Trends in Electric Vehicles

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Presentation Topics

1) What is Argonne National Lab and Interoperability Center?
2) EV charging history, New EVs, Electric vehicle charging rates
3) Context- Liquid Fuel Dispensing vs Electric ‘Fueling’
4) Example EVSEs/Displays (AC, DC); First Candidate Brands?
5) HB44 Dispensing Measurement Tools: ANL SmartLoadDAQ®
6) Question and Answer (during or after presentation)
What is Argonne National Lab and the EV-Smart Grid Interoperability Center?

ANL was designated as the first National Laboratory in 1946, initially formed to support Enrico Fermi’s work (Univ. of Chicago) on the Manhattan Project. (CP-1 75th Anniversary)

Some Statistics

- **Budget:** $760M
- **Staff:** 3350
- **Location:** Lemont IL
- **Area:** 1700 acres
- Multidiscipline research including energy, materials, computing, nuclear, bio, etc
What is Argonne National Lab and the EV-Smart Grid Interoperability Center?

ANL hosts the US EV-Smart Grid Interoperability Center, in conjunction with JRC in Ispra Italy, to develop and validate EV charging standards as well as research grid impacts.

Smart Energy Plazas at bldgs 300 and 362

**Some Statistics**
- 50 AC EVSEs Site-wide
- PV Fed Charging- 80kW
- DC Fast Chargers: 25kW, 50kW, 200kW, 350kW
- Wireless: 50kW
ANL EV-Smart Grid Interoperability Standards and Technology Development for EV Charging

SAE J1772-v6
PEV Compliance
Requirements, test equipment, procedures

SAE J2847/2-v2
DC Charging Communication
Requirements, test equipment, procedures, enabling technology

SAE J2953
PEV-EVSE Interoperability
Requirements, test equipment, procedures

SAE J2954
Wireless Charging
Requirements, standard test fixture, procedures

SAE J2847/6
Wireless Charging Communication
Test equipment, procedures, enabling technology
Electric Vehicle Charging 101

- **ALL** US electric vehicles can charge from AC sources via the SAE J1772 coupler (from 6A/120vac to 80A/240vac) {30A typ.}
- **Some** electric vehicles can accept DC power from an external charger (called DC Fast Charging); three couplers tied to specific manufacturers (Tesla only), CHAdeMO (Nissan), J1772-DC CCS (combo, everyone else); from 12kW to 400kW  Chevy Bolt accepts 80kW, Tesla up to 120kW, Porsche ~400kW
- **SOON** electric vehicles will also include wireless charging receivers from 3kW to 11kW to 50kW, to 500kW+(heavy duty)

- **Commercial/MD/HD Vehicles:** Work in progress; pilot fleets in 2019, production 2020. SAE J3068 (480vac, up to 133kW); CharIN consortium coupler 1500vdc/3000A max (up to 4.5MW) for 30 minute turn around of trucks loading, buses on route
## Charging Couplers and Charging Rates (up to 350kW)

<table>
<thead>
<tr>
<th>Type of Charging</th>
<th>Level 1 – 110V (~1.4kW)</th>
<th>Level 2 – 220V (~7.2kW)</th>
<th>DC Fast Charger (50kW)</th>
<th>Tesla SuperCharger (140kW)</th>
<th>Extreme Fast Charging (350kW)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging Station 101</td>
<td>Provides same electricity as a regular electrical outlet</td>
<td>More powerful than Level 1 charging</td>
<td>DC current directly supplied to vehicle</td>
<td>Only available for Tesla vehicles</td>
<td>Provides significantly faster charge rates than anything else on market</td>
</tr>
<tr>
<td>Range Gained per Hour of Charge</td>
<td>3-5 miles</td>
<td>25 miles</td>
<td>100 miles</td>
<td>330 miles</td>
<td><strong>787.5 miles</strong></td>
</tr>
<tr>
<td>Time to Charge for 200 miles</td>
<td>40 hours</td>
<td>8 hours</td>
<td>2 hours</td>
<td>36.55 mins</td>
<td>15.25 mins</td>
</tr>
</tbody>
</table>

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### CHAdeMO (Japan)

![CHAdeMO Connector](image1)

### GB/T (China) (CCS)

![GB/T (China) Connector](image2)

### COMBO 1 (US)

![COMBO 1 Connector](image3)

### COMBO 2 (EU)

![COMBO 2 Connector](image4)

### Tesla (AC/DC)

![Tesla Connector](image5)
Rediscovering What Others Have Advocated in the Past, Implemented Today with New Technology

Need: 150A DC coupler for ‘wide adoption of PEVs’…
Delivered: 100+ years ago—30,000 BEVs used this coupler in 1913

Need: Indoor and Curb Side Charging Station
Delivered: 100 years ago—46k miles on Electric Taxi Fleet in Detroit
Central Garage DC Charging stations (~1910)
(bright light on top is rectifier tube)

Note cable management counterweighted rope
6kW DC Off-board Charging in 1910
Also called ‘Wattstation’

8000 Chargers in use, 1910

~ Avg man can’t afford to maintain a horse, EV OK

110 Year Old Value of Electric Transportation

Steinmetz Says:

“I believe that the Electric will be the car of the future on account of its simplicity of operation and reliability. It is rare that it gets out of order. When it does so it is an accident, not as with the gasoline car, an incident. The man of moderate means cannot afford a horse and buggy because of the attention required. He will be able to afford an Electric Vehicle to take him to business because it requires no attention—I equipped with an Edison Battery. It often has to stand idle for several days and this is not good for a lead battery. I have tried to invent a lead battery that would not spoil, but gave it up.”

General Electric Company
Largest Electrical Manufacturer in the World

Principal Office:
Schenectady, N. Y.
Sales Offices in All Large Cities

EDISON STORAGE BATTERY COMPANY
Inc., Orange, N. J.
Historical Perspective On EV Batteries-
GM Electrovair (~50 Years Ago)

- Batteries in front and rear of vehicle, rear drive motor and rear electronics/cooling

Fig. 1 CUTAWAY VIEW OF GENERAL MOTORS ELECTROVAIR
Electrovair Electronics Packaging
532V Silver Zinc Batteries

- Batteries in center of rear of Corvair, electronics wrapped on the sides, motor below (belt driven fan)

GM EV-1 Powertrain
~ 25 years ago

Gen 1 Lead Acid 1310lb, Gen 2 NiMH
- PbA - 16.5kWhr (3086 lbs curb wt.)
- NiMH - 26.4kWhr (2908 lbs curb wt)
Chevy Volt EREV/PHEV (Gen 1)  
~ 10 years ago  
288 cells, 9 modules, 345v/45Ahr, 16kWhr, 435lb
Chevy Volt EREV (Gen 2) ~ 3 years ago
(Oct 2015- Feb 2019)
192 cells, 96 Cell groups, 18.4kWhr, 403lb
Tesla Model S, X - 100kWhr~Today

16 modules w/516 18650 cells; 8256 cells total; 400v/250Ah=100kWhr
Tesla Model 3 ~ Today

4416 cells (2170 size) in 4 modules; 23/25 bricks of 46 cells in each module; each row contains micro extrusion cooling channels between the cells; 480 kg, 350v/214Ahr = 75 kWhr
Flood of New Electric Vehicle Models Announced
- VW Group claims all 300 product line vehicles with electric variants by 2030; 80 more by 2025 (6 years)
Porsche Taycan (under $200k) - 350kW Charging
600hp, dual motor (800vdc) 500km range
0-200kph 12 sec, 0-60mph 3.5 seconds; 350kW charging, emotion camera, gesture input, hologram
VW ID R; (Pike’s Peak) Racing Improves the Breed
2425lbs/1100kg, 680hp/500kW, 480lbft/650 Nm
resulting in 0-62mph=2.25 sec.; Record is 8:57 for
12.42miles/19.99km; 82.8mph average (tight turns)
Flood of New Electric Vehicle Models Announced
- VW Group claims all 300 product line vehicles with electric variants by 2030; 80 more by 2025 (7 years)
Porsche Mission E (eta 2020)- 350kW Charge Rate
600hp, dual motor (800vdc) 500km range

0-200kph 12 sec, 0-60mph 3.5 seconds; 350kW charging, emotion camera, gesture input, hologram
Battery replacement life and costs; BEVs-Hybrids
Degradation different than failure

Typical EV Battery Warranties; 8 years/100k miles; 10 years/150k miles (state by state)

- Internet price references:
  - **Chevy Bolt** (60kWhr), list price of full pack is $15,734; GM notes that after 7+ years, there have been no Chevy Volt battery pack degradation warranty claims
  - **Nissan Leaf** (2018)- Refurbish program w/4R Energy; 24kWhr-$2736, New exchange price; 24 kWh-$5928; 30 kWh-$7269; 40 kWh-$7479
  - **Ford Focus** EV($10k in 2012, $8500 in 2018)

- Battery degradation is not failure; (Nissan 2015 law suit settlement; replacement of 2011-2012 Leaf packs, due to misleading limits on thermal/fast charge operation

**GM Battery Packs:**
Gen1-Gen Volt
Spark EV
Bolt EV
Battery Secondary Use Standards- Assessing Health, Repurposed Assets

- SAE J2997 Committee formed to standardize procedures and definitions on dealing with secondary use batteries; including stationary storage and repurposing applications

- ‘Reborn Light’ working with Nissan/4R Energy to PV/LED Light poles
- Spiers New Technology, packaged Leaf packs for EV charging;
- RE-STOR by Connected Energy co-located peak shaving for DC charging
US EV Sales: >1 Million total in ~10 years

U.S. Plug-In Car Sales

[Bar chart showing historical US Plug-In Car Sales from 2010 to 2019, with each month represented and sales data for each year indicated by different colors.]
Cost Parity Comparison of EV, PHEV, Hybrids, ICEs

- Effective cost of ownership and policy benefit
- Total cost of driving ($/mile)

Battery electric vehicle in each city:
- City and state policy benefit
- Cost of ownership (6-year)
- Cost per mile (right axis)
Total Cost of Ownership; Pre-Owned EV Options

- Used-car shopping site ‘Shift’ reports 4% of sales in 2019, triple that of last year.
- EVs account for less than 2% of new car sales in the US
- In 2018, Americans bought 17.3 million new cars and 40.2 million used ones.
- Used Nissan Leaf and Fiat 500e EVs often sell for under $10,000 ($30k MSRP)
- [https://www.wired.com/story/now-used-car-lot-great-electric-vehicles-cheap/](https://www.wired.com/story/now-used-car-lot-great-electric-vehicles-cheap/)
Total Cost of Ownership- EV Registration Fees
(extra fees to replace road repair fuel tax revenue)

- 20 states now have special fees for EVs; double that of just two years ago
- WI- $100 extra ($75+county taxes); already paying sales tax on electricity
- [https://www.eenews.net/stories/1060126901](https://www.eenews.net/stories/1060126901)
## Battery Electric Vehicles for Sale in 2017

### Eff., Range, Battery Capacity, Charging Rates

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Capacity kWhr</th>
<th>Charge rate-AC</th>
<th>DC Type</th>
<th>ZEV Miles</th>
<th>AC Whr/mile</th>
<th>MPGe©</th>
<th>MPGe(city)</th>
<th>MPGe(hwy)</th>
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<tbody>
<tr>
<td>Hyundai</td>
<td>Ioniq</td>
<td>28</td>
<td>7</td>
<td>CCS</td>
<td>124</td>
<td>250</td>
<td>136</td>
<td>150</td>
<td>122</td>
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<tr>
<td>BMW</td>
<td>i3 (60Ahr)</td>
<td>22</td>
<td>7.7</td>
<td>CCS</td>
<td>81</td>
<td>270</td>
<td>124</td>
<td>137</td>
<td>111</td>
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<td>280</td>
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<td>380</td>
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<td>CCS</td>
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Data compiled from [www.Fueleconomy.gov](http://www.Fueleconomy.gov) search tool and various automotive websites.
Comparison of Vehicle Range, Energy Consumption

<table>
<thead>
<tr>
<th>Model</th>
<th>City</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyundai IONIQ Electric (2019)</td>
<td>248</td>
<td>225</td>
</tr>
<tr>
<td>Tesla Model 3 Standard Range Plus (2019)</td>
<td>253</td>
<td>241</td>
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<tr>
<td>Tesla Model 3 Standard Range (2019)</td>
<td>257</td>
<td>244</td>
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<tr>
<td>Tesla Model 3 Long Range RWD (2019)</td>
<td>259</td>
<td>248</td>
</tr>
<tr>
<td>Hyundai Kona Electric (2019)</td>
<td>281</td>
<td>255</td>
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<tr>
<td>Volkswagen e-Golf (2019)</td>
<td>283</td>
<td>267</td>
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<tr>
<td>Chevrolet Bolt EV (2019)</td>
<td>283</td>
<td>263</td>
</tr>
<tr>
<td>Tesla Model 3 Long Range AWD (2019)</td>
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<td>281</td>
</tr>
<tr>
<td>Tesla Model 3 Performance LR AWD (2019)</td>
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<tr>
<td>Honda Clarity Electric (2019)</td>
<td>296</td>
<td>267</td>
</tr>
<tr>
<td>Kia Soul EV (e-Soul) (2020)</td>
<td>296</td>
<td>265</td>
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<tr>
<td>BMW i3 (2019)</td>
<td>298</td>
<td>272</td>
</tr>
<tr>
<td>BMW i3s (2019)</td>
<td>298</td>
<td>272</td>
</tr>
</tbody>
</table>
Comparison of Vehicle Range, Energy Consumption

- Fiat 500e (2019): Range 301, Energy Consumption 279, Total 327
- Nissan LEAF (40 kWh) (2019): Range 301, Energy Consumption 272, Total 340
- Tesla Model S Long Range (2019): Range 304, Energy Consumption 293, Total 317
- Nissan LEAF e+ S (62 kWh) (2019): Range 312, Energy Consumption 286, Total 347
- smart EQ fortwo Coupe (2019): Range 312, Energy Consumption 272, Total 384
- Kia Soul EV (2019): Range 312, Energy Consumption 272, Total 384
- Nissan LEAF e+ SV/SL (62 kWh) (2019): Range 324, Energy Consumption 296, Total 370
- smart EQ fortwo Cabrio (2019): Range 330, Energy Consumption 301, Total 431
- Audi e-tron (2019): Range 455, Energy Consumption 455, Total 455
Miles per Charging Time Comparison; Vehicle Dependencies, Charging Equipment Dependencies

- SAE Working Group on Charging Rate Reporting Methods Standard

Real Data: miles added vs. time

<table>
<thead>
<tr>
<th>Miles Added in Fixed Time</th>
<th>5 min</th>
<th>10 min</th>
<th>20 min</th>
<th>30 min</th>
<th>40 min</th>
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<tbody>
<tr>
<td>e-Tron</td>
<td>32</td>
<td>66</td>
<td>133</td>
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<tr>
<td>Model 3</td>
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<td>i-Pace</td>
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<table>
<thead>
<tr>
<th>Time to Fixed Distance</th>
<th>50 miles</th>
<th>100 miles</th>
<th>150 miles</th>
<th>200 miles</th>
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<td>e-Tron</td>
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<td>Model 3</td>
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<td>19</td>
<td>29</td>
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<tr>
<td>e-Niro</td>
<td>9</td>
<td>18</td>
<td>29</td>
<td>46</td>
</tr>
</tbody>
</table>

Note: model started at 10% SOC

Data extracted from published Fastned data. Cars tested on “175kW” charger → charger is no the limitation for any of these vehicles

https://support.fastned.nl/hc/en-gb/articles/115015420127-175-kW-fast-chargers
EV Charging Infrastructure - Dwell Time Impacts
Charging Rate and Cost, Commercial Transactions

http://www.workplacecharging.com/
AFDC Based Map of EVSE Deployment; ~27,500 stations

https://afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC
HB44-3.40 ‘Point of Sale’: Analogy to Liquid Fuels and Residential Electricity Delivery

SAE J2836/1 Use Case Figures:
- **Red line** is liquid fueling point of sale.
- **Green line** is utility/premise ‘point of sale’ at the premise meter; edge of premises
- **Blue line** is at the tip of the conductive charging for vehicle electricity dispensing