NREL
Transforming ENERGY

Transforming ENERGY through SUSTAINABLE Mobility

Role of Electric Vehicles in the U.S. Power Sector Transition

A System-level perspective

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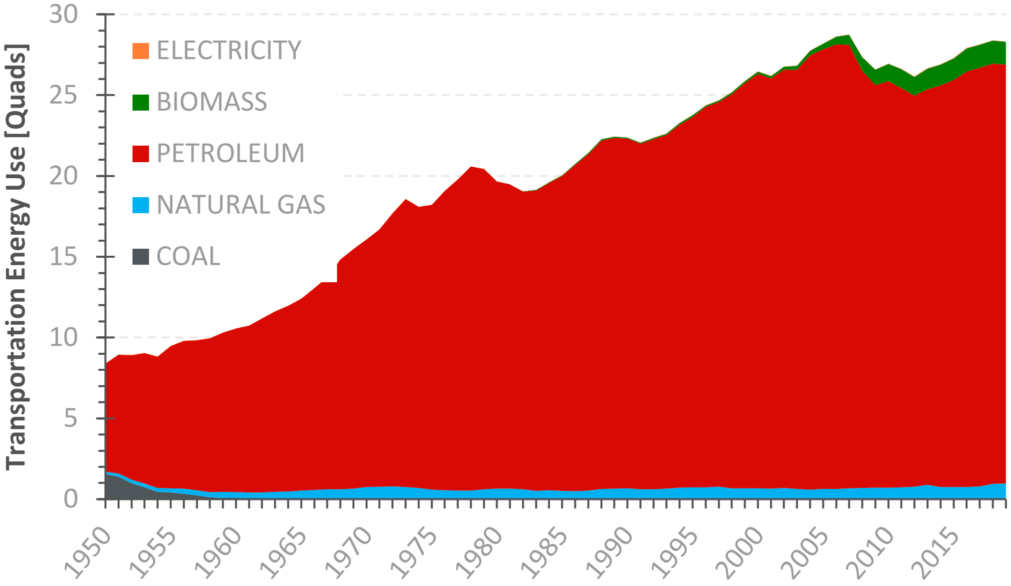
4th E-Mobility Power System Integration Symposium

Keynote Session – November 3rd, 2020

Transportation systems have relied on petroleum for over a century…

Today, transportation is the **largest source of energy-related CO_2 emissions** in the U.S. and it is responsible for ~70% of total petroleum use.



Source: NREL. Data from EIA Annual Energy Review

<u>Least-diversified energy sector</u>

Over 90% of transportation energy use from petroleum

5% from bioenergy

Electricity accounts of 0.1% of transportation energy use and transportation consumes 0.2% of electricity

… but the landscape is changing rapidly

Battery cost declined by 90% since 2010 and pack prices expected below $100/kWh by 2024.

– BloombergNEF

Cheaper to save the climate than to destroy it: **renewable energy prices** are now significantly below those for coal and gas generation, less than half the cost of nuclear.

– Forbes (LAZARD)

California **bans new combustion engine** cars starting in 2035

– State of California

Sales of electric cars topped 2.1 million globally in 2019 – 2.6% of sales – to boost the stock to 7.2 million EVs.

– International Energy Agency

2019 EV sales reached 56% in Norway and **8% in California**

– International Energy Agency

The **future of cars is electric** – but how soon is this future? By 2025, 10% of global car sales, rising to 58% in 2040.

– Electric Vehicle Outlook 2020, BloombergNEF

Amazon has placed an order for **100,000 electric delivery vans** to be on the road by 2024.

– USA Today

Average length-of-haul for heavy trucks has declined **from 800 to 500 miles** between 2000 and 2018.

– ATRI

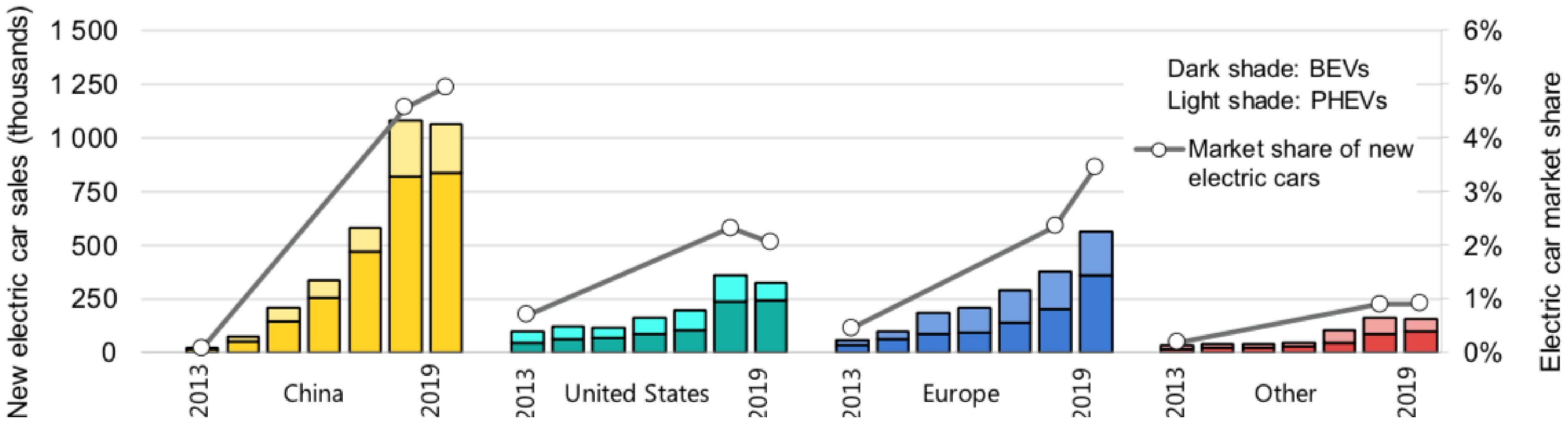
DHL: Tesla semi trucks pay for themselves in 1.5 year

–CleanTechnica

Global LDV EV market expanding rapidly

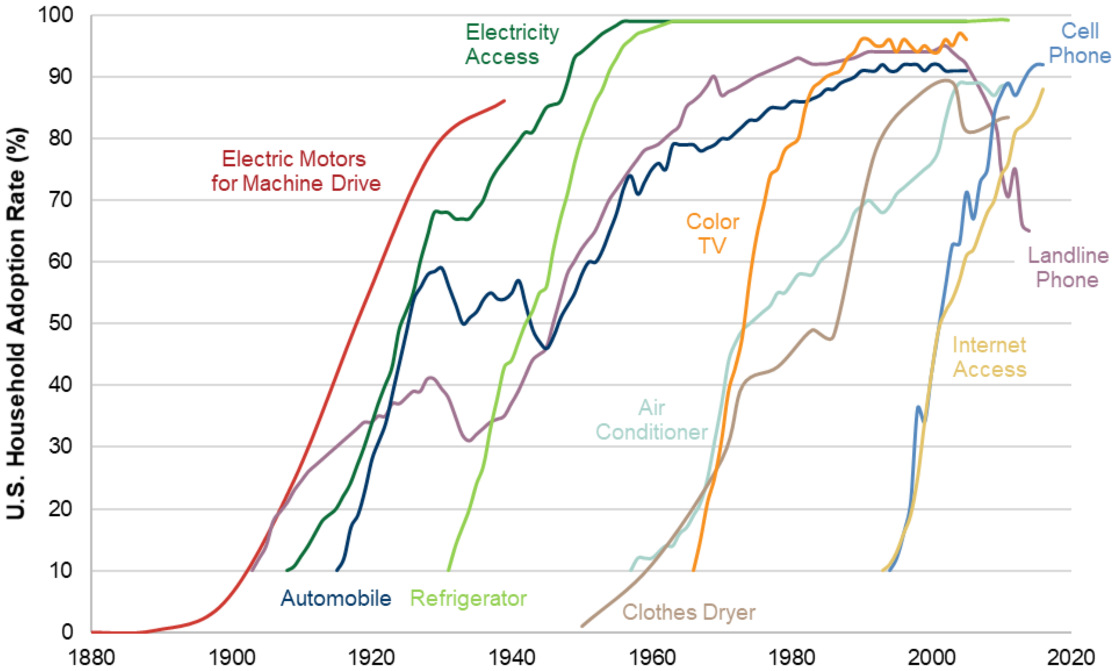
The worldwide **market share of electric cars reached a record high** of 2.6% in 2019, expanding in all major markets except Japan, Korea and United States.

Norway: 56% of 2019 sales. California: 8% of 2019 sales.



Source: 2020 IEA Global EV Outlook

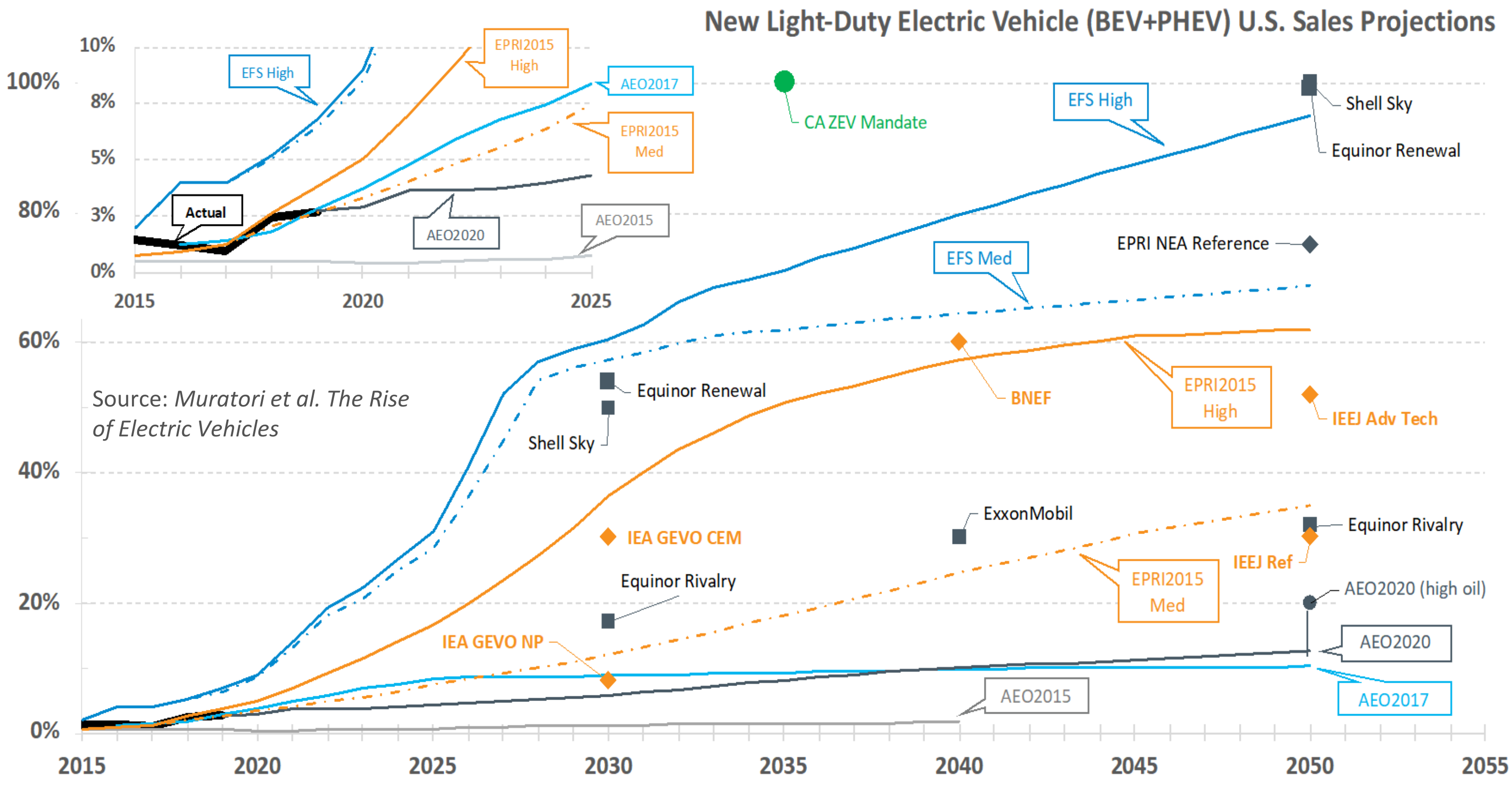
Technology adoption and energy transitions generally follow S-curve shape and are generally underestimated



invention → innovation → niche market → pervasive diffusion → saturation → senescence

Source: https://www.nrel.gov/analysis/electrification-futures.html

Future expectations: consistently adjusting US LDV EV sales projections upward



Future expectations: beyond LDV towards commercial vehicles

EVs have **zero exhaust emissions and cost less to fuel and maintain.**

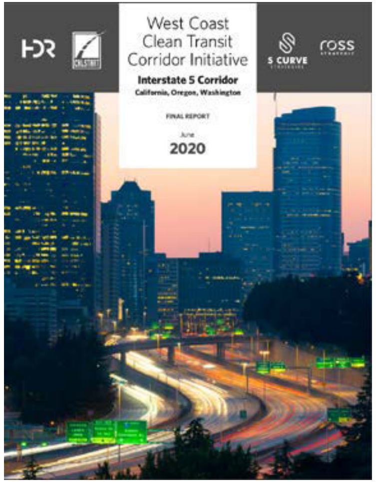
Recent policy momentum for heavy-duty truck electrification:

- In June 2020, **CARB approves M/HDV sales mandate** starting in 2024 and requiring all new sales be ZEVs by 2045[1].
- In July 2020, Governors from 15 states (+ Washington, D.C.) signed **joint MOU committing to 100% of M/HDV sales be ZEVs by 2050 with an interim target of 30% ZEV sales by 2030**[2].

CALIFORNIA
AIR RESOURCES BOARD

California takes bold step to reduce truck pollution

First-of-its-kind requirement for electric trucks will help communities hardest hit by air pollution



MONEY

Tesla stock closes at record highs on electric Semi news

Dalvin Brown USA TODAY
Published 9:43 a.m. ET Jun. 11, 2020 | Updated 4:19 p.m. ET Jun. 16, 2020

MARKETS

Meet Nikola, the speculative electric vehicle stock that traders believe is as valuable as Ford

Pippa Stevens

TRANSPORTATION

EV Truck Company Hyliion Is Soaring — and It Isn't Even Publicly Traded Yet

By Nicholas Jasinski Updated June 29, 2020 3:19 pm ET / Original June 29, 2020 2:08 pm ET

[1] California Air Resources Board – CARB, June 25, 2020, https://ww2.arb.ca.gov/news/california-takes-bold-step-reduce-truck-pollution
[2] New York State, Gov. Cuomo, July 14, 2020, https://www.governor.ny.gov/news/governor-cuomo-announces-new-york-and-14-states-and-dc-ramp-electrification-buses-and-trucks

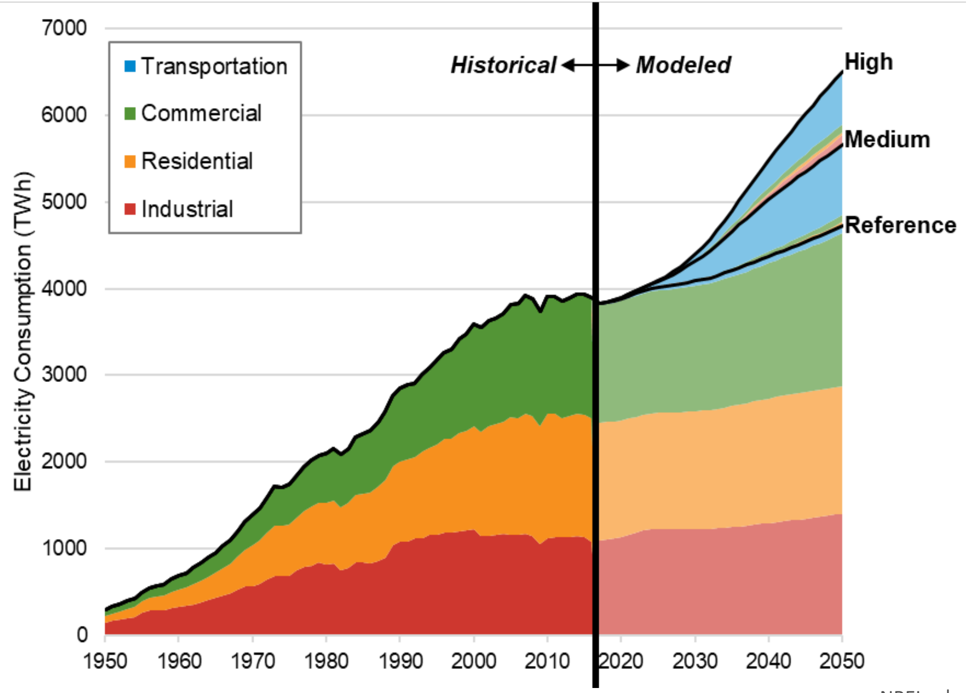
U.S. scenarios of widespread electrification

EFS scenarios project **great degree of future electrification, especially for transportation,** in line with several energy system transformation scenarios

EFS High scenario, 2050:

- Transportation share of electricity use increases **from 0.2% in 2018 to 23% of electricity consumption in 2050.**

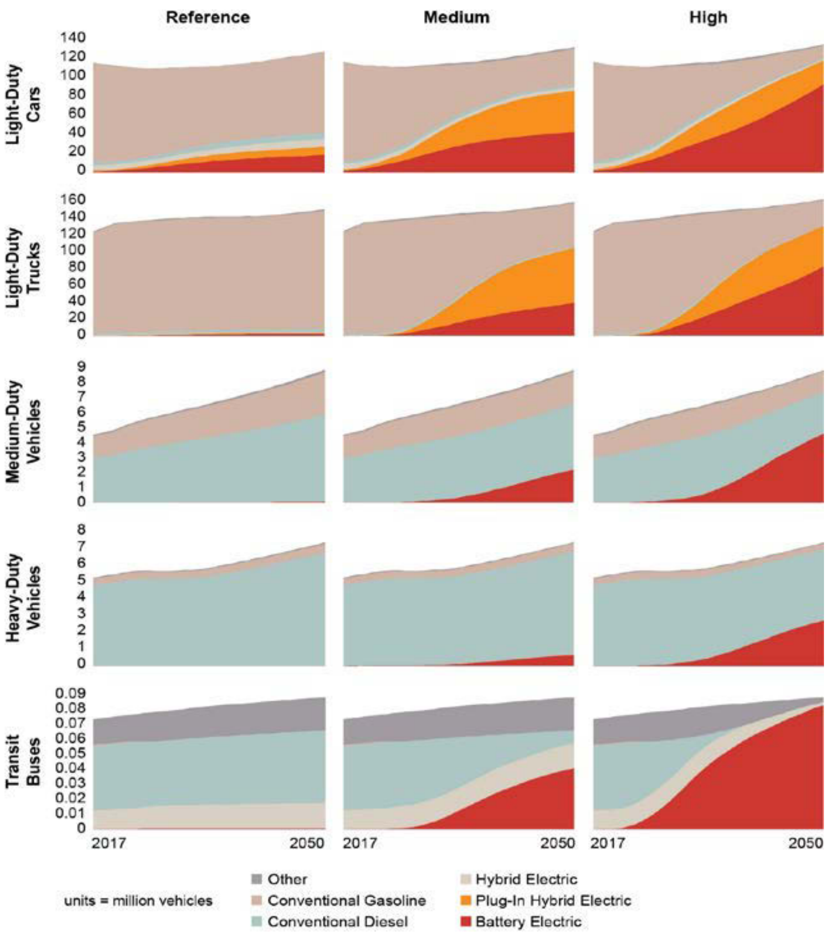
- **1,424 TWh increase in transportation-related electricity consumption** relative to the 2050 Reference scenario.



Source: https://www.nrel.gov/analysis/electrification-futures.html

EFS transportation sector details

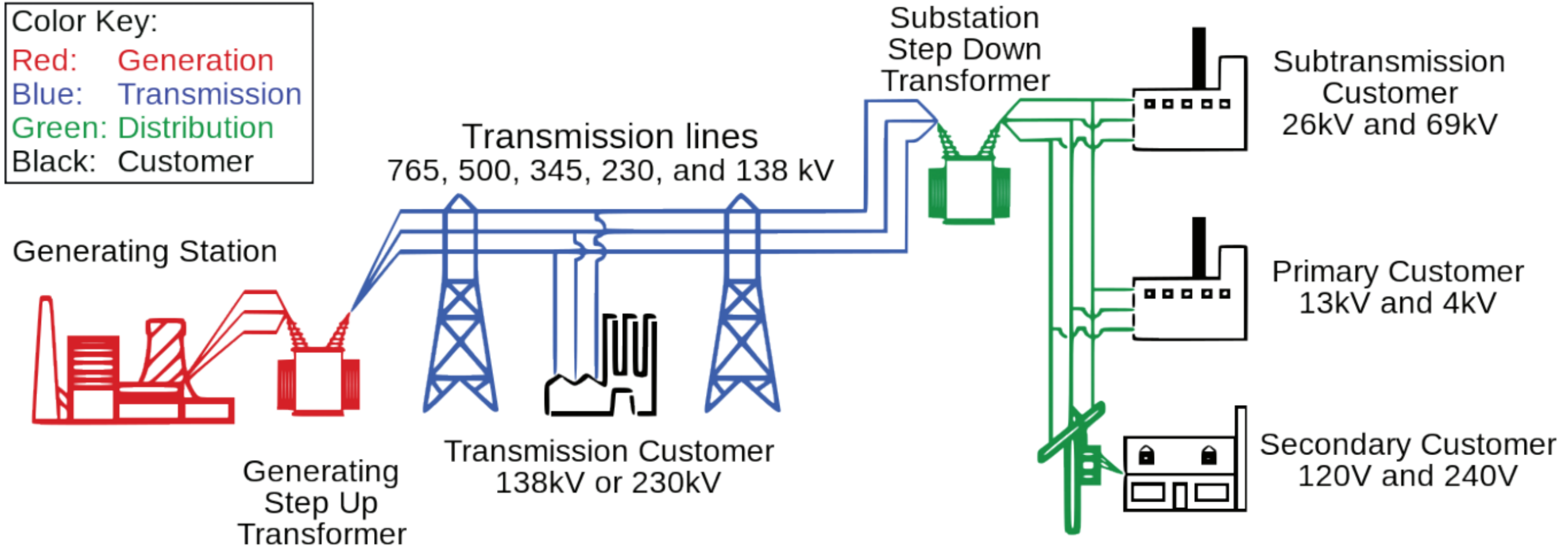
- 2050 U.S. transportation fleet (High scenario):
  - **240 million** light-duty plug-in electric vehicles
  - **7 million** medium- and heavy-duty plug-in electric trucks
  - **80 thousand** battery electric transit buses
- Together these deliver up to **76%** of miles traveled from electricity in 2050
- 138,000 DCFC stations (447,000 plugs) and 10 million non-residential L2 plugs for light-duty vehicles



Vehicle stock

Source: https://www.nrel.gov/analysis/electrification-futures.html

Traditional electricity system: large-scale generation; centralized, one-way control; and passive loads



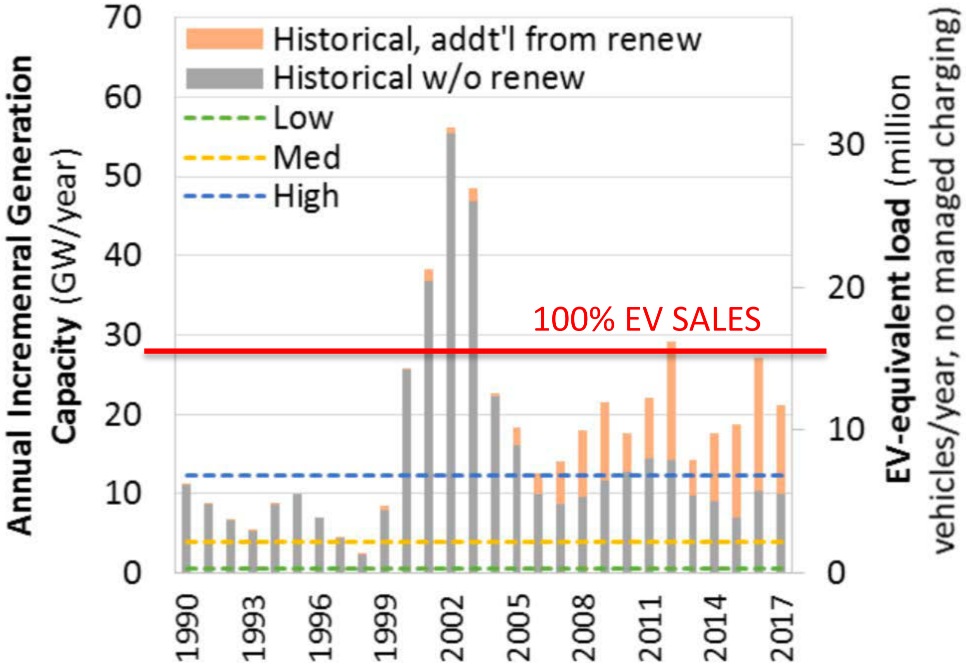
Source: DOE 2015 QTR

➢ Breakdown of **US average retail electricity prices** (data from EIA):

Generation: 58% Transmission: 13% Distribution: 29%

Are EVs going to "break" the grid (bulk systems)? Unlikely

- **~17M light-duty vehicles** are sold each year in the US
- The **grid has evolved** over time to accommodate greater annual load additions
- Based on historical growth rates, sufficient energy generation and generation capacity is expected to be available to **support a growing EV fleet as it evolves over time.**

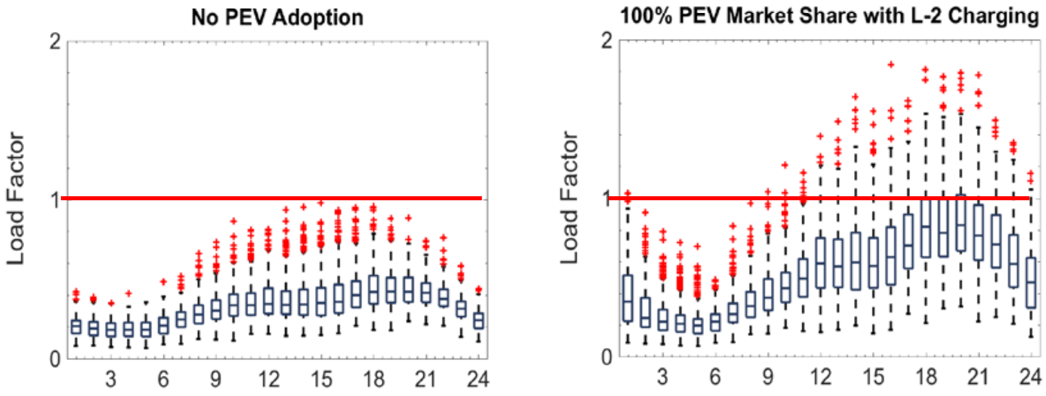


Source: US DRIVE 2019

Are EVs going to "break" the grid (local distribution systems)?

Residential EV charging represents a significant increase in household electricity consumption that can require upgrades of the household electrical system and unless properly managed it may lead to exceeding the maximum power that can be supported by distribution systems, especially for legacy infrastructure and during high demand times.

- **Clustering effects** in EV adoption and **higher power** charging exacerbates these issues
- Effective planning, smart EV charging, and distributed energy storage systems can help to cope with these potential issues.
- Key to **consider EVs in system upgrades**



Source: Muratori, M., 2018. Impact of uncoordinated plug-in electric vehicle charging on residential power demand. Nature Energy, 3(3), pp.193-201.

The grid is also transforming

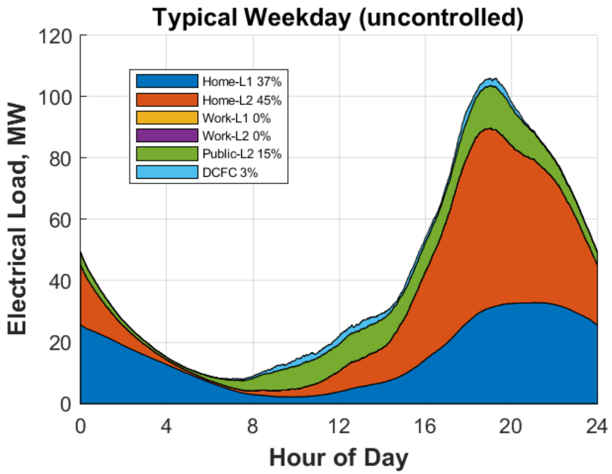
The **electric power system is undergoing profound changes**.

The traditional system based on the predicament that generation is dispatched to match demand is evolving into a more **integrated supply/demand system** in which demand-side distributed resources (generation, energy storage, and demand response) respond to supply-side requirements, mainly driven by variable renewable generation.

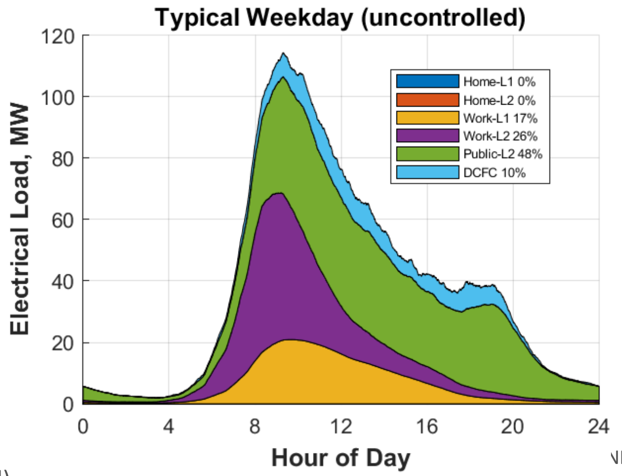
And EVs are not just a "burden", flexible EV charging can satisfy mobility needs while also supporting the grid

- **Vehicles are underutilized assets**: parked ~95% of the time. EV charging profiles can look significantly different if vehicles are charged at different locations or times
- **Flexibility is secondary to mobility needs and is enabled by charging infrastructure**

Home-dominant charging



No-home charging

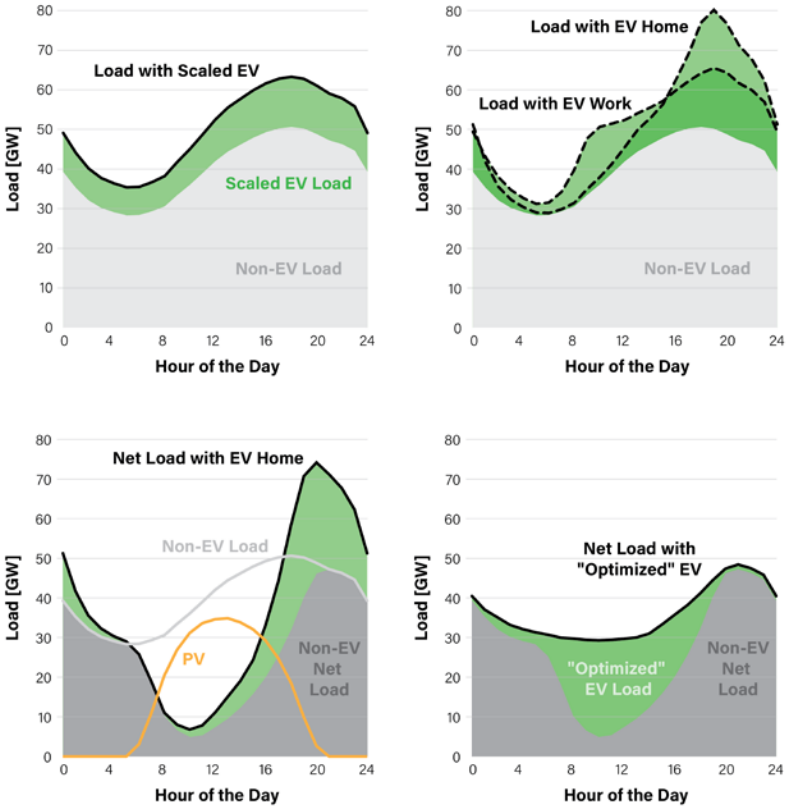


Source: NREL (EVI-Pro Model)

When and *where* EV charging occurs will be as critical as *how much* electricity is needed.

a) ASSUMPTION:
EV charging is often assumed to simply scale up electricity demand.

b) COMPLEXITY:
Future EV charging could change the shape of demand, depending on when and where charging occurs.



c) INTEGRATION:
EV charging can impact power system planning and operations, particularly with high shares of variable renewable energy.

d) FLEXIBILITY:
Optimizing EV charging timing and location could add flexibility to help balance generation and demand.

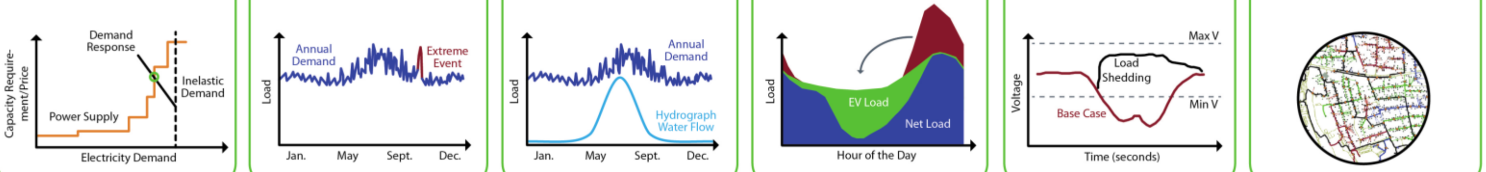
Source: *Muratori and Mai, The Shape of Electrified Transportation*

More nuanced demand-side modeling needed to assess the integration opportunities of EVs on the power system.

EVs can support the grid in multiple ways providing values for different stakeholders, including non-EV owners

Smart electric vehicle-grid integration can provide flexibility – the ability of a power system to respond to change in demand and supply – by charging and discharging vehicle batteries to support grid planning and operations over multiple time-scales

Power System Application	**Generation Capacity and Transmission/ Distribution Planning**	**Resilience To Extreme Events**	**Seasonal Planning (Hydro/Long-Term Storage Dispatch)**	**Commitment and Dispatch Decisions**	**Balancing and Power Quality**	**Support End Consumers**
Time scale	*Multi-year*	*Years (planning), hours (real-time response)*	*Months*	*Days to Hours and Sub-Hours*	*Seconds to sub-seconds*	*Years (planning), hours (real-time response)*
Vehicle-Grid Integration value	Ability to reduce peak load and capacity requirements and defer distribution systems upgrades if reliable EV charging flexibility is available	Load response to natural events (heat waves, tornados) or human-driven disasters, load postponement over days, and support microgrid management and grid restoration (V2G)	No role for EVs	Leverage EV charging flexibility to support supply dispatch and load-supply alignment (tariff management), variable renewables integration, operating reserves, energy arbitrage (V2G)	Provide voltage/frequency regulation and support distribution system operations	Tariff management (e.g., mitigate retail demand charges), complement other distributed energy resources (smart load, generation and storage), and minimize equipment aging/upgrades



Source: *Muratori et al. The Rise of Electric Vehicles*

Value of managed EV charging

Missing a holistic assessment of the value of smart charging across multiple value streams

SYSTEM-LEVEL (GRID)

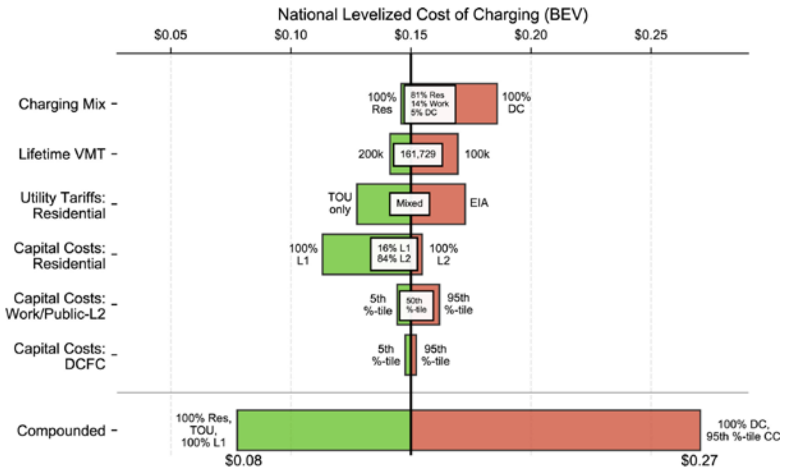
Smart charging of **3M EVs in California in 2030**:

- 3%–8% reduction in **electricity production costs** ($210–$660M)
- Reduce **peak demand** by 2.8% (avoided capacity)
- Reduce **renewable curtailment** by up to 13%
- Reduce grid **CO_2 emissions** by 3%–5%

Source: *Zhang et al. 2018*

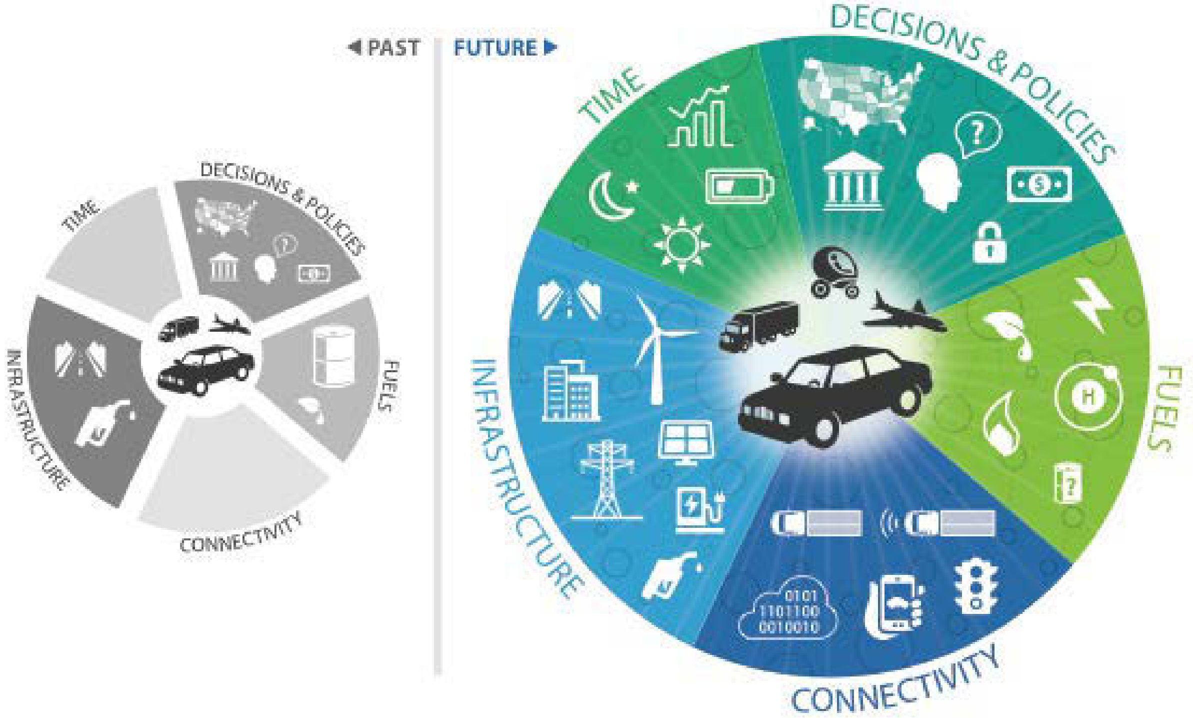
RETAIL-LEVEL (CONSUMER)

Shifting residential charging to off-peak time-of-use (TOU) periods **reduces charging costs by 26%**



Source: *Borlaug et al. 2020*

We envision a future transportation system that will be optimally **integrated** with smart buildings, the electric grid, renewables, and other infrastructure to maximize energy productivity and achieve an economically competitive, secure, and sustainable future.



Emerging topic: electric vehicles are rapidly changing the transportation demand landscape

Integration challenges/opportunities:

- **Electric vehicles provide a pathway** to decarbonize the transportation system, eliminate tailpipe emissions, solve petroleum dependency, and improve system efficiency
- EV success is dependent on **cheap and abundant clean electricity**, but EV flexibility enables for **synergistic improvement** of the efficiency & economics of mobility and electricity systems:
  - **Optimize the design and operation** of future integrated systems
  - **Reduce mobility and energy costs** for all consumers
  - Smart charging unlocks the synergies between EVs and VRE as both promise large-scale deployment
- **System-level integrated demand/supply thinking** is required

Two large and complex industries are on a "collision path": how to enable effective integration?

- What are the **tradeoffs across different VGI value streams**?
- What **technologies and infrastructure** are required to enable smart charging?
- How to **engage and properly compensate EV users** for providing flexibility?

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Thank you!

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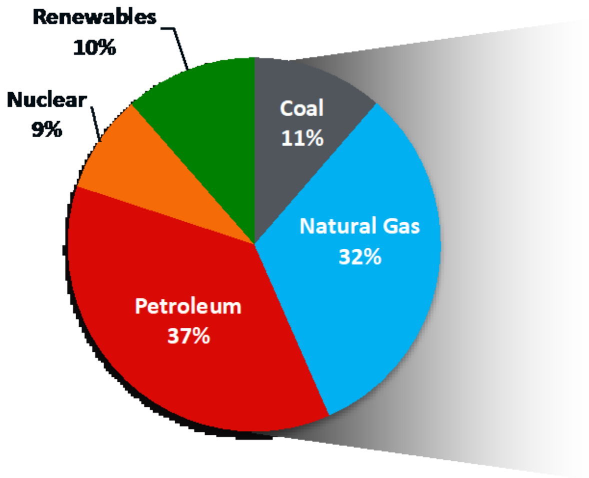
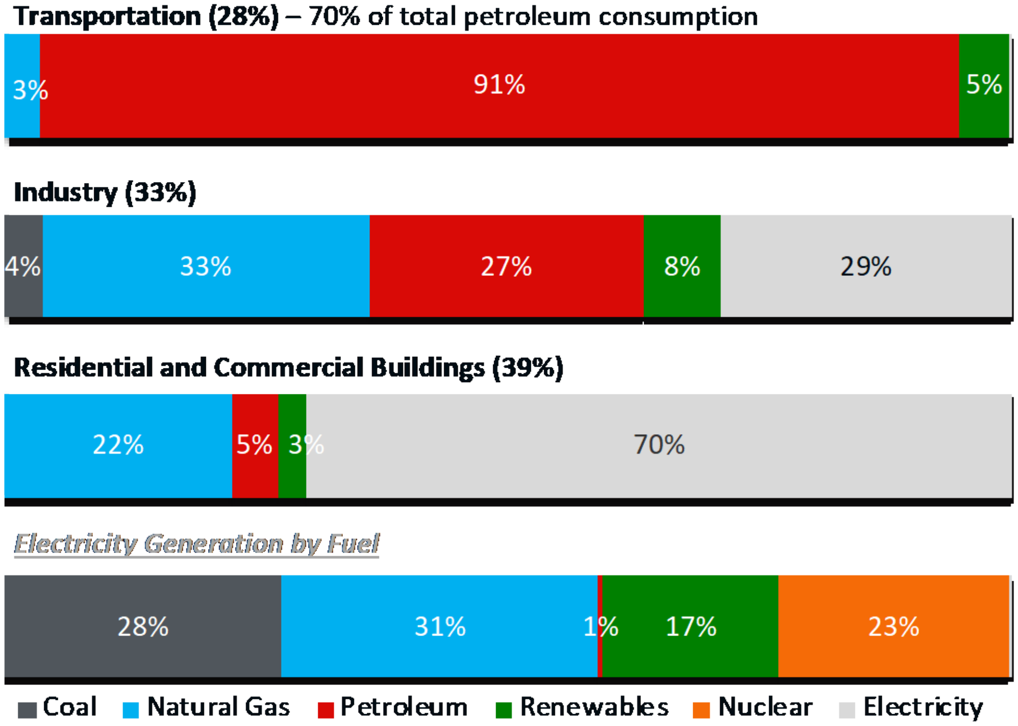
Transportation in the energy context

U.S. Primary Energy By Fuel (2019)



Source: NREL. Data from U.S. Energy Information Administration Annual Energy Review

U.S. Energy Consumption by Sector and Fuel (2019)



Over 90% of transportation energy use from petroleum: least-diversified energy sector

Projecting disruptive pathways is complex, and requires new “thinking” (modeling)

TEMPO (Transportation Energy & Mobility Pathway Options) is intended to generate future **pathways to achieve system-level goals**, explore the impacts of technological breakthroughs and behavioral changes, estimate energy/emissions implications of different scenarios and decisions, affordability and infrastructure use impacts, and assess **multi-sectoral integration opportunities**.