaged scenarios.**
  - **For the examined scenario the increased infrastructure cost of managed charge was small relative to required flexibility (storage) and associated cost.**
  - **Relative cost has heavy dependence on future storage and T&D cost.**
- **For examined scenario grid investment is fraction of vehicle cost. Amortized, relatively inexpensive (100s $/yr) compared to EVs (1000s $/yr).**

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