NREL
Transforming ENERGY

Transforming ENERGY through SUSTAINABLE Mobility

System-Level Electric Vehicle - Grid Integration

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IAEE Webinar – April 14th, 2021

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NREL at a Glance

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Employees,
postdoc researchers, interns, visiting professionals, and subcontractors

World-class
facilities, renowned technology experts

871

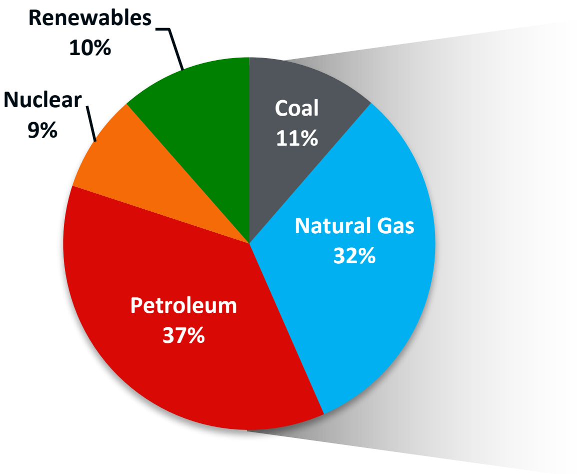
Partnerships
with industry, academia, and government

Campus
operates as a living laboratory

INTRODUCTION & CONTEXT

Transportation in the energy context

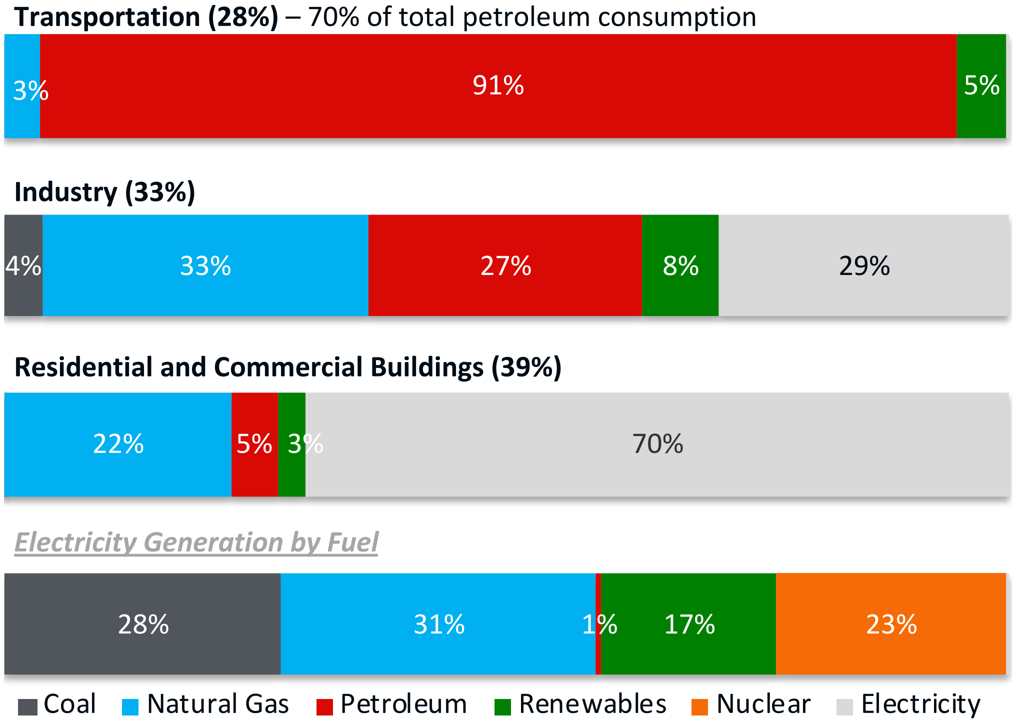
U.S. Primary Energy By Fuel (2019)



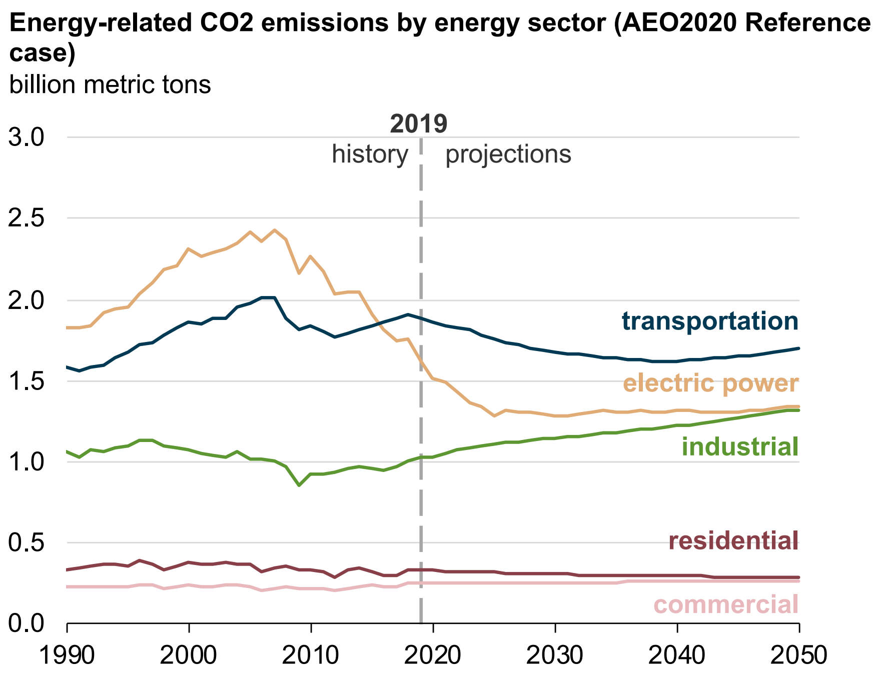
Source: NREL. Data from U.S. Energy Information Administration Annual Energy Review

Over 90% of transportation energy use from petroleum: <u>least-diversified energy sector</u>

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



Today, transportation relies heavily on petroleum and it is the largest source of energy-related CO_2 emissions in the US. And mobility needs for passenger and freight are growing rapidly.



… 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

Transportation is at a turning point

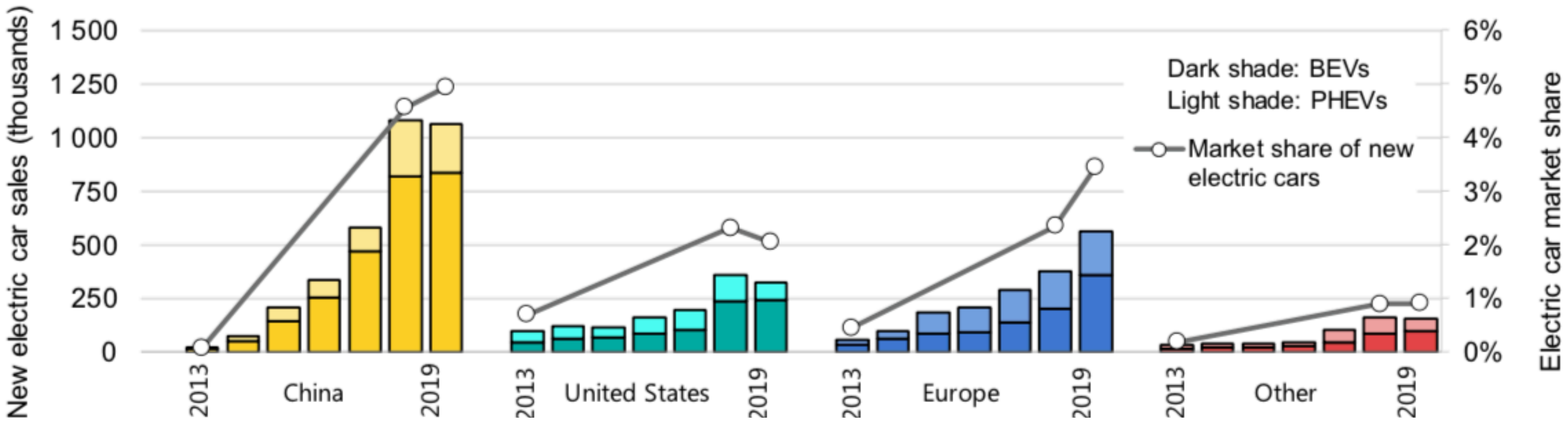
- On the horizon lies a future where **affordable and abundant renewable electricity can be used to power cost-competitive battery electric vehicles (EVs) and produce energy-dense low-carbon fuels** enabling to fully decarbonize transportation systems across all modes.
- The **grid integration of EVs** presents unique opportunities for synergistic improvement of the efficiency and economics of e-mobility and the power grid.
- At NREL, we're laying the scientific groundwork to get there. Among many other things, our research is finding ways for **EVs to support grid planning and operations across several timescales and to fully exploit the synergies between EVs and renewables** to provide transformative sustainable solutions for the integrated energy systems of the future.

ELECTRIC VEHICLE ADOPTION & ELECTRICTY DEMAND

Global LDV EV market expanding rapidly

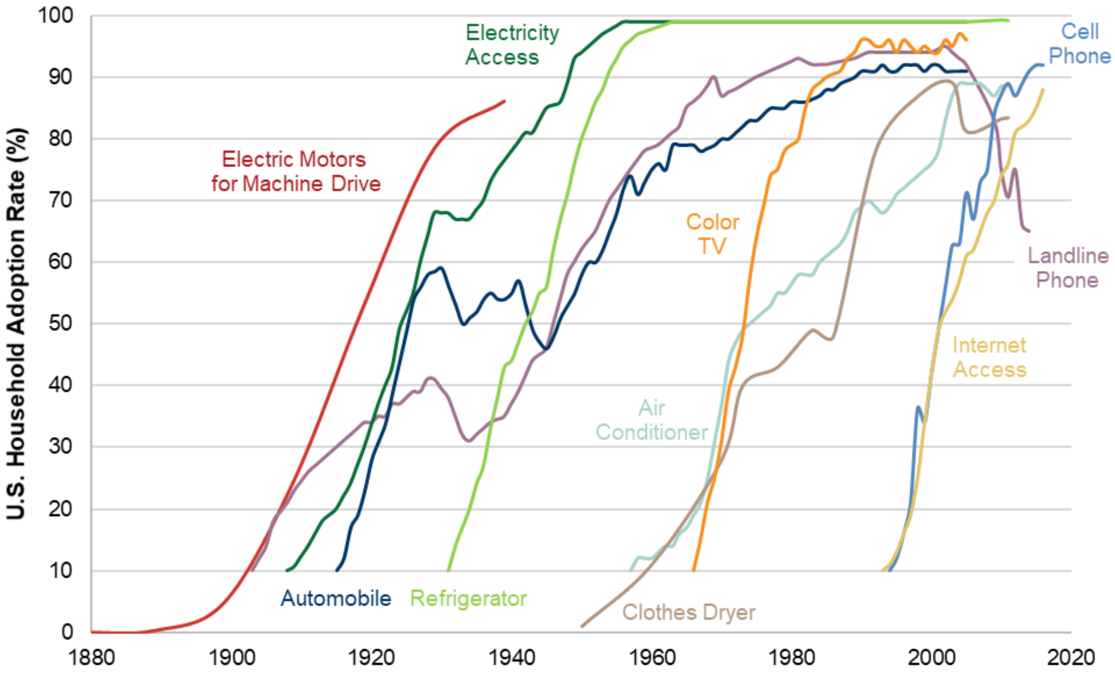
The worldwide **market share of electric cars reached a record high** of 2.6% in 2019, expanding in all major markets except Japan, Korea and United States.

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



Source: 2020 IEA Global EV Outlook

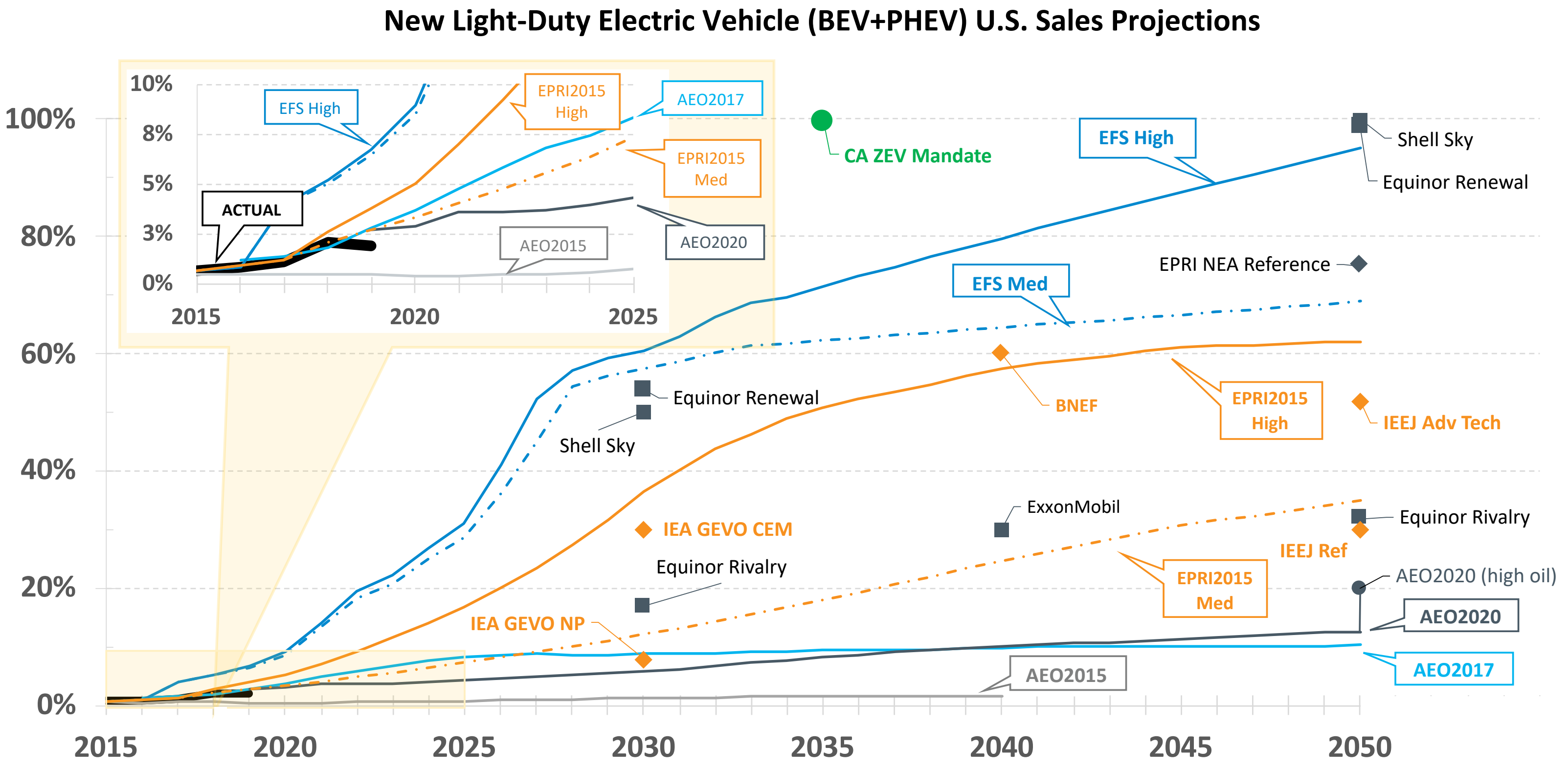
Technology adoption and energy transitions generally follow S-curve shape and are generally underestimated



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



Source: Muratori et al. "The Rise of Electric Vehicles" Progress in Energy

What are the main drivers of the rise in EV adoption

1. **Technology**: batteries and electric drive systems
2. **Markets**: industry support and make/model availability
3. **Charging infrastructure**
4. **Consumers**: maintenance and fuel costs
5. **Decarbonization** pathway and policy support

Future expectations: beyond LDV towards commercial vehicles

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

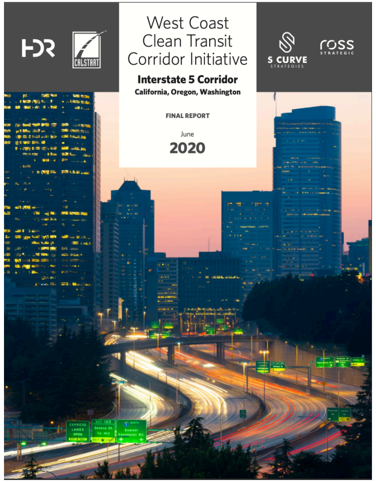
Recent policy momentum for heavy-duty truck electrification:

- 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

PUBLISHED TUE, JUN 9 2020·9:21 AM EDT | UPDATED WED, JUN 17 2020·7:53 AM EDT

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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

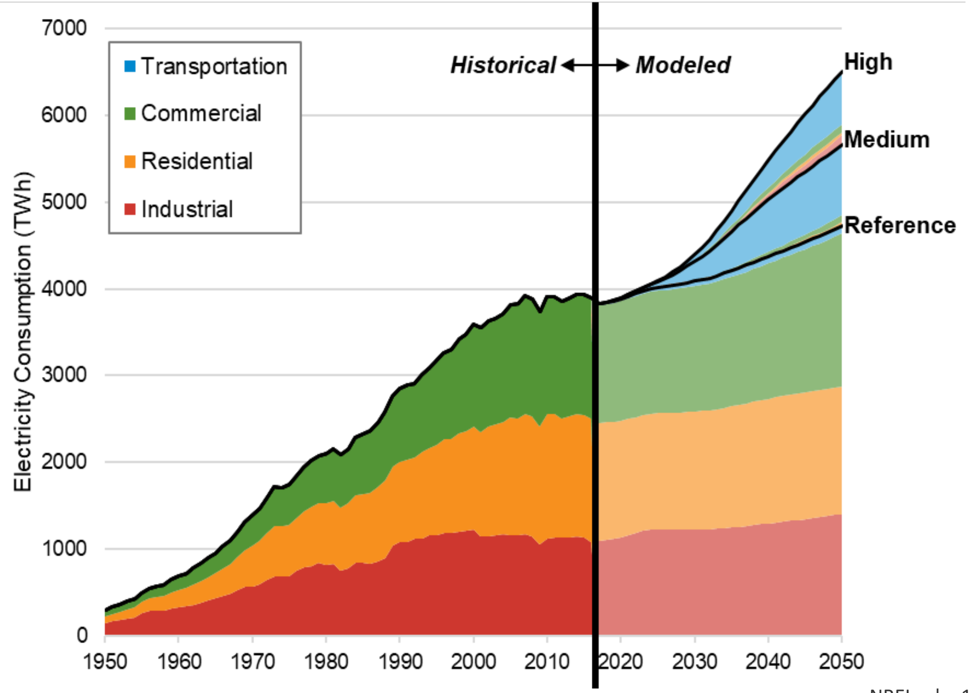
U.S. scenarios of widespread electrification

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.**

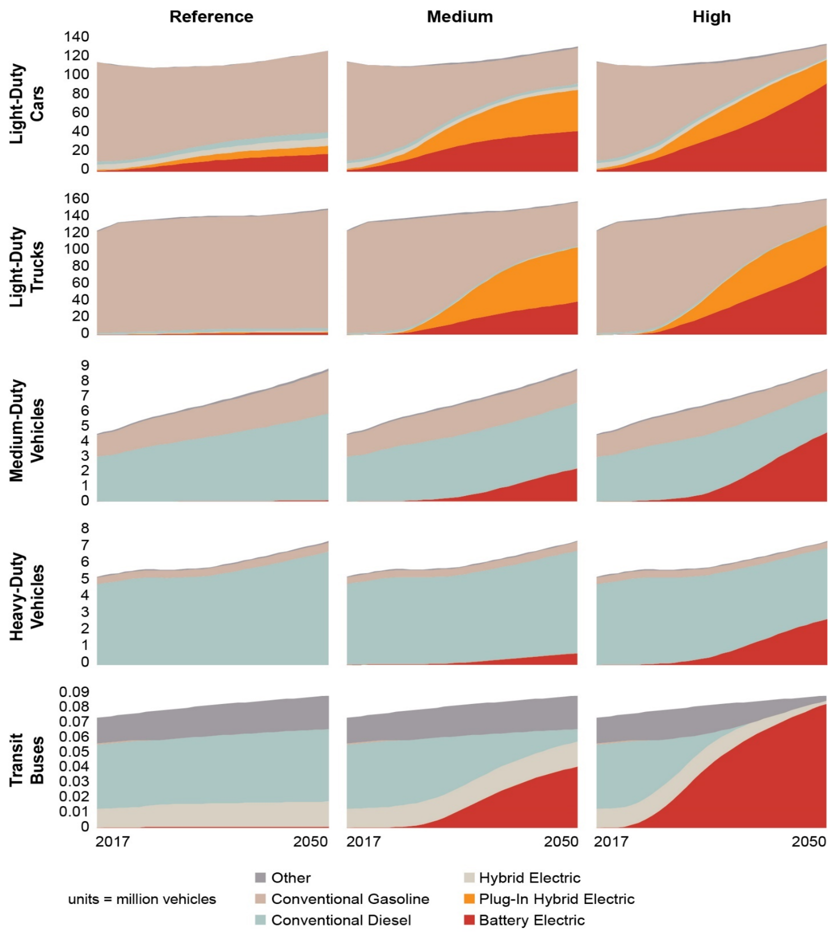
- **1,424 TWh increase in transportation-related electricity consumption** relative to the 2050 Reference scenario.



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



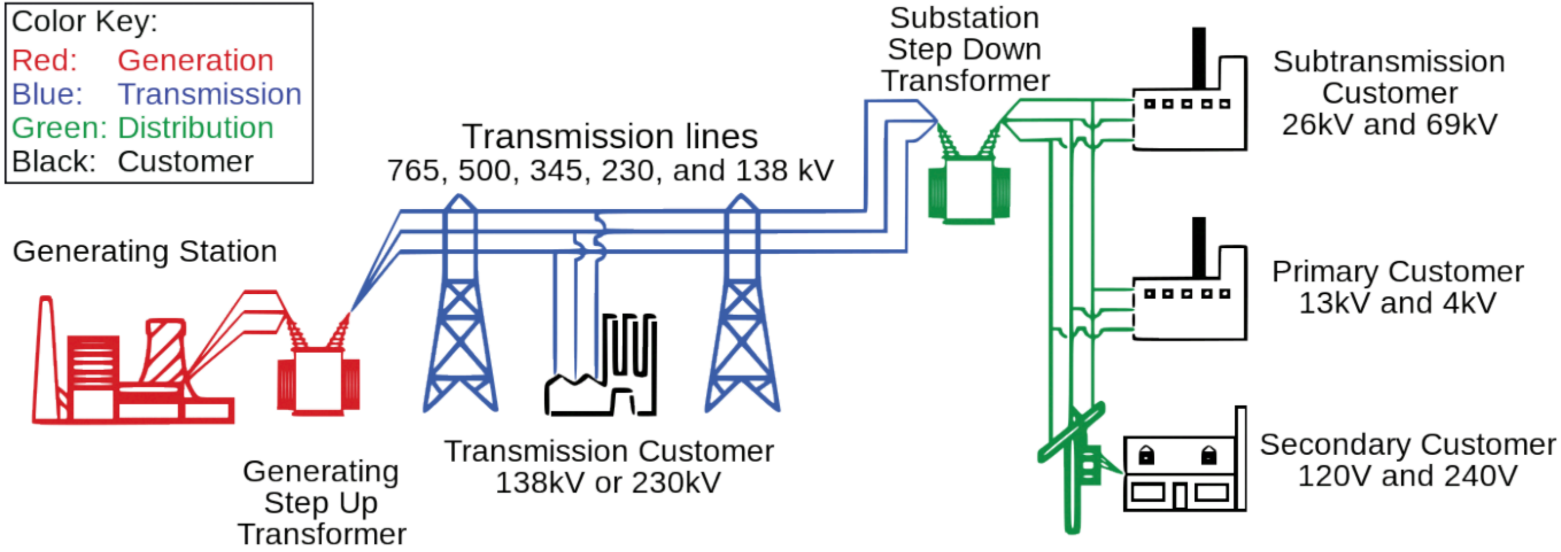
Vehicle stock

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

EV-GRID INTEGRATION

Backward looking – lessons learned

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



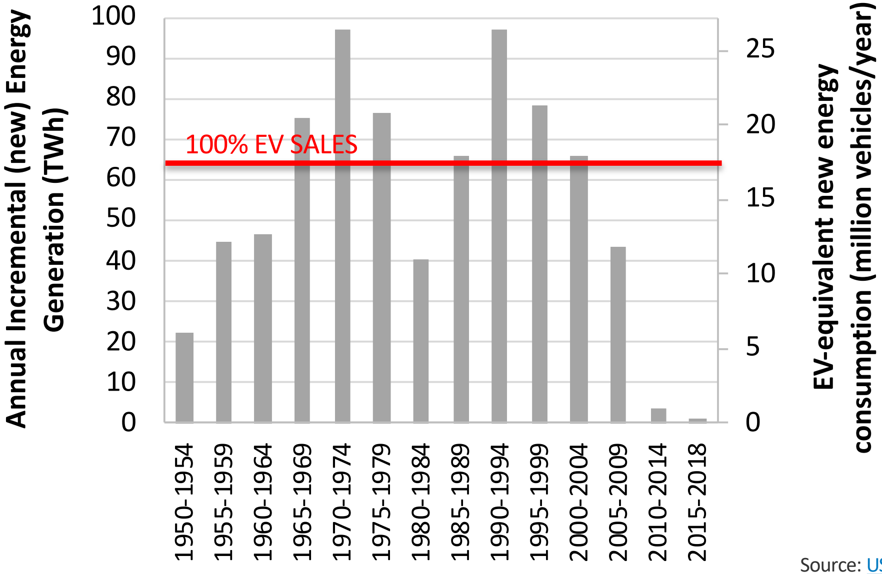
Source: DOE 2015 QTR

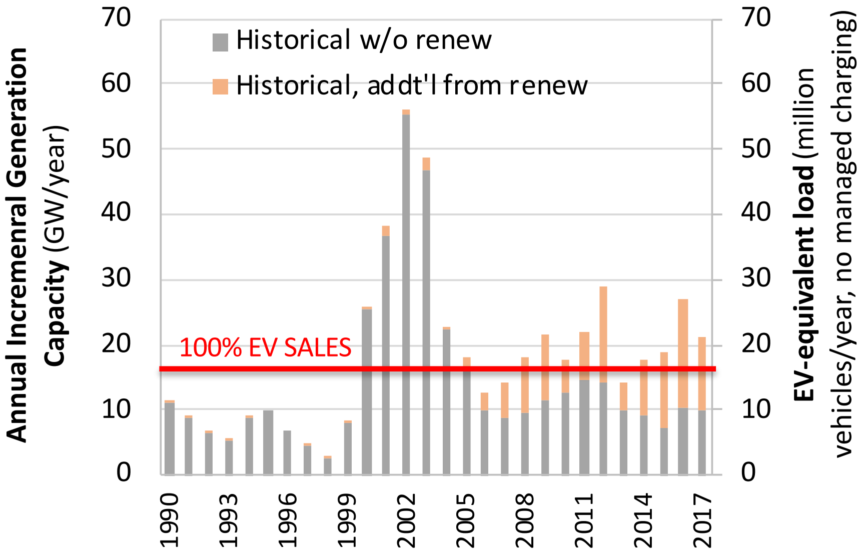
- Breakdown of **US average retail electricity prices** (data from EIA):

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

The grid has evolved over time to accommodate greater annual load additions than 100% light-duty EV sales

~17M vehicles sold each year in the US: greatest opportunity for electricity demand growth





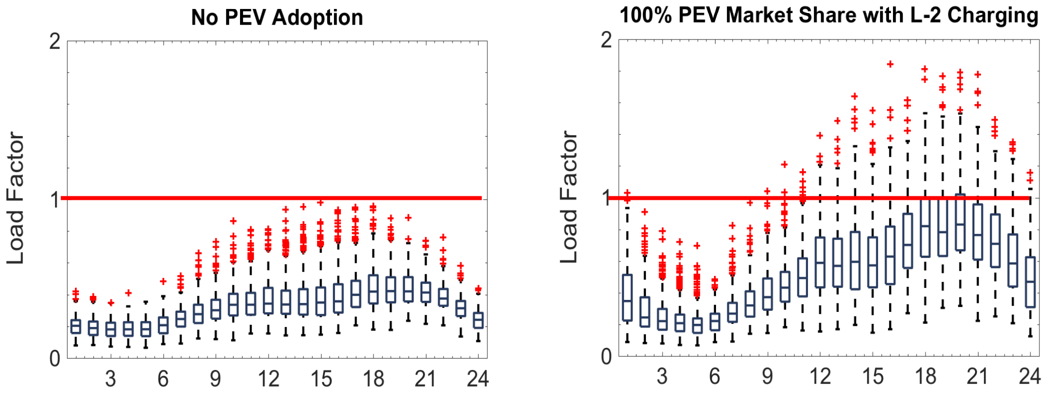
Source: US DRIVE 2019

Based on historical growth rates, sufficient energy generation and generation capacity is expected to be available to support EVs, even for 100% EV sales.

What about 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.

EV-GRID INTEGRATION

Forward looking – modeling and analysis

The grid is also transforming

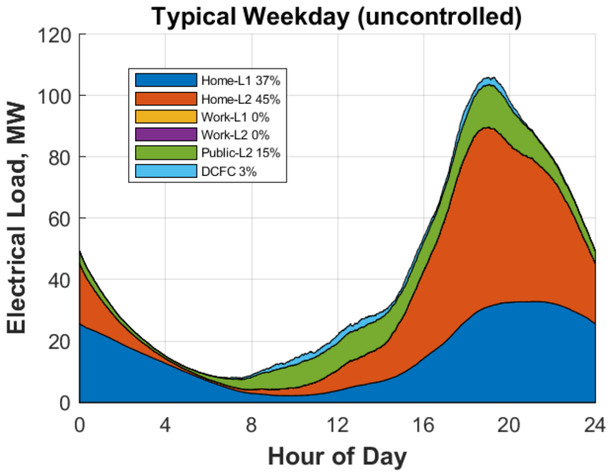
The **electric power system is undergoing profound changes**.

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.

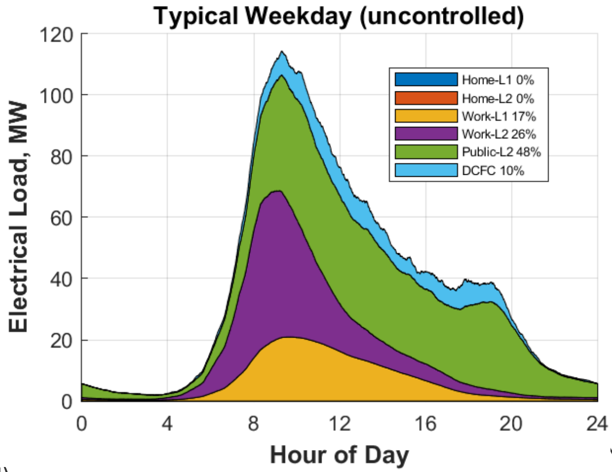
And EVs are not just a ”burden”, flexible EV charging can satisfy mobility needs while also supporting the grid

- **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

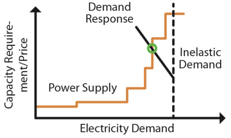


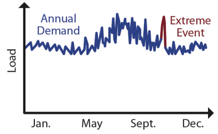
Source: NREL (EVI-Pro Model)

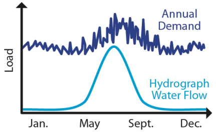
EVs can support the grid in multiple ways providing values for different stakeholders, including non-EV owners

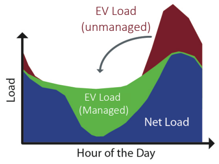
Smart electric vehicle-grid integration can provide flexibility – the ability of a power system to respond to change in demand and supply – by charging and discharging vehicle batteries to support grid planning and operations over multiple time-scales

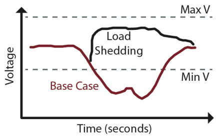
Power System Application	Generation Capacity and Transmission/ Distribution Planning	Resilience To Extreme Events	Seasonal Planning (Hydro/Long-Term Storage Dispatch)	Commitment and Dispatch Decisions	Balancing and Power Quality	Support End Consumers
Time scale	*Multi-year*	*Years (planning), hours (real-time 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

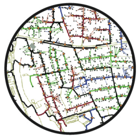








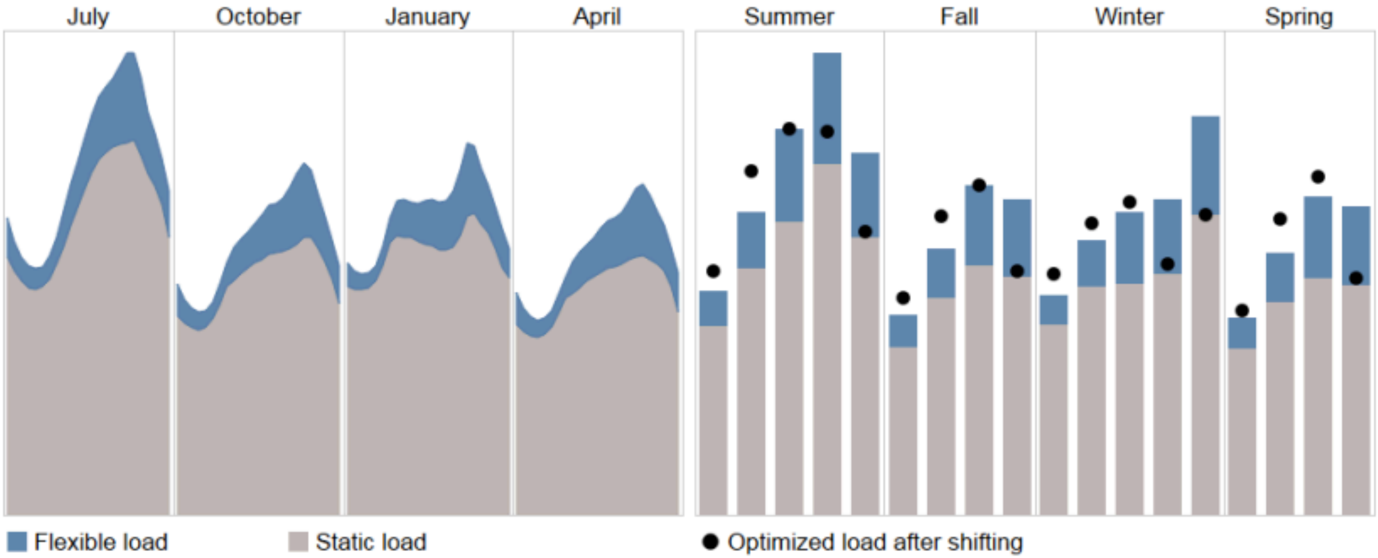




Source: Muratori et al. "The Rise of Electric Vehicles" Progress in Energy

EFS: flexible load is "dispatched" by shifting electricity demand to minimize total bulk electric system costs

The flexible portion of the load (2/3 of the total from EVs) is dispatched in ReEDS considering the constraints on flexibility and factors related to the generation mix (e.g., amount and profile of VRE generation)



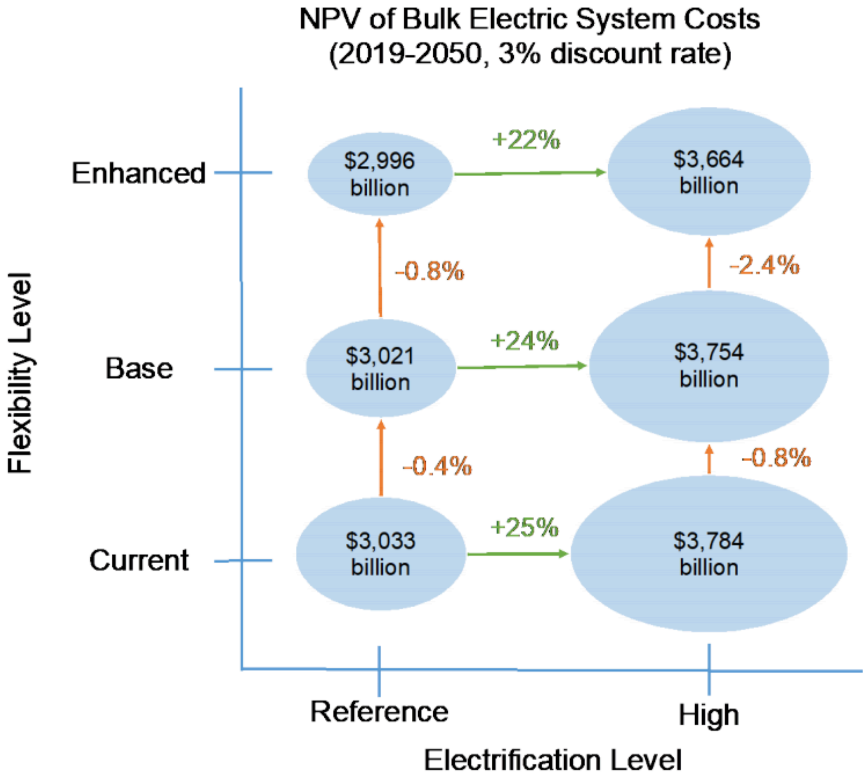
Source: https://www.nrel.gov/analysis/electrification-futures.html

EFS: flexible loads provide value to the bulk power system

Demand-side flexibility provides value by:

- **Reducing total bulk electric system costs** in all scenarios
- **Mitigating** some of the electrification-induced **investments needed**
- **Reduce operational costs by up to 10%** (lower electricity cost for all)
- Complement renewable and enhance the ability of electrification to decarbonize the energy sector by **reducing VRE curtailment**

Caveat: no incremental cost to implement load shifting considered



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

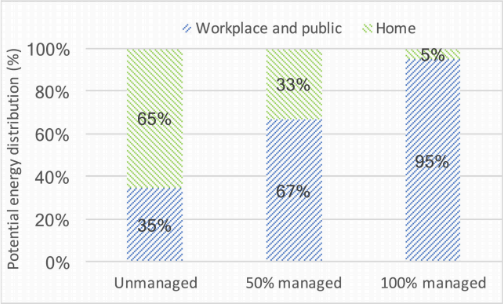
Value of managed EV charging, more examples

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**:

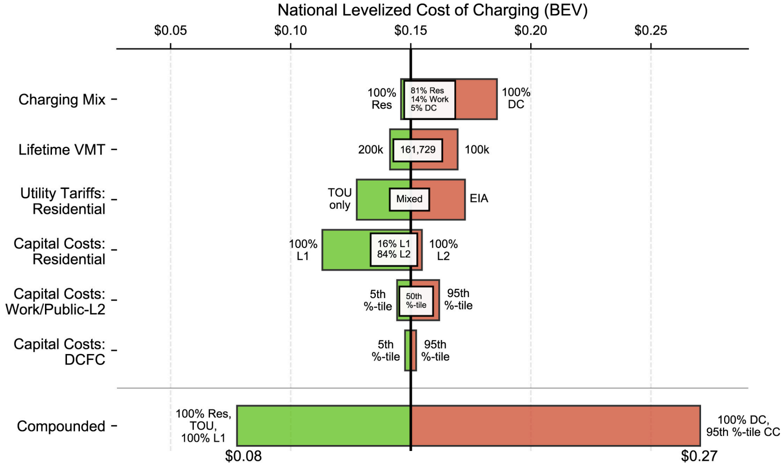
- 3%–8% reduction in **electricity production costs** ($210–$660M)
- Reduce **peak demand** by 2.8% (avoided capacity)
- Reduce **renewable curtailment** by up to 13%
- Reduce grid **CO_2 emissions** by 3%–5%



Source: *Zhang et al. 2018*

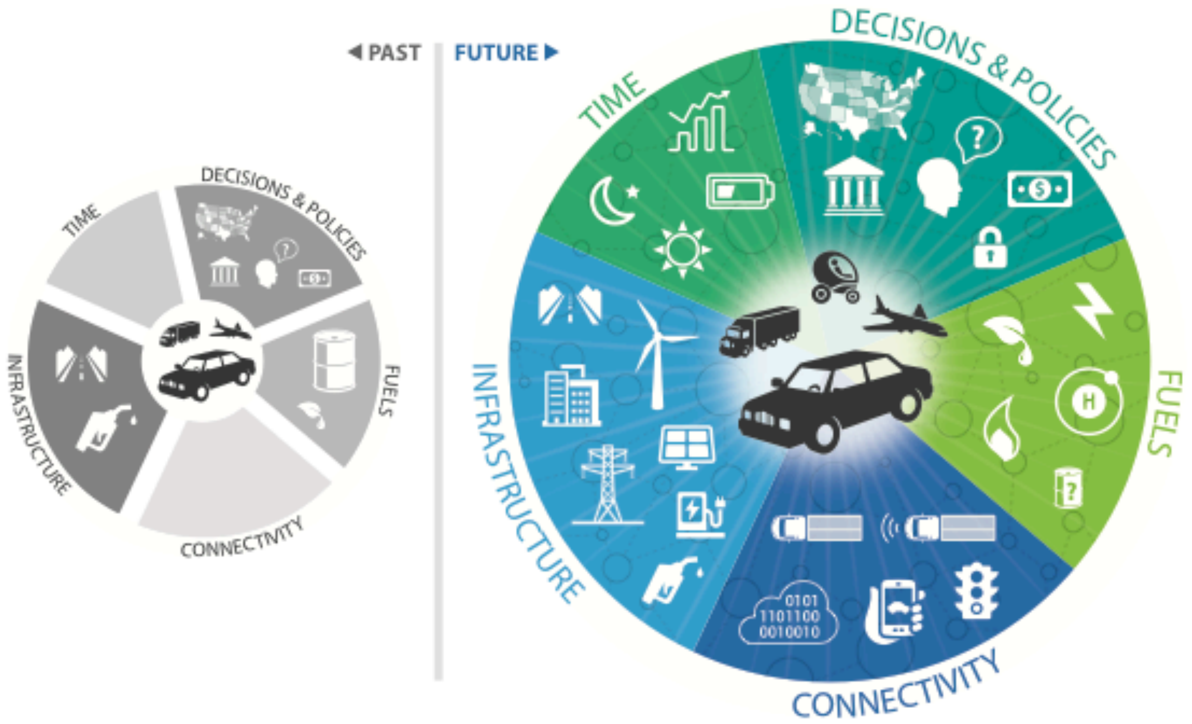
RETAIL-LEVEL (CONSUMER)

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

- **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 **technologies and infrastructure** are required to enable smart charging?
- What are the **tradeoffs across different VGI value streams,** and how to address the seams between bulk power and distribution systems?
- How to **engage and properly compensate EV users** for providing flexibility?

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Thank you!

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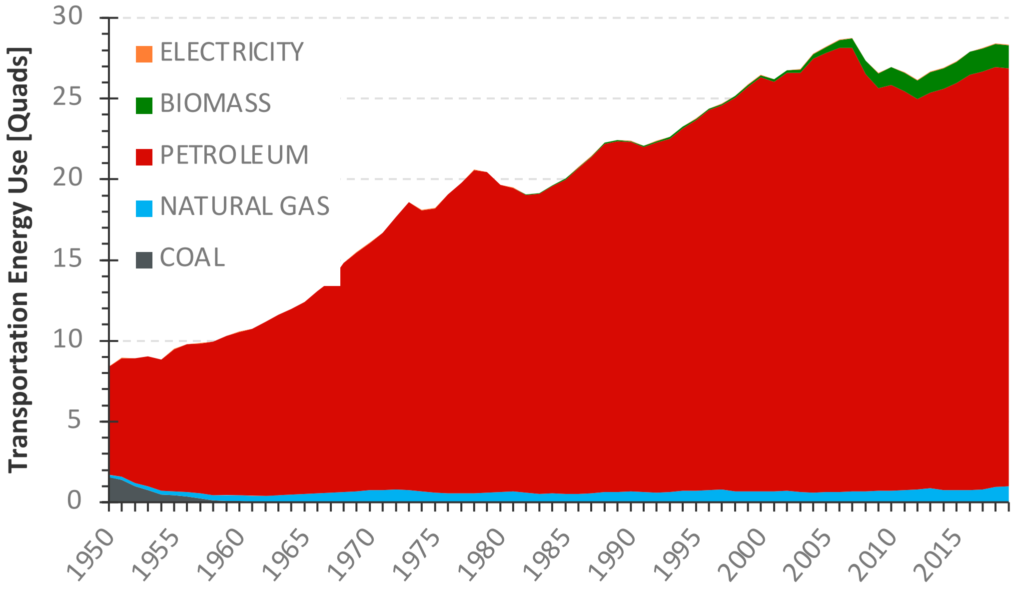
Abstract

Transportation is already the largest source of CO2 emissions in the U.S. and mobility needs for passenger and freight are growing rapidly. However, after over a century of petroleum dominance, new disruptive technologies and business models offer a pathway to decarbonize the sector. Transportation is at a turning point. On the horizon lies a future where affordable and abundant renewable electricity can be used to power cost-competitive battery electric vehicles (EVs) and produce energy-dense low-carbon fuels enabling to fully decarbonize transportation systems across all modes. And the integration of EVs into power systems presents unique opportunities for synergistic improvement of the efficiency and economics of mobility and the power grid. At NREL, we're laying the scientific groundwork to get there. Among many other things, our research is finding ways for EVs to support grid planning and operations across several timescales and to fully exploit the synergies between EVs and renewables to provide transformative sustainable solutions for the integrated energy systems of the future.

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

Least-diversified energy sector

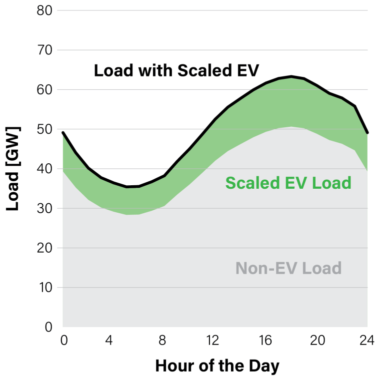
Over 90% of transportation energy use from petroleum

5% from bioenergy

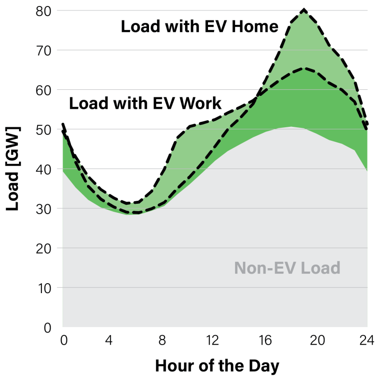
Electricity accounts of 0.1% of transportation energy use and transportation consumes 0.2% of electricity

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

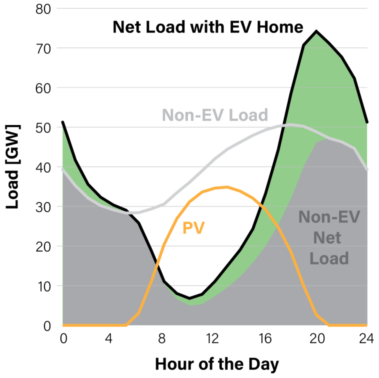
a) ASSUMPTION:
EV charging is often assumed to simply scale up electricity demand.



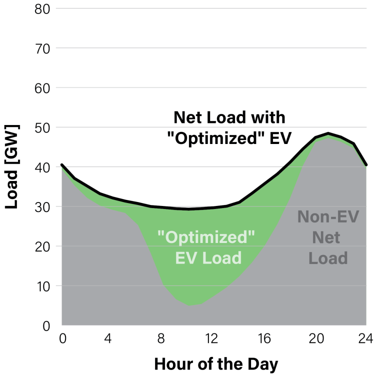
b) COMPLEXITY:
Future EV charging could change the shape of demand, depending on when and where charging occurs.



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.



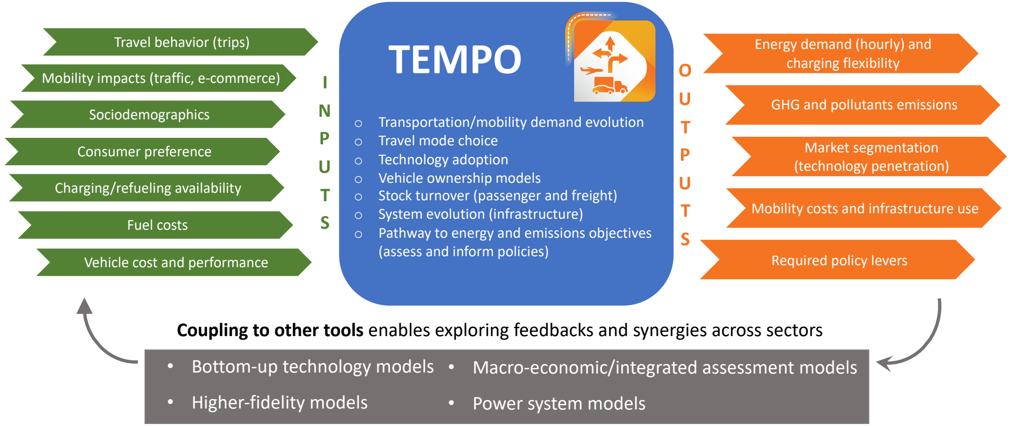
More nuanced demand-side modeling needed to assess the integration opportunities of EVs on the power system.

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

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**.

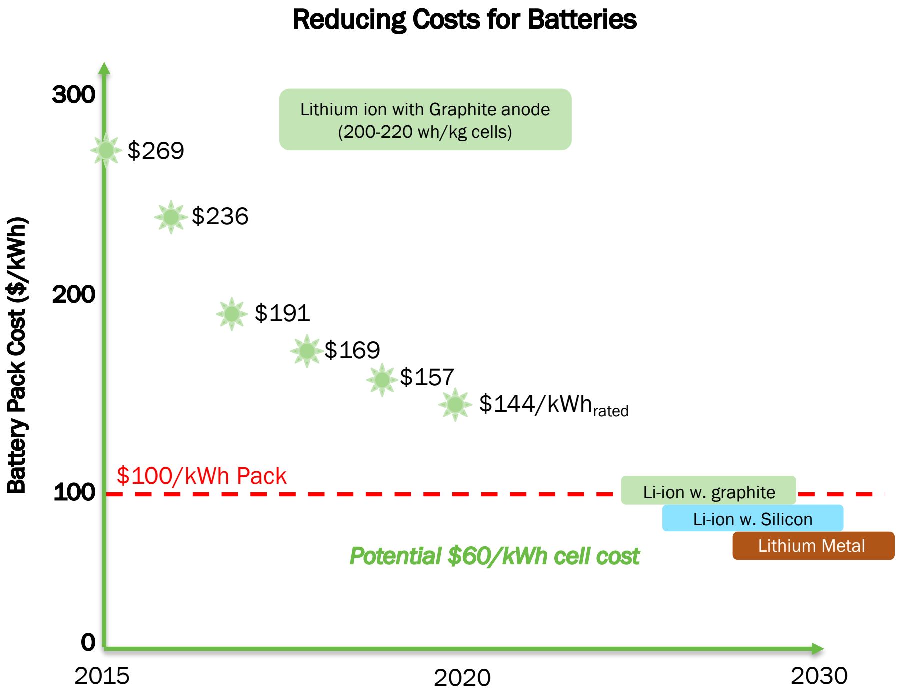
TEMPO *finds pathways* to achieve energy/emissions goals and estimates implications of different scenarios and decisions



Technology: batteries and electric drive systems

1

- **Battery pack cost** dropped by 85% since 2010, reaching ~$150/kWh today
- EVs **already cost-competitive** for some users, over the vehicle life
- Consensus that **$80-100/kWh needed for MSRP-parity** (~$60 cell level)
- **Multiple pathways** to achieve that cost
- Three major **challenges/goals:**
  - Continue reducing battery costs
  - Eliminate dependance on critical materials
  - Develop safe batteries that charge in <15 minutes



Markets: industry support and make/model availability

2

- 2020: 200+ EV models available globally (40+ in the US)
- Number of models will grow dramatically: over 500 different EV models by 2022 globally
- Largest growth in bigger vehicles and less premium models will expand market
- Growth is primarily in BEVs but still a lot of PHEV during transition