Exploring enhanced load flexibility from grid-connected electric vehicles on the Midcontinent Independent System Operator grid

*Final project report*
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Growth of EVs has been exponential, but less so in 2019-2020

- Year-end 2019 cumulative sales: 7.5M
- Surpassed 3% of total sales in 2020
- Electric trucks also surpassed previous sales records in 2019
- EVs are poised for explosive global growth as climate regulations tighten

Sources
Focus areas of 2020 report

<table>
<thead>
<tr>
<th>Development of medium- and heavy-duty EV forecasts</th>
<th>Exploration of new EV charging protocols</th>
<th>Investigation of regional grid effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Chart" /></td>
<td><img src="image3.png" alt="Map" /></td>
</tr>
</tbody>
</table>

- Estimation of carbon dioxide emissions from EV charging
- Development of an EV availability index
- Interviews with EV industry stakeholders
## Medium- and heavy-duty vehicle (MHDV) market segments

<table>
<thead>
<tr>
<th>Segment</th>
<th>% of total sales</th>
<th>% of total est. energy use</th>
<th>% ARB thinks electrifiable</th>
<th>Justification for inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medium-duty vehicles</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light van (class 3)</td>
<td>41%</td>
<td>15%</td>
<td>100%</td>
<td>Highly electrifiable; large % of sales</td>
</tr>
<tr>
<td>Delivery/box truck (class 4-7), short range</td>
<td>19%</td>
<td>13%</td>
<td>100%</td>
<td>Highly electrifiable; large % of sales</td>
</tr>
<tr>
<td>Delivery/box truck (class 4-7), medium range</td>
<td>26%</td>
<td>24%</td>
<td>76%</td>
<td>Highly electrifiable; large % of sales and energy use</td>
</tr>
<tr>
<td>Local tractor</td>
<td>6%</td>
<td>10%</td>
<td>89%</td>
<td>Highly electrifiable</td>
</tr>
<tr>
<td>Regional tractor</td>
<td>3%</td>
<td>6%</td>
<td>100%</td>
<td>Highly electrifiable</td>
</tr>
<tr>
<td>Long-haul tractor</td>
<td>22%</td>
<td>50%</td>
<td>3%</td>
<td>Ostensibly difficult to electrify, but very large fraction of energy use; will do sensitivity of long-haul electrification</td>
</tr>
<tr>
<td>School bus</td>
<td>9%</td>
<td>9%</td>
<td>100%</td>
<td>Highly electrifiable; charismatic</td>
</tr>
<tr>
<td>Refuse &amp; dump trucks</td>
<td>10%</td>
<td>32%</td>
<td>72%</td>
<td>Highly electrifiable; charismatic</td>
</tr>
<tr>
<td>Transit bus</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Not included in ARB analysis, but highly likely to electrify</td>
</tr>
<tr>
<td><strong>Heavy-duty vehicles</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Buses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bucket truck</td>
<td>2%</td>
<td>2%</td>
<td>53%</td>
<td>Small percentage of energy use</td>
</tr>
<tr>
<td>Specialized</td>
<td>2%</td>
<td>4%</td>
<td>22%</td>
<td>Small percentage of energy use; very diverse; not highly electrifiable</td>
</tr>
</tbody>
</table>

**Deprioritized**
MHDV forecasts

- Forecast growth by scenario and vehicle class (aggregated for clarity)
MHDV forecasts

- Scenarios designed to span range of existing forecasts
In addition to sales forecasts, we also developed vehicle class-specific estimates of:

- Average battery size
- Average charging speed
- Travel itineraries (e.g., usage patterns), which governed availability for charging and energy demand

<table>
<thead>
<tr>
<th>Category</th>
<th>2020</th>
<th></th>
<th>2040</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kWh/mi</td>
<td>Range</td>
<td>Capacity</td>
<td>kWh/mi</td>
</tr>
<tr>
<td>Light van (class 3)</td>
<td>0.49</td>
<td>100</td>
<td>110</td>
<td>0.36</td>
</tr>
<tr>
<td>Delivery/box truck (class 4-7), short</td>
<td>1.12</td>
<td>100</td>
<td>250</td>
<td>0.86</td>
</tr>
<tr>
<td>Delivery/box truck (class 4-7), medium</td>
<td>1.12</td>
<td>150</td>
<td>374</td>
<td>0.86</td>
</tr>
<tr>
<td>Local tractor</td>
<td>2.03</td>
<td>100</td>
<td>450</td>
<td>1.50</td>
</tr>
<tr>
<td>Regional tractor</td>
<td>2.03</td>
<td>250</td>
<td>1125</td>
<td>1.50</td>
</tr>
<tr>
<td>Long-haul tractor</td>
<td>2.03</td>
<td>300</td>
<td>1350</td>
<td>1.50</td>
</tr>
<tr>
<td>School bus</td>
<td>1.67</td>
<td>100</td>
<td>371</td>
<td>1.26</td>
</tr>
<tr>
<td>Refuse &amp; dump trucks</td>
<td>2.74</td>
<td>50</td>
<td>304</td>
<td>2.07</td>
</tr>
<tr>
<td>City bus</td>
<td>2.61</td>
<td>150</td>
<td>871</td>
<td>1.99</td>
</tr>
</tbody>
</table>
Basic simulation results

- Slight modifications made to 2019 light-duty vehicle (LDV) forecasts
- Simulations performed for:
  - MHDVs only
  - LDVs only
  - MHDVs + LDVs
- Find that LDVs dominate results, despite aggressive MHDV growth
Basic simulation results

Net load under different EV growth scenarios: all vehicles, 2039
New charging protocols: Hybrid optimization
New charging protocols: Emergency V2G

- Reflects real-world scenario where V2G is not used frequently, but is available in emergencies
- Specify a 10% cap for each vehicle class battery capacity that can be used for V2G (e.g., export)
For V1G, EV loads are shifted to times when locational marginal prices (LMPs) are lowest.

For V2G, such shifts are exacerbated, and loads are also actively lowered when LMPs are highest.

Cost-based optimization can drive significant inter-hour arbitrage with V2G.

**New charging protocols: Cost-based optimization**

- V1G: Allow charging only at lowest prices
- V2G: Inverse relationship between price and load
Regional impacts

- Focus on two LRZs: 1 (highest renewable penetration) and 7 (highest EV penetration)
Regional impacts

V1G results for 2039

March

June

September

December
Regional impacts

V2G results for 2039

March

June

September

December
**EV availability index ("slack capacity")**

- **Slack capacity**: How much charging/discharging capacity is available from EV fleet after optimization has already been performed?
EV availability index ("slack capacity")

- Results for MHDVs (June 1, 2039, very high EV case)

![Graph showing EV availability index](image)
EV availability index ("slack capacity")

- Comparison with system load and aggregate fleet capacity
EV availability index or “slack capacity”

Very High EVs

Base EVs

MHDVs only

LDVs only
EV availability: Seasonal differences

- March
- June
- September
- December
EV availability: V1G vs. V2G

V1G

V2G

Graphs showing the availability of EV charging and discharging capacity (V1G) and additional available slack capacity on top of original optimization (V2G) throughout the day in MW. The graphs compare the performance of V1G and V2G in managing energy demand.
Industry stakeholder interviews

We interviewed three industry stakeholders representing different roles/perspectives:

<table>
<thead>
<tr>
<th>Organization</th>
<th>Type</th>
<th>People contacted</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alliance for Automotive Innovation</td>
<td>Automaker trade association</td>
<td>Dan Bowerson</td>
<td>autosinnovate.org</td>
</tr>
<tr>
<td>General Motors</td>
<td>Automaker</td>
<td>Jamie Hall and Kelly Helfrich</td>
<td>gm.com</td>
</tr>
<tr>
<td>Nuvve</td>
<td>EV charging service provider</td>
<td>Marc Trahand and Jackie Piero</td>
<td>nuvve.com</td>
</tr>
</tbody>
</table>

We asked each group variations on the following questions:

■ What is your opinion and assumptions about the use of controlled charging (especially V2G) with regard to physical, legal, and economic barriers?
■ How do you see these opinions evolving over time? What needs to change to expand adoption?
■ How engaged are you with utilities and/or regulators about these things?
■ Do you see yourself leading the charge? Which auto manufacturers are leading/lagging?
Industry stakeholder interviews

V1G
- Automakers see V1G as “low-hanging fruit”: TOU rates are well-subscribed; demand for V1G is high
- Controlled charging is an opportunity for automakers, but could lose it with poor implementation
- Automakers and utilities are actively involved in the Open Vehicle Grid Integration Platform (OVGIP)

V2G
- Utilities and not customers will likely ask for V2G—and only after V1G is more widespread
- Most V2G activity is happening in California, but interest is growing elsewhere in the U.S.
- While some manufacturers are concerned about V2G’s effect on battery lifetimes, Nuvve is convinced that the impact will be minimal, and manufacturers do not expect warranty issues
  - Some concern over battery degradation at high charging rates, but active cooling can mitigate
Industry stakeholder interviews

Challenges

- Customers need clear price signals to participate in either V1G or V2G; they will not “help the grid” without compensation
- Currently less opportunity for V2G, because of less customer willingness and lack of education
- Hardware to facilitate V2G will be more expensive; value must justify additional investment
- Adoption may be more regional, where peak power constraints are higher
- Policy is currently being driven by utilities; vehicle manufacturers must advocate for themselves
- How is V2G categorized (Generator? Load? Storage? None of these?) and how is market accessed?
  - Nuvve prefers categorizing V2G as storage (Energy Storage Associations support this)

More information is available in the final report
Questions?

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