Transforming ENERGY through SUSTAINABLE Mobility

Integrated Transportation-Energy Systems Modeling

Matteo Muratori, Ph.D.

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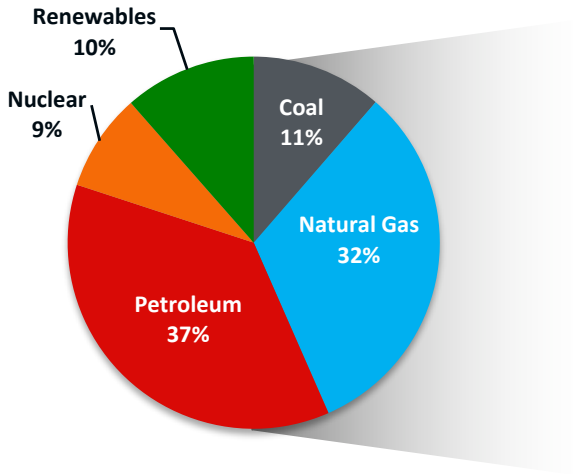
Transportation is currently the least-diversified energy demand sector

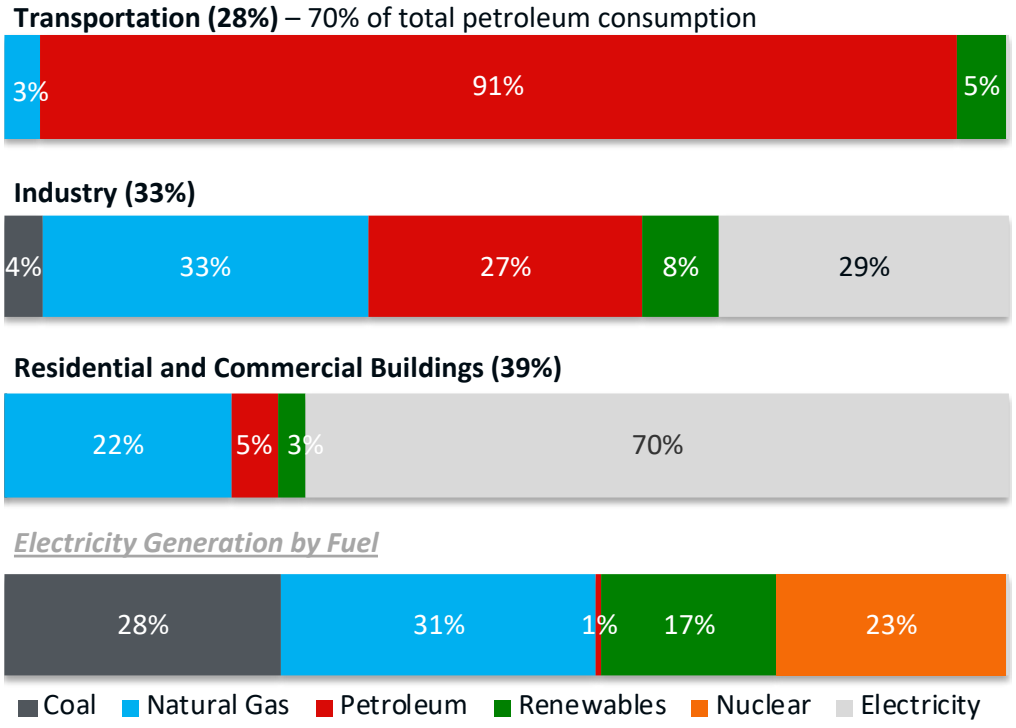
U.S. Primary Energy By Fuel (2019)



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

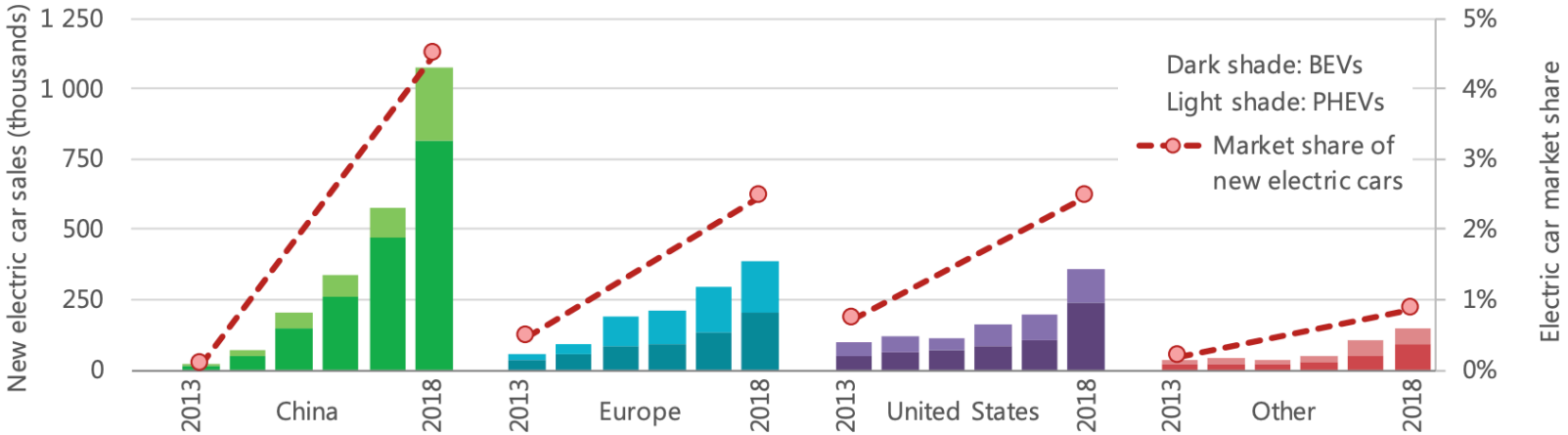
Over 90% of transportation energy use from petroleum

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



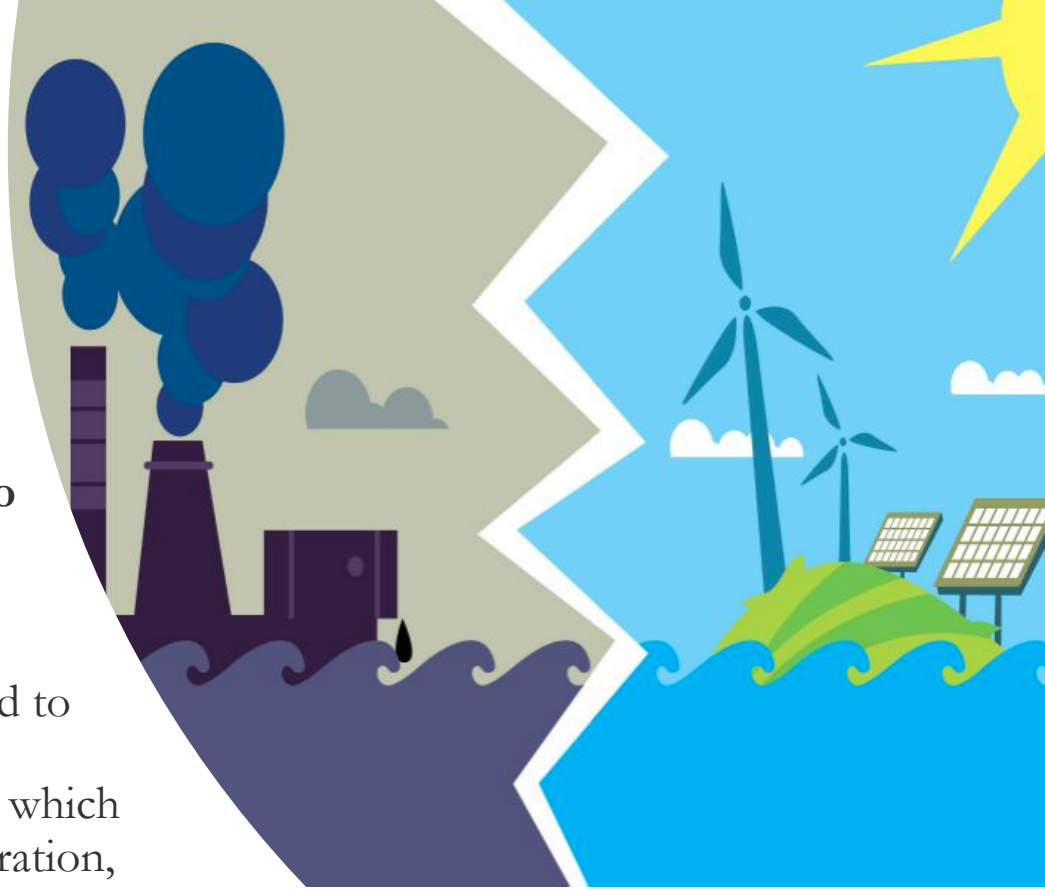
After over a century of petroleum dominance, however, many leading experts anticipate major electrification trends that could disrupt the transportation energy demand landscape

The global **electric car fleet exceeded 5.1 million in 2018**, up by 2 million since 2017, almost doubling the unprecedented amount of new registrations in 2017.



Source: 2019 IEA Global EV Outlook

Transforming Electricity Grid



This revolution is happening at a time in which the **electric power system is also 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.

How will transportation electrification impact electricity demand and supply?

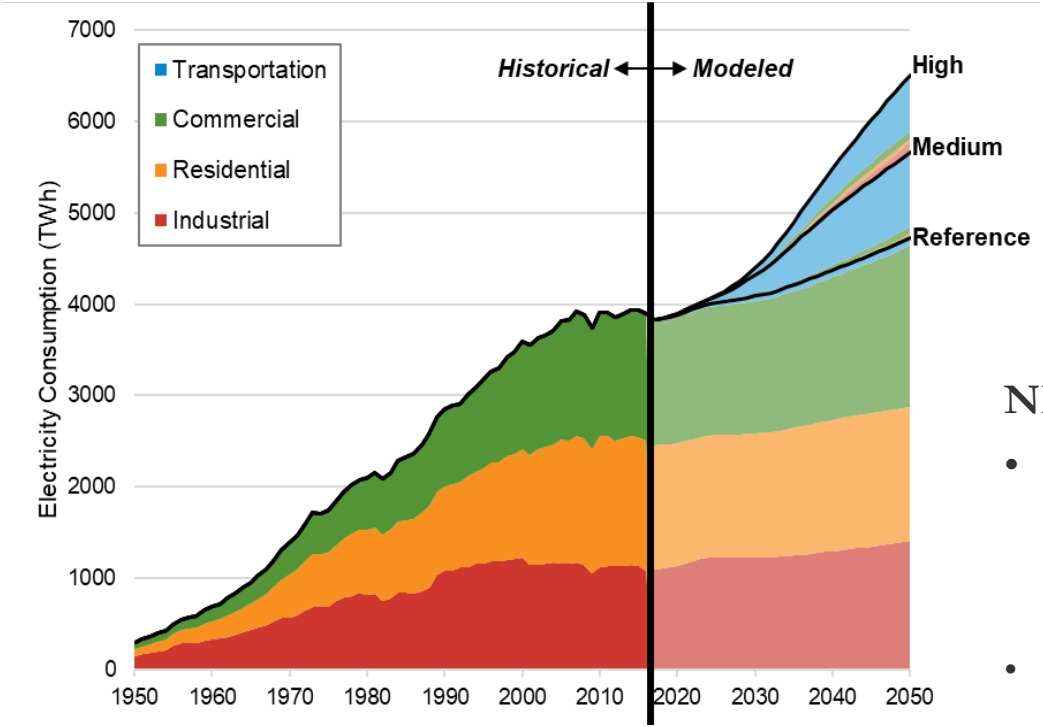
Including charging infrastructure requirements, localized considerations, and system-level changes in the load shapes and opportunities to leverage flexible EV charging to more cost-effectively balance demand and supply

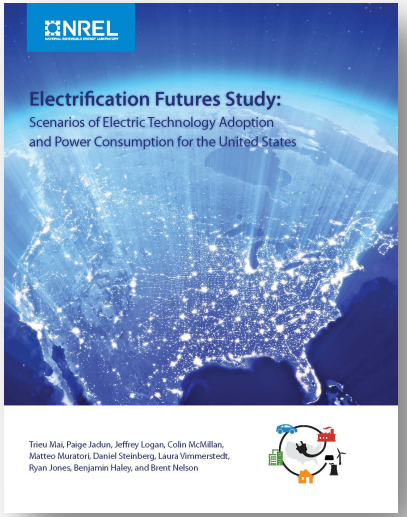
Vehicle Electrification Opportunities

- Plug-in electric vehicle (EV) charging will undoubtedly impact electricity demand, both in terms of overall energy use and **load shapes**, and can support system planning and operation.
- EV **charging patterns are highly uncertain** and determined by multiple factors (e.g., infrastructure, vehicle adoption, electricity pricing, etc.).
- Different opportunities exist to **electrify different applications** (e.g., personally owned car, ride-hailing vehicle, school or transit buses, trucks, etc.)

➢ **Understanding mobility requirements and different opportunities for transport electrification** and their impact on the power system is the first step to successfully **integrate transport and power systems**

Impact of Vehicle Charging on Power Demand





nrel.gov/docs/fy18osti/71500.pdf

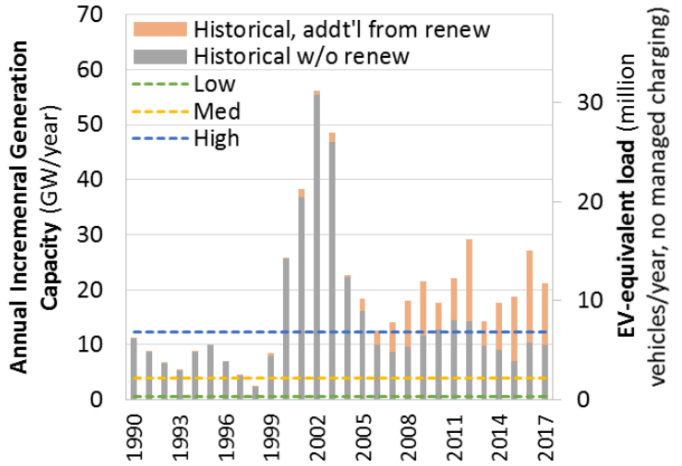
NREL high electrification scenario in 2050:

- **76% of on-road miles** traveled on electricity.
  - **240 million** light-duty plug-in electric vehicles
  - **7 million** medium- and heavy-duty EVs
  - **80 thousand** battery electric transit buses
- Transportation represents **23% of electricity consumption**, up from 0.3% today.

Are EVs going to break the grid?

The latter half of the 20th century included periods of annual energy generation growth equivalent to the electrical **consumption of up to 25 million new light duty EVs/year** (the equivalent of roughly 150% of all new light-duty vehicle sales in the U.S. today).

- Based on historical growth rates, sufficient energy generation and **generation capacity is expected to be available** to support a growing light-duty EV fleet.
- **Operations requirements** of the bulk power system should be considered for EVs at Scale.
- **Distribution & transmission** capacity expansion could present additional costs.

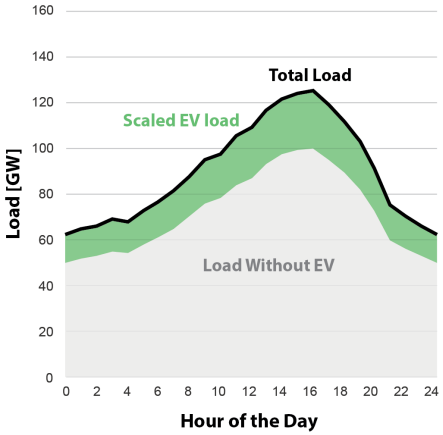


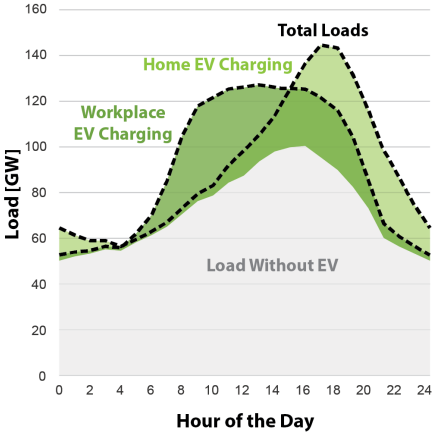
Source: US DRIVE. 2019. Summary Report on EVs at Scale and the U.S. Electric Power System.

Possible impacts of EV charging on total electricity demand

EVs are an additional load that increases total electricity demand and changes its shape. EV charging looks significantly different and requires different charging infrastructure if **vehicles are charged at different locations/times** (while respecting mobility needs).

a) ASSUMPTION: EV charging 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.

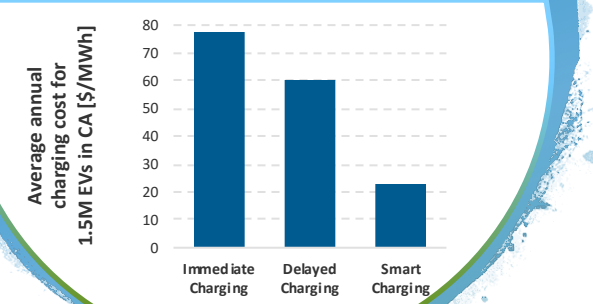
Source: Muratori and Mai, Forthcoming.

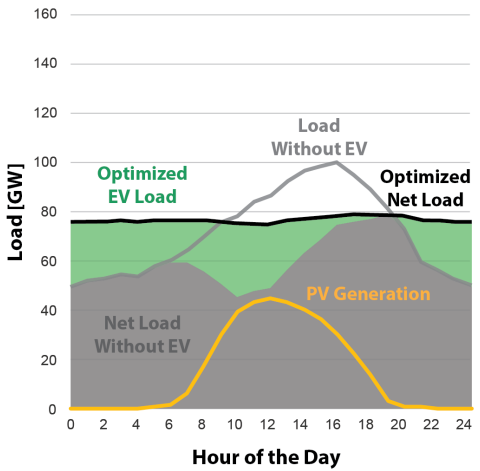
Flexible EV Charging

The grid is evolving into a more integrated supply/demand system in which **demand-side distributed resources respond to supply-side requirements.**

Flexible PEV charging can satisfy mobility needs while also supporting the grid (cheaper electricity) by optimizing the **design and operation of the electric power systems** and facilitate the **integration of renewables**:

- Peak shaving /valley filling
- Ramping mitigation
- Support operations (e.g., curtailment)
- Distributed services (e.g., reserve, contingency)



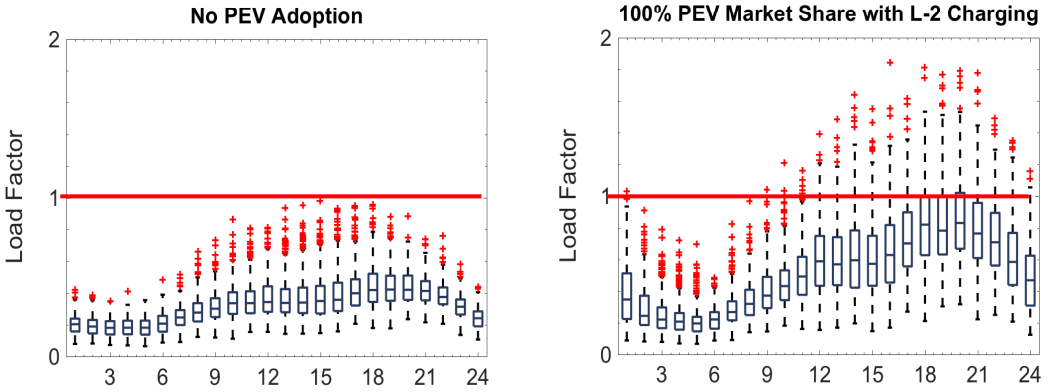


Source: Muratori and Mai, Forthcoming.

Impact of Vehicle Charging on Power Demand – Local perspective

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.

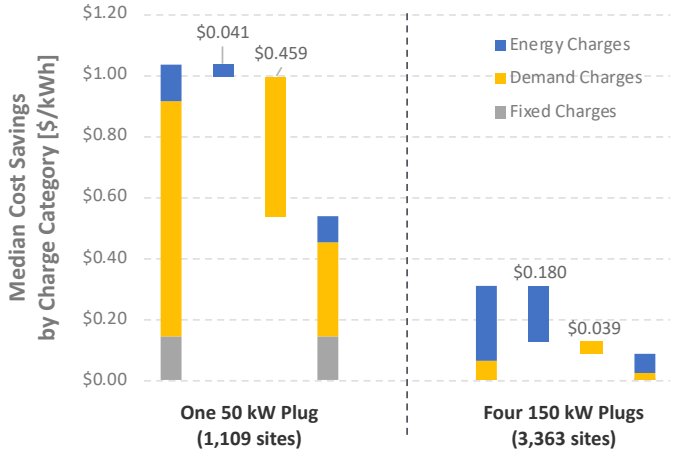


Source: Muratori, M., 2018. Impact of uncoordinated plug-in electric vehicle charging on residential power demand. Nature Energy, 3(3), pp.193-201.

Impact of Vehicle Charging on Power Demand – Local perspective

Commercial EV charging usually involves higher power and stations located in remote areas where electricity systems are less developed (e.g., highways). Commercial DC fast charging can pose a burden on distribution systems (and might require upgrades) that can impact their cost-effectiveness, especially if stations experience low utilization (**demand charges**).

- **Batteries can be cost effective** at mitigating cost associated with demand charges at public fast charging stations by up to 50%, especially for "peaky" or low-utilization EV charging loads.
- Moreover, batteries can facilitate **coupling EV charging stations with local PV** and provide other grid services.



Source: Muratori, et al. 2019. *Technology solutions to mitigate electricity cost for electric vehicle DC fast charging*. Applied

Conclusions

Emerging topic:

Vehicle electrification is rapidly changing the transportation demand landscape

Integration challenges/opportunities:

- **Integrated demand/supply models** are required to inform this transformation, including the key role of recharging infrastructure and flexible EV charging.
- **Smart charging** of EV's creates an **opportunity to support** the integration of VRE in the power system; this potential needs to be assessed reasonably given that flexibility will likely be secondary to mobility service demands.
- Integrating EV charging with distribution systems and related issues is geographically and use-case specific. One open question remains to assess the **trade-offs between bulk power and distribution system needs** when it comes to load "reshaping".

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Thank You!

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matteo.muratori@nrel.gov

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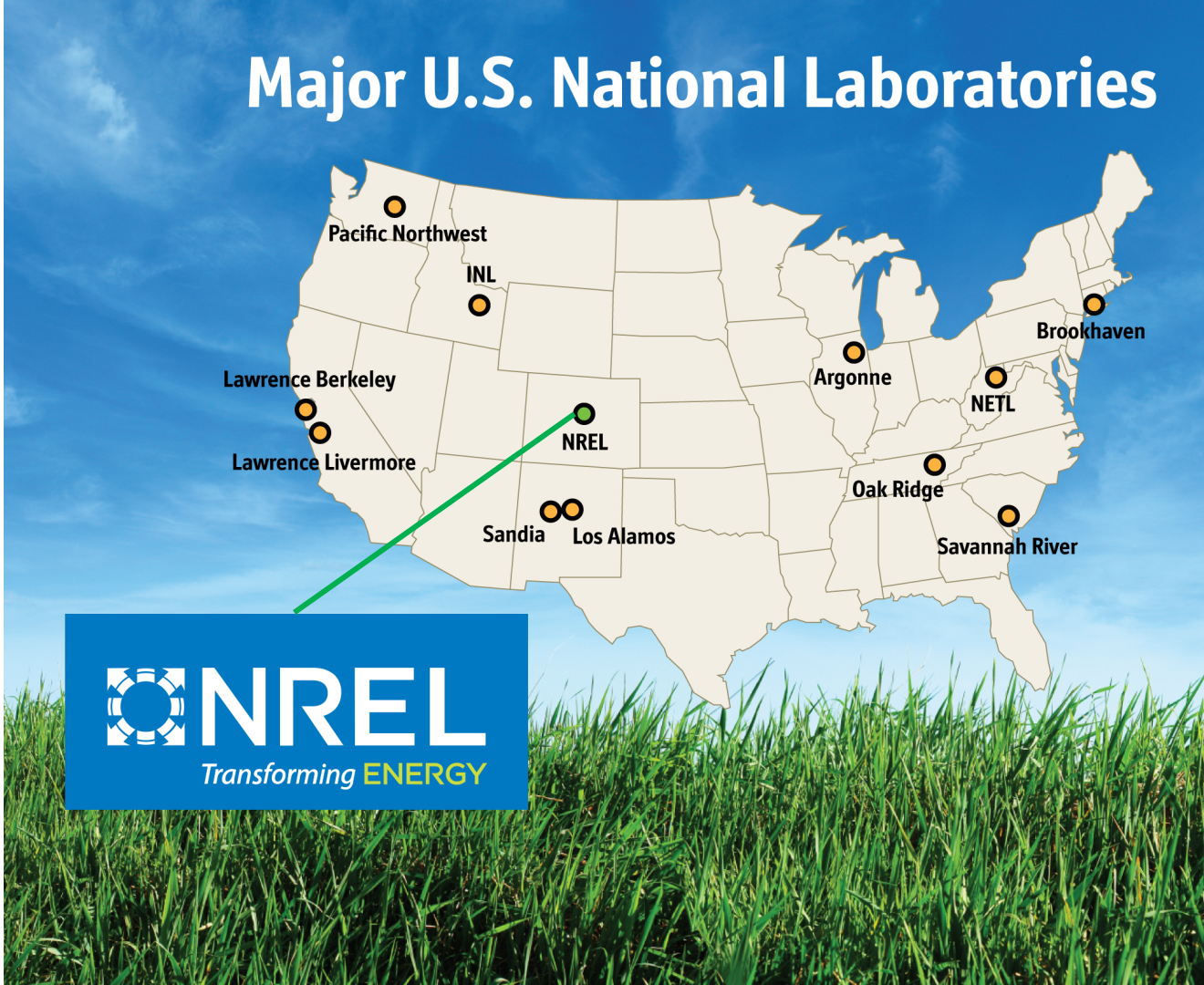


NREL Advanced Vehicles and Fueling Infrastructure

NREL Transforming ENERGY

The National Renewable Energy Laboratory (NREL) **spearheads transportation research, development, and deployment** to accelerate the widespread adoption of high-performance, low-emission, energy-efficient passenger and freight vehicles.

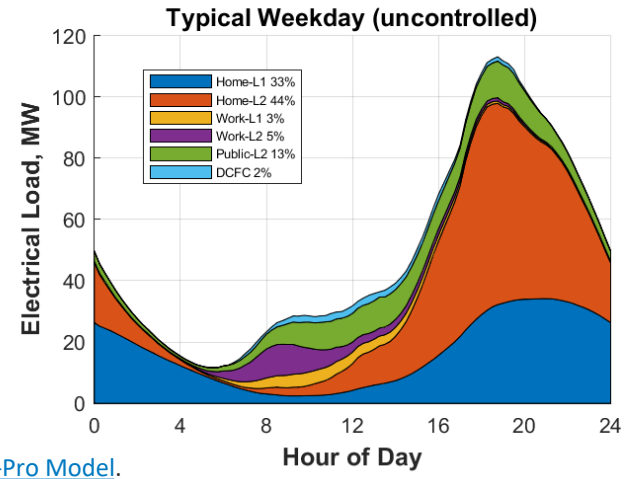
NREL is assessing the potential for **energy diversification** in transportation (CNG, biofuels, hydrogen and electrification) and related **infrastructure requirements** and providing technical support to national, state, and local entities to:

- ✓ Assess long-term **electrification opportunities** across different transportation segments & evaluate policy/technology scenarios for **alternative fuel vehicle adoption**
- ✓ Estimate **infrastructure requirements** to support vehicle electrification
- ✓ Understand **EV charging costs** (affordability) and optimize DCFC station design
- ✓ Explore opportunities for **EV integration with buildings and the electric grid**

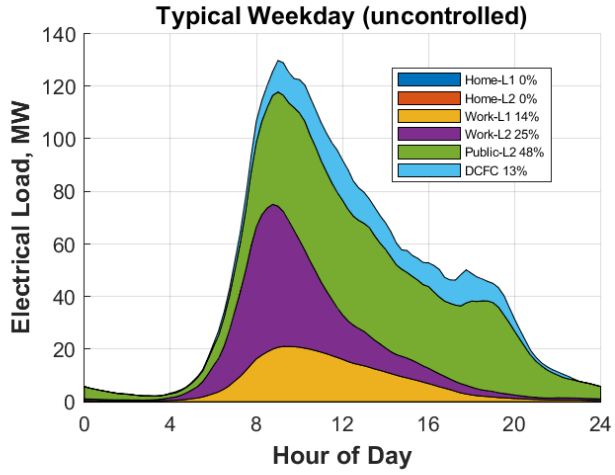
EV Charging Infrastructure

EV charging looks significantly different and requires different charging infrastructure if **vehicles are charged at different locations/times** (while respecting mobility needs)

Home-Dominant Charging



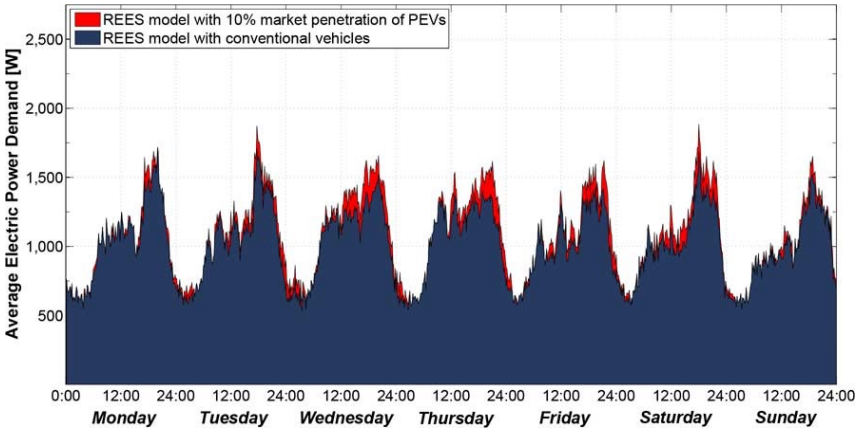
No Home Charging

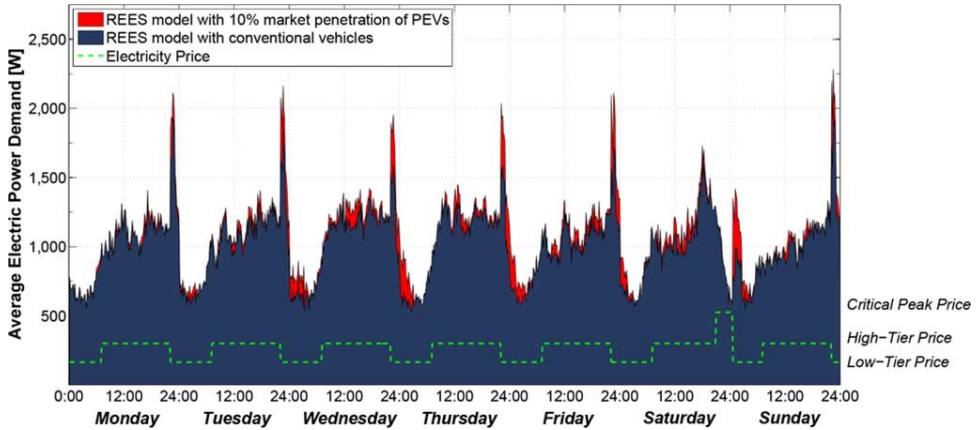


Source: NREL EVI-Pro Model.

Rebound peaks

Widespread participation (automated energy management systems) in demand response programs using time-varying electricity pricing (e.g., TOU) might create pronounced rebound peaks.





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