Transforming ENERGY through SUSTAINABLE Mobility

California 2045: Integrating 100% ZEVs with 100% Clean Energy

Matteo Muratori, Ph.D. – Senior Engineer & Team Lead

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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
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 2045¹.

• 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 2030².


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

Source: https://www.nrel.gov/analysis/electrification-futures.html
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
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.
Not just “how much” electricity EVs will consume, but “when” and “where” is what really matters

- **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**

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.

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<tr>
<th>Power System Application</th>
<th>Time scale</th>
<th>Vehicle-Grid Integration value</th>
<th>Generation Capacity and Transmission/Distribution Planning</th>
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<td>Multi-year</td>
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<td>Ability to reduce peak load and capacity requirements and defer distribution systems upgrades if reliable EV charging flexibility is available</td>
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<th>Resilience To Extreme Events</th>
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<td>Years (planning), hours (real-time response)</td>
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<td>Load response to natural events (heat waves, tornados) or human-driven disasters, load postponement over days, and support microgrid management and grid restoration (V2G)</td>
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<th>Seasonal Planning (Hydro/Long-Term Storage Dispatch)</th>
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<td>Leverage EV charging flexibility to support supply dispatch and load-supply alignment (tariff management), variable renewables integration, operating reserves, energy arbitrage (V2G)</td>
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<th>Commitment and Dispatch Decisions</th>
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<td>Days to Hours and Sub-Hours</td>
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<th>Balancing and Power Quality</th>
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<td>Seconds to sub-seconds</td>
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<td>Provide voltage/frequency regulation and support distribution system operations</td>
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<th>Support End Consumers</th>
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<td>Years (planning), hours (real-time response)</td>
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<td>Tariff management (e.g., mitigate retail demand charges), complement other distributed energy resources (smart load, generation and storage), and minimize equipment aging/upgrades</td>
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Source: Muratori et al. The Rise of Electric Vehicles
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?
U.S. Energy Information Administration (EIA). *Annual Energy Review*


Mai et al., 2020. *Electrification futures study: Scenarios of electric technology adoption and power consumption for the united states*. NREL Report


Muratori, 2018. *Impact of uncoordinated plug-in electric vehicle charging on residential power demand*. Nature Energy


Clean Energy Ministerial (CEM), 2020. *Electric Vehicle and Power System Integration: Key insights and policy messages from four CEM workstreams*

Zhang et al., 2018. *Value to the Grid From Managed Charging Based on California’s High Renewables Study*. IEEE Trans. on Power Systems

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

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

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

Source: DOE 2015 QTR
Transportation in the energy context

U.S. Primary Energy By Fuel (2019)

- Coal: 11%
- Natural Gas: 32%
- Petroleum: 37%
- 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
- 3% Coal
- 91% Natural Gas
- 5% Petroleum

Industry (33%)
- 4% Coal
- 33% Natural Gas
- 27% Petroleum
- 8% Nuclear
- 29% Renewables

Residential and Commercial Buildings (39%)
- 22% Coal
- 5% Natural Gas
- 3% Petroleum
- 70% Renewables

Electricity Generation by Fuel
- 28% Coal
- 31% Natural Gas
- 1% Petroleum
- 17% Renewables
- 23% Nuclear

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