Electrification Opportunities in the Transportation Sector and Impact of Residential Charging

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Status Quo

U.S. Primary Energy By Fuel (2016)

- Coal: 15%
- Natural Gas: 29%
- Petroleum: 37%
- Renewables: 10%
- Nuclear: 9%


- **Transportation (29%)** – 72% of total petroleum consumption
  - 3% Coal
  - 92% Natural Gas
- **Industry (32%)**
  - 4% Coal
  - 31% Natural Gas
  - 27% Petroleum
- **Residential and Commercial Buildings (39%)**
  - 20% Coal
  - 4% Natural Gas
  - 2% Petroleum
  - 73% Renewables

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

- Accounts for one-third of total energy use and greenhouse gas emissions
- Accounts for more than 70% of total petroleum consumption
- Is the least diversified sector, with minor multi-sectoral synergies

Alternative fuel vehicles have long been proposed to:

- Reduce oil dependency and increase energy security
- Reduce environmental impact (local air quality and climate change)
- Stimulate economic growth and job creation
Changing Landscape

Ford plans **$11 billion investment**, 40 electrified vehicles by 2022
– Reuters Business News

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

LG Chem Expects Chevrolet Bolt Sales to Exceed **30,000 in 2017**
– Inside EVs

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

Tesla puts pedal to the metal, **500,000 cars planned in 2018**
– Reuters Business News

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

Volvo Cars announces new target of **1 million electrified cars sold by 2025**
– Volvo Car Group
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
Several energy system transformation scenarios assume a great degree of future electrification, especially for transportation.

Preliminary results from NREL’s EFS study

Source: https://www.nrel.gov/analysis/electrification-futures.html
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 (dynamic charging or battery swapping also have big infrastructure components)

NREL analyzes charging behavior and infrastructure requirements to support PEV adoption, including estimating PEV supply equipment counts, location, use, and resulting hourly load profiles.
Impact of Residential Charging

Given the projected adoption of PEVs (primarily being charged at home), the impact on residential power demand needs to be carefully assessed.

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

PEVs change the electricity demand in two ways:

- Overall demand increases, given that an additional load is introduced.
- The shape of the demand is modified.

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
Approach and Key Assumptions

• Literature gaps:
  – Building load models don’t consider PEVs
  – PEV impact studies usually assume ubiquitously ‘smart’ charging, and most studies rely on average statistics to estimate PEV charging loads

• This paper:
  – Highly resolved modeling of residential power demand and PEV use—based on a bottom-up approach that quantifies consumer behavior
  – Assumes 100% residential uncoordinated charging

➢ Objective: Assess aggregate and local impact of uncoordinated PEV charging for different adoption levels and EVSE types
Methods

Source: Muratori 2018
Aggregate load profile from 200 residential households in the Midwest is used as a proxy for the aggregate residential load to assess PEV charging impact

- Capture seasonal and diurnal fluctuations
- Validated against AEP metered data

Source: Muratori et al. 2013
• PEVs are an additional load that increases total electricity demand and changes its shape

• Impact on the overall energy consumption increase is limited (e.g., 10% PEV market share → demand increase of 5%)

• The shape of the aggregate residential power demand is more affected by the introduction of PEVs—especially for Level 2 charging

Source: Muratori 2018
The increase in peak demand is less than linear compared with the number of PEVs: that not all PEVs are charged at the same time (vehicle charging timing is predicted by the model), and vehicle charging does not always correspond with residential peak demand.

<table>
<thead>
<tr>
<th>PEV market share</th>
<th>3%</th>
<th>10%</th>
<th>25%</th>
<th>50%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging level</td>
<td>L1</td>
<td>L2</td>
<td>L1</td>
<td>L2</td>
<td>L1</td>
</tr>
<tr>
<td>PEVs simultaneously charged per total PEVs</td>
<td>8/10</td>
<td>5/10</td>
<td>20/35</td>
<td>11/35</td>
<td>39/87</td>
</tr>
<tr>
<td>Share of PEVs simultaneously charged (%)</td>
<td>80</td>
<td>50</td>
<td>57</td>
<td>31</td>
<td>45</td>
</tr>
<tr>
<td>Average per-household incremental peak demand (W)</td>
<td>9</td>
<td>32</td>
<td>85</td>
<td>121</td>
<td>257</td>
</tr>
</tbody>
</table>

Source: Muratori 2018

L1 and L2 denote Level 1 and 2 PEV charging.
A residential distribution transformer connected to six households is considered to evaluate the local impact of uncoordinated in-home PEV charging on the electric power distribution infrastructure

- Household characteristics taken from RECS
- 19 residents, 11 vehicles

**Table 3 | Households considered to assess the local impact of PEV charging on residential power demand**

<table>
<thead>
<tr>
<th>Household</th>
<th>Number of residents</th>
<th>House size (m²)</th>
<th>Number of passenger vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household 1</td>
<td>6</td>
<td>254</td>
<td>3</td>
</tr>
<tr>
<td>Household 2</td>
<td>1</td>
<td>773</td>
<td>1</td>
</tr>
<tr>
<td>Household 3</td>
<td>2</td>
<td>133</td>
<td>1</td>
</tr>
<tr>
<td>Household 4</td>
<td>4</td>
<td>91</td>
<td>2</td>
</tr>
<tr>
<td>Household 5</td>
<td>4</td>
<td>337</td>
<td>2</td>
</tr>
<tr>
<td>Household 6</td>
<td>2</td>
<td>106</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>1,694</td>
<td>11</td>
</tr>
</tbody>
</table>

Source: Muratori 2018
• At the local level, clustering effects in PEV adoption exacerbate the impact

• The introduction of PEVs—even considering L1 charging—leads to significant increases in peak demand at the transformer

• Level 2 charging significantly aggravates the impact of PEVs on the residential distribution infrastructure, since charging events are shorter but steeper
When no PEV is connected to the transformer the load factor is always lower than 1.

As more PEVs are introduced and higher charging power is adopted, PEV charging increases the stress on the distribution infrastructure that might no longer reliably support the local electricity demand.

Load factor = \( \frac{\text{hourly power consumption}}{\text{transformer nominal power}} \)

Source: Muratori 2018
Overall Results

• A 3% PEV market share, which translates to about **7.5 million vehicles on the road**—a number far above the current 0.6 million PEVs deployed—**does not seem to significantly impact the aggregate residential power demand** under either charging level considered.

• The introduction of one single PEV in a residential distribution network consisting of six households **can potentially increase the peak load factor** of the distribution transformers if Level 2 charging (6.6 kW) is adopted.

• All residential and PEV load profiles (10-minute resolution) are available for **download**: [https://data.nrel.gov/submissions/69](https://data.nrel.gov/submissions/69)
Conclusions

• Future research should focus more heavily on understanding consumer driving and charging behavior (to better estimate charging requirements) and the nuances determining the choice of PEV charging infrastructure (e.g., use of Level 1 versus Level 2 residential charging)

• Future studies could leverage the approach and data presented in this paper to explore opportunities related to controlled charging as well as vehicle-to-grid opportunities
Future Research and Collaboration Opportunities

Future research planned at NREL:

• Assess opportunities to leverage PEV charging flexibility to support grid operation and facilitate renewable integration (demand response assessment)

• Assess the impact of non-residential PEV charging on the power system, especially DC fast charging

• Better capture the infrastructure implications of transportation electrification, including:
  – The “PEV adoption–EVSE availability” nexus for light-duty vehicles
  – Electrification strategies for different medium- and heavy-duty vocations
I’d like to acknowledge Trieu Mai (lead of the EFS project), Eric Wood (lead of the national infrastructure assessment study), Maggie Mann, and Jeff Logan for useful discussion and comments.


References:


Thank you
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www.nrel.gov

NREL/PR-5400-71102
L1 vs. L2 Charging

With 12% of the population of the United States, California has 24% of the public PEV charging stations and 30% of the outlets for charging PEVs.

159 BEV owners and 156 PHEV owners responded to questions in the 2016 California Vehicle Survey about where and when they charged their vehicles on a typical weekday.
Widespread participation (automated energy management systems) in demand response programs using time-varying electricity pricing (e.g., TOU) might create pronounced rebound peaks.

Key Capabilities and Tools

Data
Transportation Secure Data Center & Alternative Fuels Data Center

ADOPT
Vehicle Adoption Modeling

FASTSim
Vehicle Powertrain Modeling

EVI-PRO
Plug-in Electric Vehicle Charging Infrastructure

SERA
Alternative Fuel Infrastructure Supply and Infrastructure