Emerging Topics in Energy Systems Integration: Vehicle Electrification

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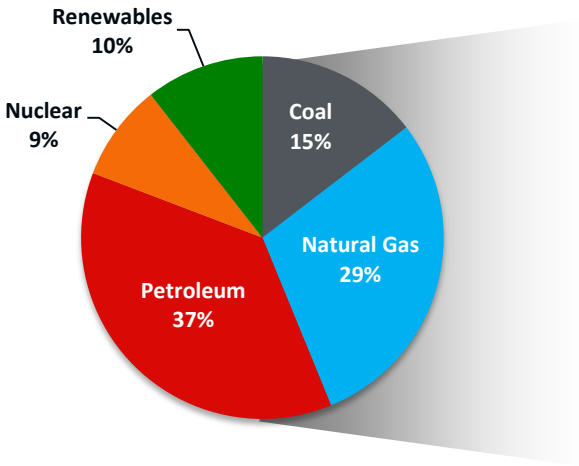
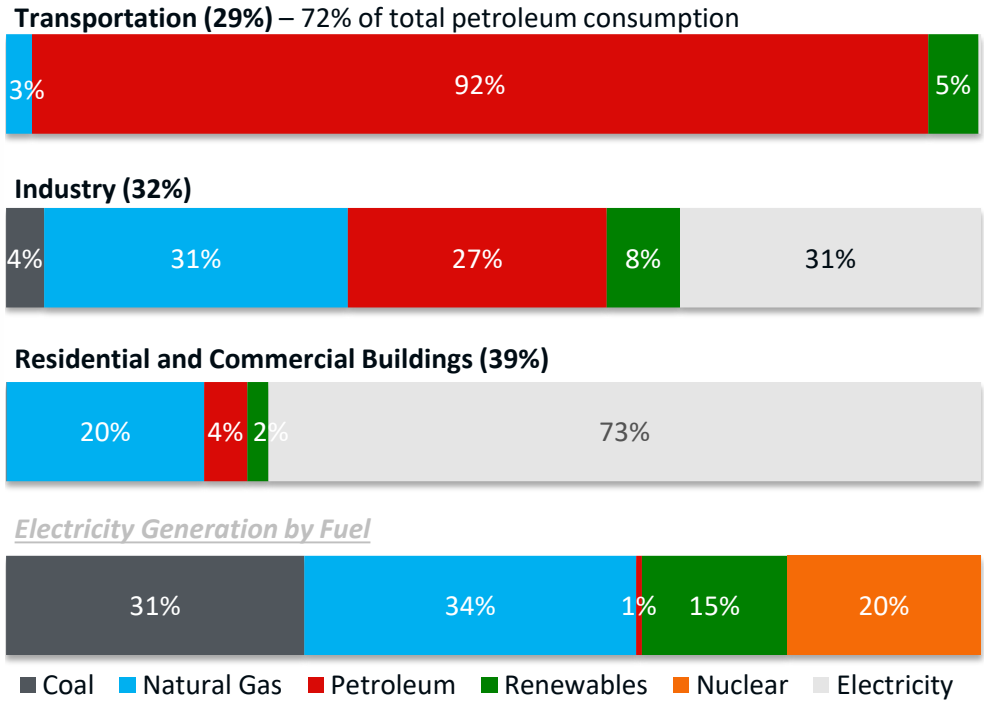
Background (Problem)

U.S. Primary Energy By Fuel (2016)



Source: Matteo Muratori. 2018. "Electrification Opportunities in the Transportation Sector and Impact of Residential Charging." https://www.nrel.gov/docs/fy18osti/71102.pdf

U.S. Energy Consumption by Sector and Fuel (2016)



Rapidly Changing Landscape (Opportunity) – AFV & CAV

Several opportunity to move from petroleum to **alternative fuels**, enabled by **technology advances** in batteries, hydrogen, and biofuels

Self-driving cars will drastically change our world, so when does the revolution begin?
– Globe & Mail

Investments in electrified vehicles announced to date (Jan 2018) include at least **$19 billion by automakers in the U.S., $21 billion in China and $52 billion in Germany**
– Reuters

General Motors believes the **future is all-electric** and announced 20 fully electric models by 2023
– Wired

With 27 members including Toyota, Audi, BMW, Daimler, Honda, Hyundai, Shell and Total, **the Hydrogen Council** has lobbying policymakers and investors on hydrogen

Tesla's electric semi truck: Elon Musk unveils his new freight vehicle
– Tesla

Agenda

Emerging topic:

- **Vehicle electrification**, automation, and new mobility business models are changing the transportation demand landscape.

System changes:

- Electrified vehicles (PEVs and FCEVs) require **infrastructure support.**

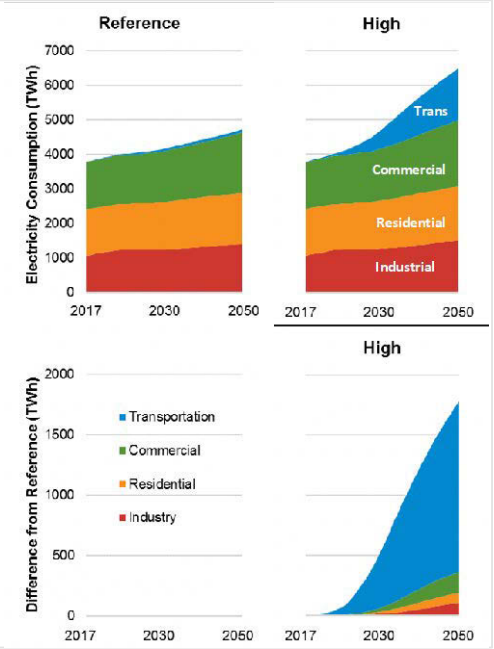
Integration challenges/opportunities:

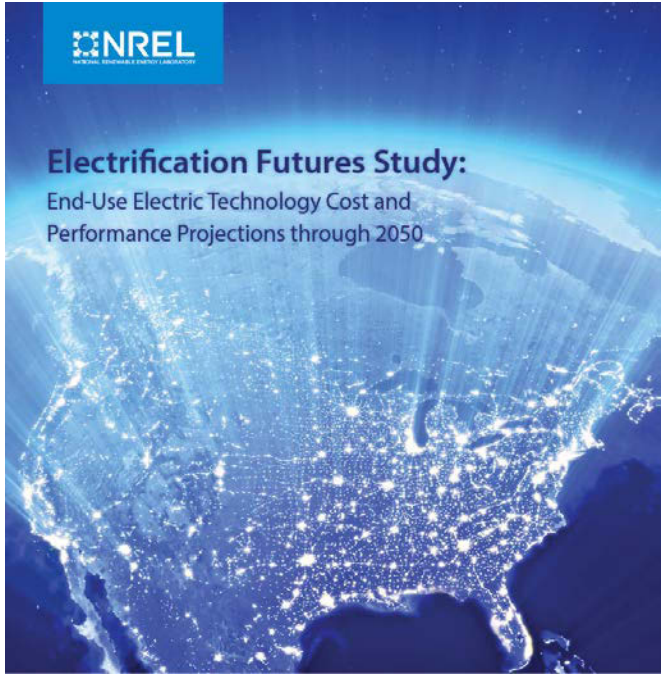
- Electrified vehicles have a potential **game-changing role in the future integrated transportation/energy systems:**
  - What is the **impact on the electricity systems?**
  - What are the opportunities to **support electricity supply**?

U.S. Scenarios of Electrification

Several **energy system transformation scenarios** assume a great degree of future electrification, especially for transportation.

In the EFS High scenario, more widespread electrification, including adoption of electric medium- and heavy-duty trucks, leads to an increase of 1,424 TWh in transportation-related electricity consumption relative to the 2050 Reference scenario.



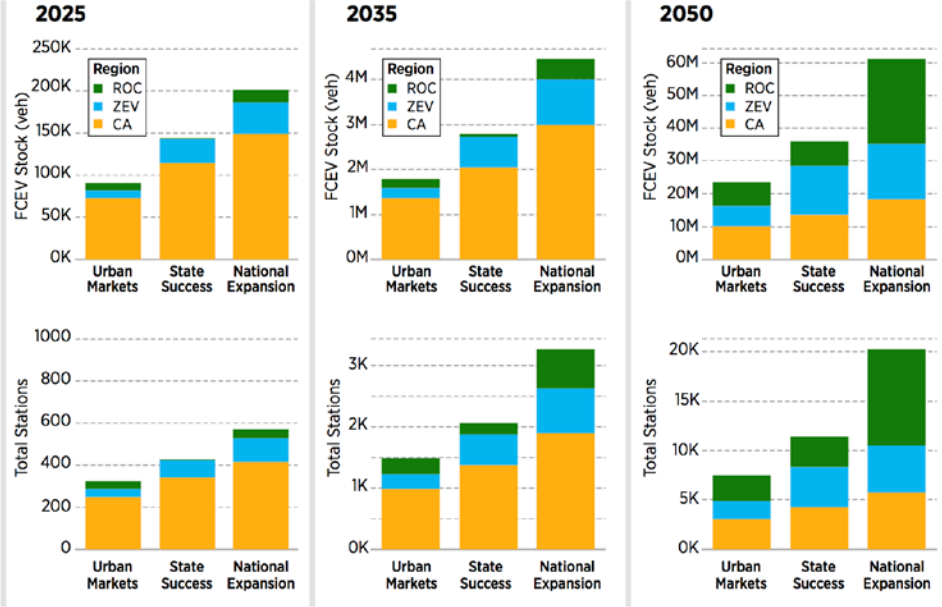


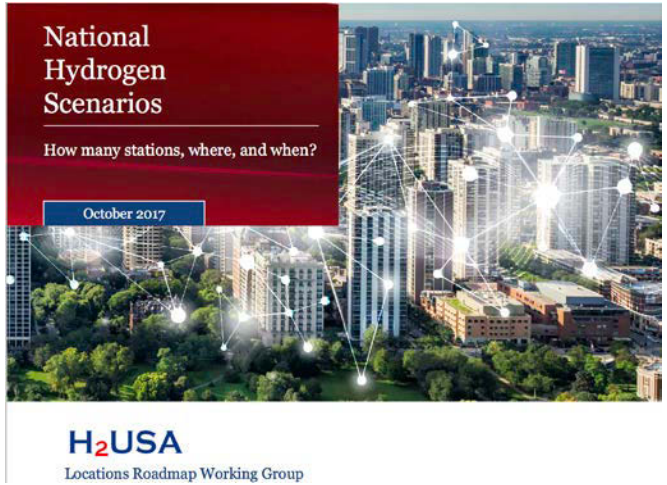
Source: *https://www.nrel.gov/analysis/electrification-futures.html*

U.S. Scenarios of H_2 Adoption

Other energy system transformation scenarios project a significant degree of future electrification using **hydrogen fuel cell vehicles.**

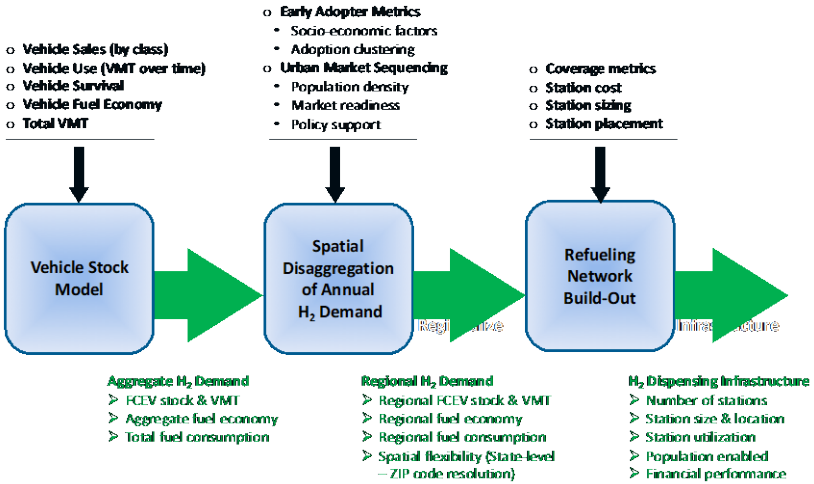
Refueling infrastructure is fundamental to enable FCEV adoption

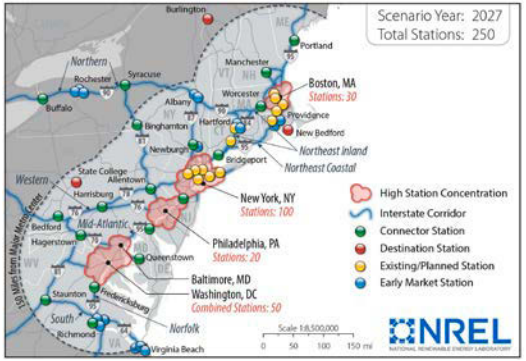


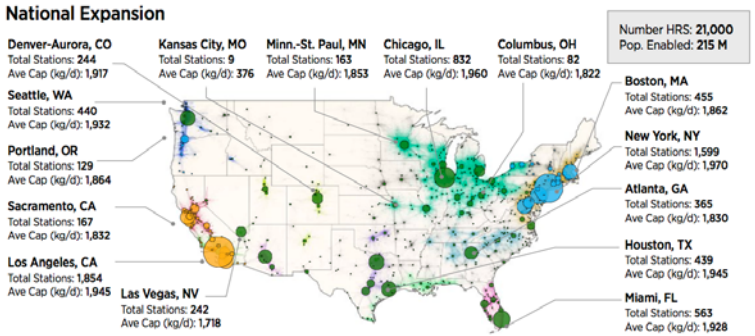


NREL's FCEV Infrastructure Analysis

NREL analyzed vehicle adoption sequencing **and infrastructure requirements** to support FCEV adoption, including estimating hydrogen refueling stations counts, location, use, and related electricity consumption







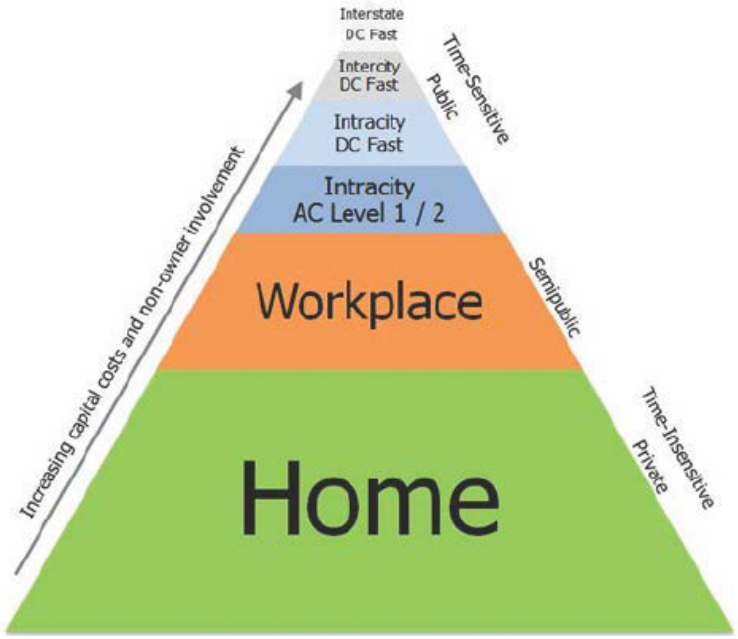
Source: Melaina et al. 2017. Model: NREL's SERA

Charging Requirements

While the majority of plug-in electric vehicle (PEV) charging is expected to come from residential plugs, a network of **non-residential chargers** is still required to:

- Support adopters that cannot reliably charge at home
- Enable long-distance travel
- Cope with range anxiety (safety net)

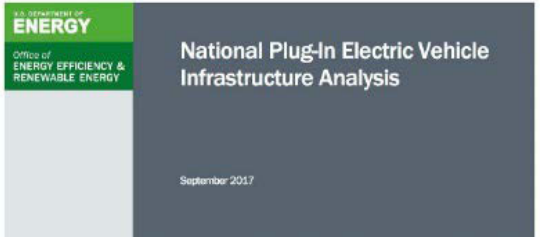
Infrastructure plays a big role in enabling and supporting PEV adoption

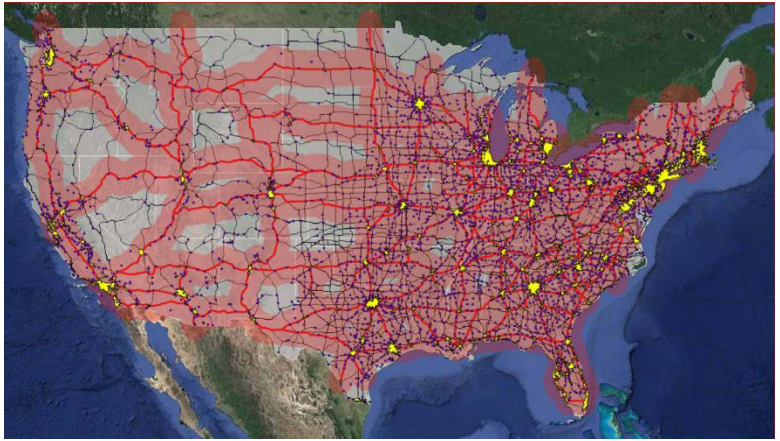


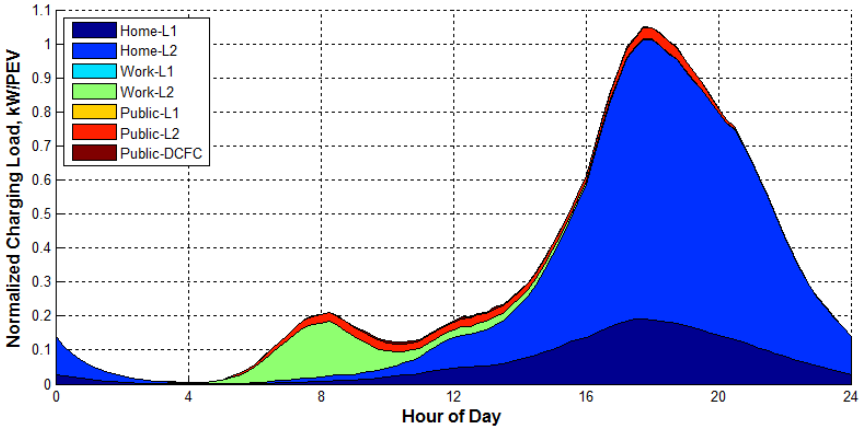
Source: National Research Council. *Overcoming barriers to deployment of plug-in electric vehicles*. National Academies Press, 2015.

NREL's PEV Infrastructure Analysis

NREL analyzed **charging behavior and infrastructure requirements** to support PEV adoption, including estimating PEV supply equipment counts, location, use, and resulting hourly load profiles







Source: Wood et al. 2017. Model: NREL's EVI-Pro

Integration Challenges/Opportunities

- Traditionally, electricity **supply matched the demand** at each instant, following seasonal patterns and instantaneous fluctuations.
- Increase use of non-dispatchable **renewable sources** makes this balancing more challenging
- **Demand-side resources** such as distributed energy storage or demand response – especially flexible EV charging and/or H_2 production – can help support grid operation and facilitate renewable integration.
- Electrified vehicles have a potential **game-changing role** in the future integrated transportation/energy systems. Transport electrification will create **challenges and opportunities** in a system of growing complexity.
  - What is the **impact on the grid**?
  - What are the opportunities to **support electricity supply**?

EV-Grid Impact

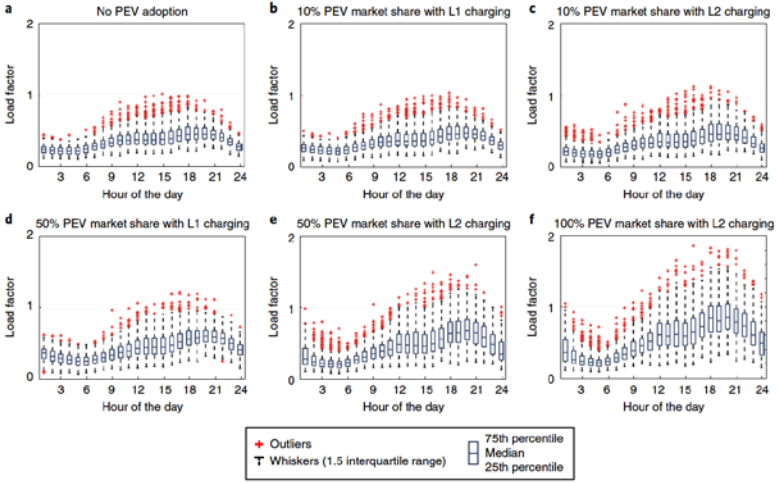
Nature Energy | Articles (Jan 2018)

doi:10.1038/s41560-017-0074-z

Impact of uncoordinated plug-in electric vehicle charging on residential power demand | **Matteo Muratori**

Integrating PEVs creates **load growth opportunities** for electric utilities but also poses **new challenges** in a system of growing complexity

- **Impact on the overall energy consumption increase is limited** (e.g., 10% PEV market share → demand increase of 5%)
- At the local level, **clustering effects** in PEV adoption exacerbate the impact
- **Level 2** charging significantly aggravates the impact of PEVs on the residential distribution infrastructure



$$Load\ factor = \frac{hourly\ power\ consumption}{transformer\ nominal\ power}$$

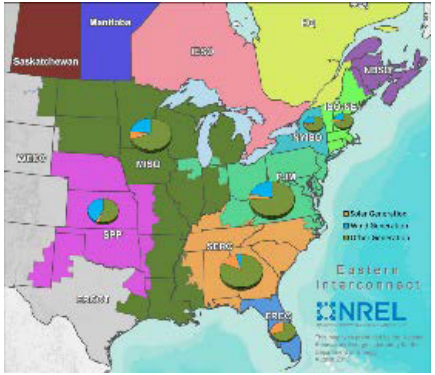
EV-Grid Impact Assessment

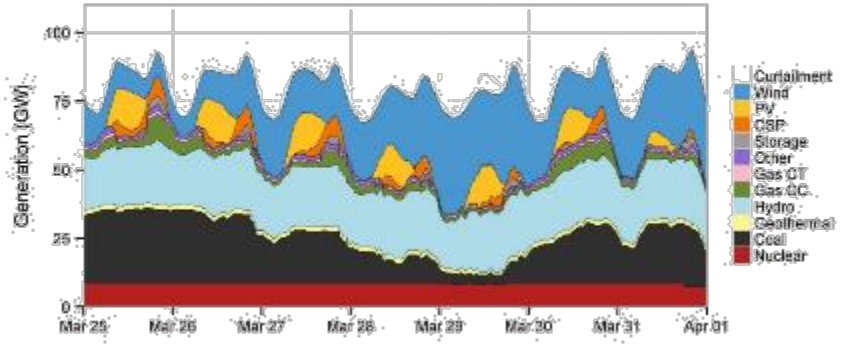
- Large-scale **power system models** can assess the impact of EVs on the grid
- Production cost models can determine the **value of different charging patterns** for EVs (e.g., smart charging, immediate, delayed)

- Generator properties
- Load requirements
- Transmission network (electric & gas)
- Reliability requirements
- Other System Constraints

Production Cost Model

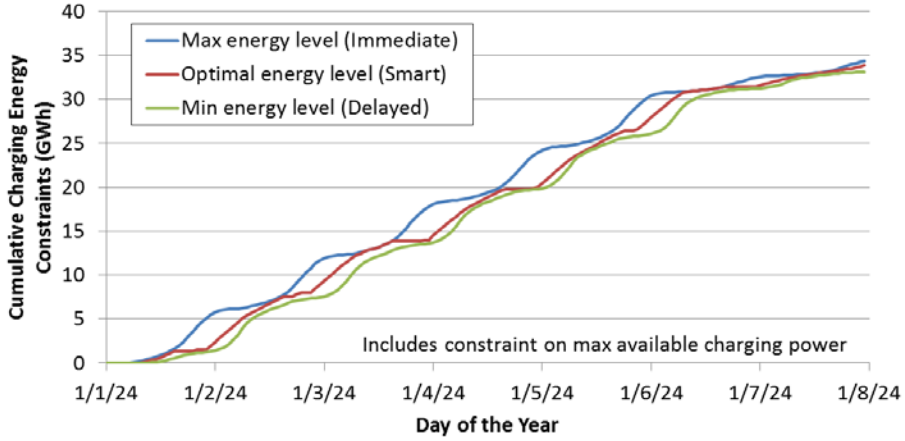
- Operation
- Production cost
- Fuel use
- Electricity price
- Emissions

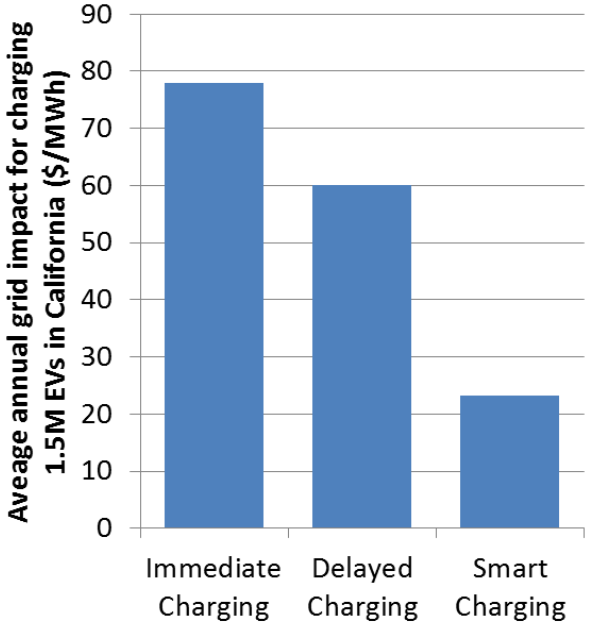




EV Charging Cost

- PEV availability and charging power limits **constrained to respect mobility needs**
- Determine **total production cost** to charge PEVs:
  - Immediately
  - Delayed
  - Optimally





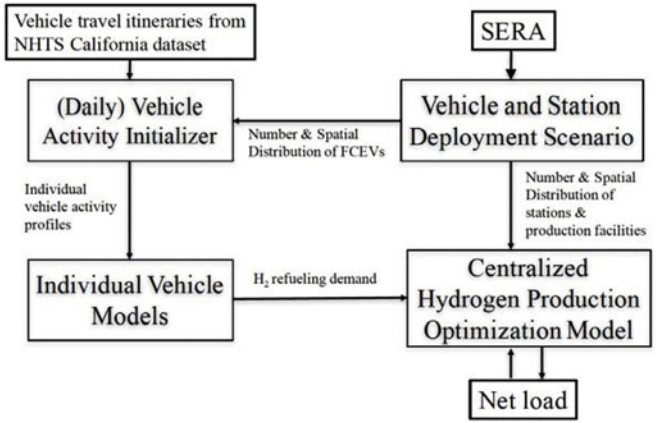
Flexible H_2 Production

The **flexibility of hydrogen production systems** can create synergistic opportunities to better integrate renewable sources into the electricity system.

To quantify this potential, we project the hourly system-wide balancing challenges in California out to 2025 as more renewables are deployed.

Passenger FCEV adoption and refueling behavior are modeled in detail to spatially and temporally resolve the hydrogen demand.

We quantify the **system-wide balancing benefits of controlling hydrogen production from water electrolysis to mitigate renewable intermittency**.

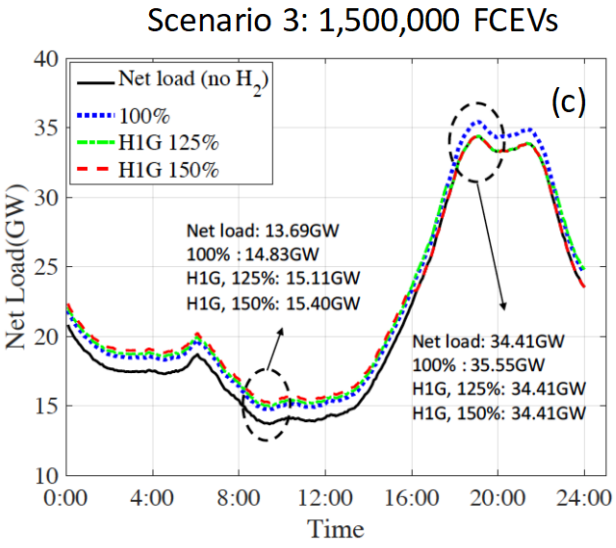


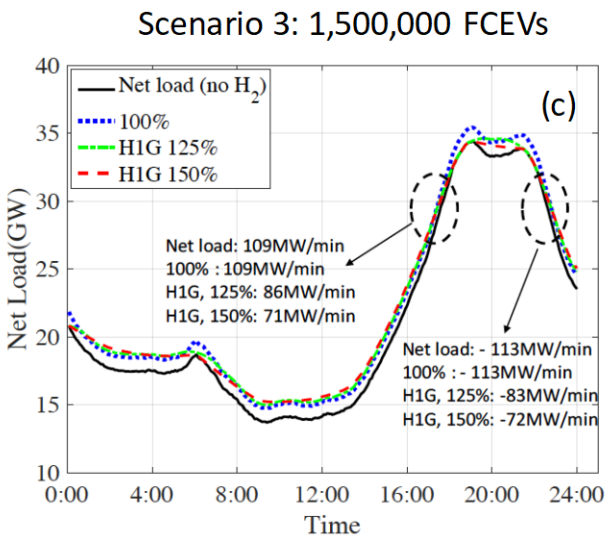
Wang, D., Muratori, M., Eichman, J., Wei, M., Saxena, S. and Zhang, C., 2018. Quantifying the flexibility of hydrogen production systems to support large-scale renewable energy integration. Journal of Power Sources, 399, pp.383-391.

Flexible H_2 Production

Controlled electrolytic hydrogen production for 750,000 FCEVs can greatly help:

- **Peak shaving/valley filling**: 1.4 GW net load valley-to-peak shifting
- **Ramping mitigation**: 50 MW/min ramp mitigation





Conclusions

Emerging topic:

- **Vehicle electrification** is rapidly changing the transportation demand landscape.

System changes:

- **Recharging infrastructure** is required to support this transformation.

Integration challenges/opportunities:

- Electrified vehicles introduce load that the grid was not designed to accommodate and can **impact the electricity system**, especially the distribution.
- Electrified vehicles offers great opportunities to **optimize the design and operation of a future integrated transportation/energy systems.**

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Thanks! Questions?

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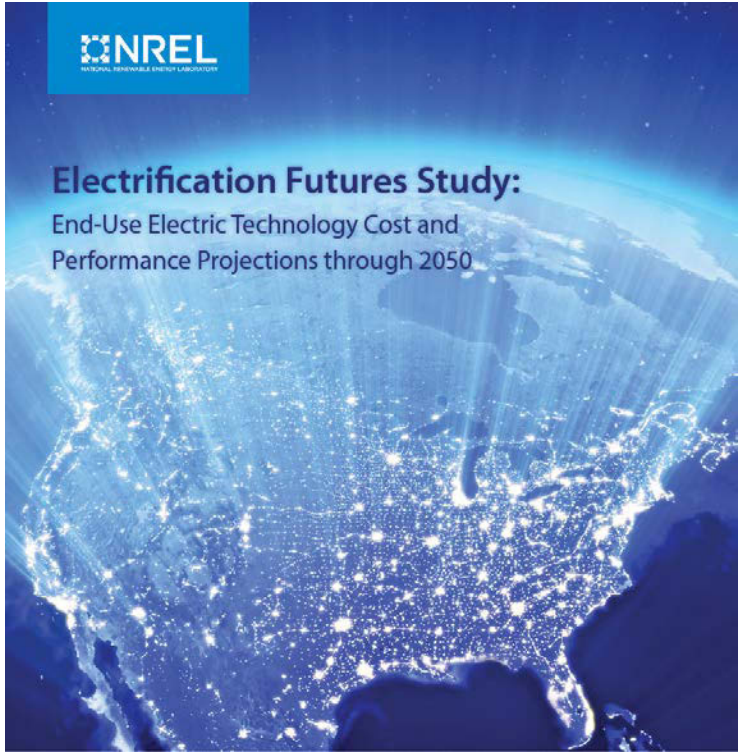
NREL
Transforming ENERGY

NREL's Electrification Futures Study

Through the **Electrification Futures Study**, the National Renewable Energy Laboratory (NREL) is exploring scenarios with and impacts of widespread electrification in the United States:

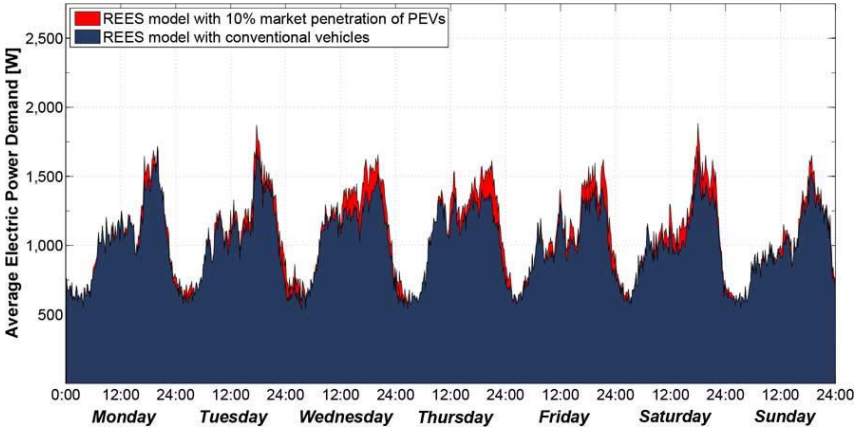
- How might widespread electrification impact **national and regional electricity demand?**
- How would the U.S. **electricity system need to transform**?

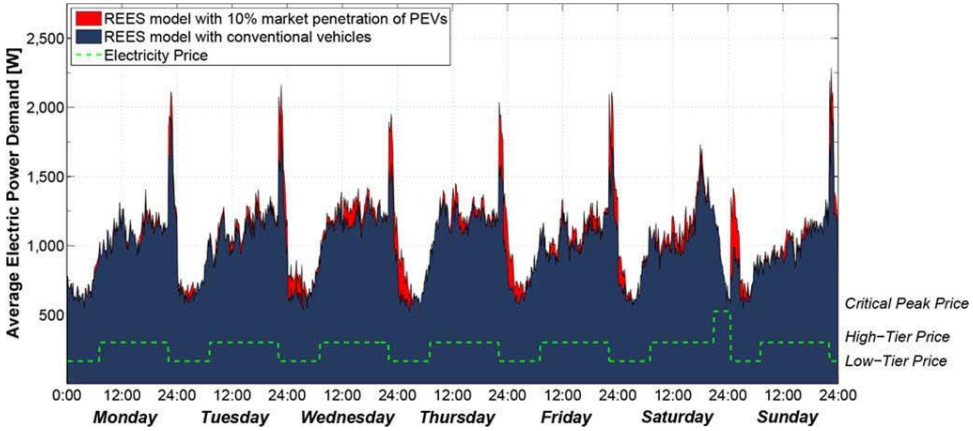


https://www.nrel.gov/analysis/electrification-futures.html

Rebound Peaks

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





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