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

_A System-level perspective_

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Transportation systems have relied on petroleum for over a century…

Today, transportation is the **largest source of energy-related CO₂ emissions** in the U.S. and it is responsible for ~70% of total petroleum use.

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
... 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)

**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

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

— State of California

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

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
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\(^2\).


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](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

Source: [https://www.nrel.gov/analysis/electrification-futures.html](https://www.nrel.gov/analysis/electrification-futures.html)
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

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**
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.
EVs can support the grid in multiple ways providing values for different stakeholders, including non-EV owners.
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 **CO₂ emissions** by 3%–5%

**RETAIL-LEVEL (CONSUMER)**

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

Source: Borlaug et al. 2020

Source: Zhang et al. 2018
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?
References

4. Mai et al., 2020. Electrification futures study: Scenarios of electric technology adoption and power consumption for the united states. NREL/TP-6A20-71500
Thank you!

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Transportation in the energy context

U.S. Primary Energy By Fuel (2019)

- Petroleum: 37%
- Natural Gas: 32%
- Coal: 11%
- Nuclear: 9%
- Renewables: 10%

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

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


**Transportation (28%) — 70% of total petroleum consumption**

- Transportation: 28%
- Petroleum: 91%
- Natural Gas: 5%

**Industry (33%)**

- Industry: 33%
- Petroleum: 27%
- Natural Gas: 8%
- Coal: 29%

**Residential and Commercial Buildings (39%)**

- Residential and Commercial Buildings: 39%
- Natural Gas: 70%

**Electricity Generation by Fuel**

- Coal: 28%
- Natural Gas: 31%
- Petroleum: 1%
- Renewables: 17%
- Nuclear: 23%
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.