Electric Vehicles: Performance, Cost, Penetration

John German

October 27, 2014
CCAP MAIN-Latin American Regional Dialogue
Washington, DC
ICCT is working with governments in the top vehicle markets worldwide

Number of light-duty vehicles on the road in 2010

- U.S.: 231
- Mexico: 22
- Latin America excl. Brazil: 20
- Brazil: 28
- EU-27: 239
- Non-EU Europe: 28
- Russia: 34
- China: 59
- Japan: 58
- South Korea: 15
- Rest of Asia: 40
- Australia: 12
- India: 15
- Middle East: 26
Driving Electrification – A “kick-off” report

http://www.theicct.org/driving-electrification-global-comparison-fiscal-policy-electric-vehicles
The starting point

How many EVs are sold, and where?
Electric vehicles on the rise

- From nearly no sales in 2009 to over 200,000 per year globally in 2013
- About 40% of global electric vehicle sales are in the US
  - The EU, Japan, China are other leading markets
## U.S. Electric vehicles, by type and automaker

<table>
<thead>
<tr>
<th>Company</th>
<th>Battery electric vehicle (BEV)</th>
<th>Plug-in hybrid electric vehicle* (PHEV)</th>
<th>Fuel cell electric vehicle (FCEV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMW</td>
<td>Active-E, i3</td>
<td>i8, i3</td>
<td></td>
</tr>
<tr>
<td>Ford</td>
<td>Focus</td>
<td><strong>C-Max Energi, Fusion Energi</strong></td>
<td></td>
</tr>
<tr>
<td>General Motors</td>
<td>Spark</td>
<td><strong>Volt, ELR</strong></td>
<td></td>
</tr>
<tr>
<td>Honda</td>
<td>Fit</td>
<td>Accord Plug-in</td>
<td><strong>FCX Clarity</strong></td>
</tr>
<tr>
<td>Mercedes</td>
<td>Smart fortwo</td>
<td></td>
<td><strong>F-Cell</strong></td>
</tr>
<tr>
<td>Nissan</td>
<td><strong>Leaf</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tesla</td>
<td>Roadstar, <strong>Model S</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toyota</td>
<td>Scion iQ, RAV4</td>
<td><strong>Prius Plug-in</strong></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Mitsubishi i-MiEV, Fiat 500E</td>
<td><strong>Porsche Panamera e-Hybrid, Fisker Karma</strong></td>
<td><strong>Hyundai Tucson</strong></td>
</tr>
</tbody>
</table>

The six models **underlined in bold** represent over 90% of US 2013 electric vehicle sales

* Includes plug-in electric vehicle types (blended, charge depleting, extended range, etc) that can also utilize gasoline fuel
# Li-ion Batteries – Early stages of Development

*xEV Battery Technology and Market*, Menahem Anderman, *Advanced Automotive Batteries*, February 2014

## Current PHEV Cells

<table>
<thead>
<tr>
<th>Cell Maker</th>
<th>Chemistry</th>
<th>Capacity</th>
<th>Configuration</th>
<th>Voltage</th>
<th>Weight</th>
<th>Spec Ener</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanyo</td>
<td>NMC</td>
<td>22</td>
<td>Prismatic</td>
<td>3.68</td>
<td>0.73</td>
<td>112</td>
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<tr>
<td>Samsung</td>
<td>NMC-LMO</td>
<td>26</td>
<td>Prismatic</td>
<td>3.7</td>
<td>0.85</td>
<td>113</td>
</tr>
<tr>
<td>LEJ</td>
<td>LFP</td>
<td>21</td>
<td>prismatic</td>
<td>3.3</td>
<td>0.64</td>
<td>108</td>
</tr>
<tr>
<td>LG</td>
<td>LMO-NMC</td>
<td>15</td>
<td>Pouch</td>
<td>3.7</td>
<td>0.38</td>
<td>148</td>
</tr>
<tr>
<td>A123</td>
<td>LFP</td>
<td>20</td>
<td>Pouch</td>
<td>3.3</td>
<td>0.49</td>
<td>135</td>
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<tr>
<td>AESC</td>
<td>LMO-NCA</td>
<td>23</td>
<td>Pouch</td>
<td>3.75</td>
<td>0.57</td>
<td>151</td>
</tr>
</tbody>
</table>

## Current BEV Cells

<table>
<thead>
<tr>
<th>Cell Maker</th>
<th>Chemistry</th>
<th>Capacity</th>
<th>Configuration</th>
<th>Voltage</th>
<th>Weight</th>
<th>Volume</th>
<th>Ener dens</th>
<th>Spec Ener</th>
<th>Used in:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Anode/Cathode</td>
<td>Ah</td>
<td></td>
<td>V</td>
<td>Kg</td>
<td>liter</td>
<td>Wh/liter</td>
<td>Wh/kg</td>
<td>Company</td>
</tr>
<tr>
<td>1 AESC</td>
<td>G/LMO-NCA</td>
<td>33</td>
<td>Pouch</td>
<td>3.75</td>
<td>0.80</td>
<td>0.40</td>
<td>309</td>
<td>155</td>
<td>Nissan</td>
</tr>
<tr>
<td>2 LG Chem</td>
<td>G/NMC-LMO</td>
<td>36</td>
<td>Pouch</td>
<td>3.75</td>
<td>0.86</td>
<td>0.49</td>
<td>275</td>
<td>157</td>
<td>Renault</td>
</tr>
<tr>
<td>3 Li-Tec</td>
<td>G/NMC</td>
<td>52</td>
<td>Pouch</td>
<td>3.65</td>
<td>1.25</td>
<td>0.60</td>
<td>316</td>
<td>152</td>
<td>Daimler</td>
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<tr>
<td>4 Li Energy Japan</td>
<td>G/LMO-NMC</td>
<td>50</td>
<td>Prismatic</td>
<td>3.7</td>
<td>1.70</td>
<td>0.85</td>
<td>218</td>
<td>109</td>
<td>Mitsubishi</td>
</tr>
<tr>
<td>5 Samsung</td>
<td>G/NMC-LMO</td>
<td>64</td>
<td>Prismatic</td>
<td>3.7</td>
<td>1.80</td>
<td>0.97</td>
<td>243</td>
<td>132</td>
<td>Fiat</td>
</tr>
<tr>
<td>6 Lishen Tianjin</td>
<td>G-LFP</td>
<td>16</td>
<td>Prismatic</td>
<td>3.25</td>
<td>0.45</td>
<td>0.23</td>
<td>226</td>
<td>116</td>
<td>Coda</td>
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<tr>
<td>7 Toshiba</td>
<td>LTO-NMC</td>
<td>20</td>
<td>Prismatic</td>
<td>2.3</td>
<td>0.52</td>
<td>0.23</td>
<td>200</td>
<td>89</td>
<td>Honda</td>
</tr>
<tr>
<td>8 Panasonic</td>
<td>G/NCA</td>
<td>3.1</td>
<td>Cylindrical</td>
<td>3.6</td>
<td>0.045</td>
<td>0.018</td>
<td>630</td>
<td>248</td>
<td>Tesla</td>
</tr>
</tbody>
</table>
Norway and Netherlands were leading EV markets in 2013
In Norway market is dominated by BEV
In Netherlands there are mostly PHEV
Incentives and Policy

Why are EVs successful in some markets but not in others?
Evaluation of EV incentives and sales shares in leading markets

- Norway, Netherlands, California are only markets with major policies driving up EV sales
  - EV sales shares of 3-6% in 2013, compared to less than 1% elsewhere
  - Fiscal incentives matter, but many other EV promotion actions are critical too


### Direct (one-time) subsidies

<table>
<thead>
<tr>
<th>Country</th>
<th>Renault Zoe (BEV)</th>
<th>Volvo V60 (PHEV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>7,000 EUR</td>
<td>5,000 EUR</td>
</tr>
<tr>
<td>UK</td>
<td>5,800 EUR</td>
<td>5,800 EUR</td>
</tr>
<tr>
<td>Sweden</td>
<td>4,500 EUR</td>
<td>4,500 EUR</td>
</tr>
<tr>
<td>US</td>
<td>5,400 EUR</td>
<td>3,900 EUR</td>
</tr>
<tr>
<td>California</td>
<td>7,200 EUR</td>
<td>5,000 EUR</td>
</tr>
<tr>
<td>Japan</td>
<td>4,600 EUR</td>
<td>3,400 EUR</td>
</tr>
<tr>
<td>China</td>
<td>6,000 EUR</td>
<td>4,200 EUR</td>
</tr>
</tbody>
</table>

*all numbers are approximations only*
Other fiscal incentives

- **Value added tax (VAT) savings**
  e.g. Norway: 4,500 EUR (BEV), 0 EUR (PHEV)

- **One-time purchase / registration tax savings**
  e.g. Denmark: 14,000 EUR (BEV), 17,000 EUR (PHEV)

- **Annual circulation tax savings**
  e.g. Netherlands: 380 EUR (BEV), 1,900 EUR (PHEV)

- **Company car tax savings**
  e.g. Netherlands: 1,100 EUR (BEV), 4,300 EUR (PHEV)
Different markets, different incentive systems

Total Cost of Ownership includes vehicle purchase and registration costs, as well as ownership taxes and fuel / electricity costs for 4 years. All data estimates for tax year 2013.
Norway and Denmark provide highest incentive levels for BEV

- Norway
- Netherlands
- California
- US (incl. California)
- France
- Japan
- Sweden
- Denmark
- Austria
- Germany
- UK
- China

Total incentives for EV (Renault Zoe BEV vs. Clio) [EUR]

- Private car
- Company car
Netherlands and UK provide highest incentive levels for PHEV
High incentive level leads to high sales – but not always!
How many EVs will it take to meet 2025 goals?

- To comply with federal “54 mpg” efficiency standards → 2% EVs
  - Efficiency standards primarily promote efficiency technologies, not plug-ins

- To comply with California’s Zero Emission Vehicle program → 15% EVs
  - Standards allow mix of various electric vehicle types (e.g., EV, PHEV, BEVx, EREV, FCV)
  - State Governors’ goal: 3.3 million cumulative electric vehicles by 2025

- Other policies and factors are also important
  - Consumer fiscal incentives (vehicle and charging equipment), preferential lane and parking access, utility pricing policy, public and workplace charging infrastructure, car sharing, government fleet purchasing, public awareness campaigns

and CARB Zero Emission Vehicle: [http://www.arb.ca.gov/msprog/zevprog/zevprog.htm](http://www.arb.ca.gov/msprog/zevprog/zevprog.htm)
US electric vehicle incentive comparison

- Evaluation of EV policy and sales shares within the US
  - Large variation in US states’ policies, incentives, infrastructure, and EV sales share
    - California, Georgia, Hawaii, Oregon, and Washington have electric vehicle sales shares that are 2-4 times the US average; Others have very high incentives and low EV sales
  - Subsidies are important, but non-fiscal incentives, charging infrastructure are key too
  - ICCT study due in November 2014
  - Battery electric vehicle consumer incentives and sales share by US state:

Source: Jin, Searle, and Lutsey, (forthcoming)
Efficiency and Cost


### Fuel Cell and BEV Efficiency Assumptions

#### TABLE 2.6 Fuel Cell Efficiency Projections

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midrange</td>
<td>53%</td>
<td>53%</td>
<td>55%</td>
<td>60%</td>
</tr>
<tr>
<td>Optimistic</td>
<td>53%</td>
<td>55%</td>
<td>57%</td>
<td>62%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>E-Machine Efficiency</th>
<th>Battery Efficiency</th>
<th>Net E-Machine Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>89.5%</td>
<td>96.5%</td>
<td>75.4%</td>
</tr>
<tr>
<td>Motor</td>
<td>90.5%</td>
<td>96.5%</td>
<td>75.4%</td>
</tr>
<tr>
<td>Charge</td>
<td>96.5%</td>
<td>96.5%</td>
<td>79.4%</td>
</tr>
<tr>
<td>Discharge</td>
<td>96.8%</td>
<td>96.8%</td>
<td>77.4%</td>
</tr>
<tr>
<td>2010 Baseline</td>
<td>89.5%</td>
<td>96.5%</td>
<td>75.4%</td>
</tr>
<tr>
<td>2030 Midrange</td>
<td>91.6%</td>
<td>96.8%</td>
<td>79.4%</td>
</tr>
<tr>
<td>2050 Midrange</td>
<td>90.5%</td>
<td>96.7%</td>
<td>77.4%</td>
</tr>
<tr>
<td>2030 Optimistic</td>
<td>92.6%</td>
<td>97.2%</td>
<td>81.7%</td>
</tr>
<tr>
<td>2050 Optimistic</td>
<td>93.4%</td>
<td>97.2%</td>
<td>81.7%</td>
</tr>
</tbody>
</table>
Load Reduction

- **Weight reduction**
  - 20-25% by 2030 and 30-40% by 2050
  - Body-on-frame trucks improved 20% less

- **Tire rolling resistance**
  - Decreased 2%/year 1980-2010
  - Assumed 16-25% by 2030 and 30-38% by 2050

- **Aerodynamic drag**
  - 15-20% Cd reduction by 2030 and 25-30% by 2050
  - Assumed 5% reduction in frontal area (2030 optimistic and 2050 midrange)
Cost Assumptions

- High volume production
- ICE costs based upon 2007 MIT estimates
- Differential costs (ICE to hybrid, hybrid to PHEV, BEV, and FCV) carefully assessed
  - Hybrid system components costs based on FEV teardown studies
- Powertrains downsized to maintain constant performance with load reduction
  - Large cost reductions in battery and fuel cell
Car Incremental Cost over Baseline: High-Production Midrange Estimates

Cars: Mid-Range Costs
Incremental Direct Manufacturing Costs over 2010 Baseline

- In the long run, both BEV (100-mile range) and fuel cell vehicles should be cheaper than conventional vehicles.
- Even with low battery costs, PHEV always command a significant cost penalty.
Outlook

What are the future considerations for EVs?
Figure 2-1 Historical and Projected Light-duty Vehicle Fuel Economy
Note: All data is new fleet only using unadjusted test values, no in-use fuel consumption. FTP values, projections assume light duty fleet is 38% light duty trucks
## Fuels: Electricity versus Hydrogen

- Both are energy carriers – can be dirty or clean, depending on how created

<table>
<thead>
<tr>
<th>Electricity</th>
<th>Infrastructure</th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Existing electricity generation</td>
<td>• Existing electricity generation</td>
<td>• More efficient than fuel cell</td>
</tr>
<tr>
<td>• Although need to add safe public charging stations and clean up grid</td>
<td>• Although need to add safe public charging stations and clean up grid</td>
<td>• Recharge time with Li-ion is inadequate (30+ min)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Without energy storage breakthrough, limited to 2\textsuperscript{nd} or 3\textsuperscript{rd} vehicle in multivehicle households</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrogen</th>
<th>Infrastructure</th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Must create hydrogen competitively and build new infrastructure for dispensing</td>
<td>• Must create hydrogen competitively and build new infrastructure for dispensing</td>
<td>Better than ICE in all ways:</td>
</tr>
<tr>
<td>• Remote generation (wind, geothermal, solar) potential advantage</td>
<td>• Remote generation (wind, geothermal, solar) potential advantage</td>
<td>Fast refill, good range, more efficient, cheaper, quieter, faster torque response, more torque, more room, safer</td>
</tr>
</tbody>
</table>
Strategy promoting both Fuel Cell and Plug-In Vehicles – NRC 2013
Greene LAVE Model results:
Large incentives needed to make transition happen

- Benefit net present value through 2050 about ten times the cost
- Subsidies required exceed $3 billion per year in early years
No Early Infrastructure = No FCV Transition

Without Early Infrastructure

Estimated Electric Drive Market in California and the Section 177 States: Scenario 1

Estimated Electric Drive Market in the Rest of US: Scenario 1

With Early Infrastructure

Estimated Electric Drive Market in California and the Section 177 States: Scenario 1

Estimated Electric Drive Market in the Rest of US: Scenario 1
Key Messages

- More running room for conventional technologies & hybrids
  - 2050 Midrange: 95 mpg (cars 112 mpg)
- **Battery electrics and fuel cells cost competitive long-term**
  - Li-ion battery costs drop by 80%
  - Electric drive and fuel cell stack costs scale with reduced power demand associated with lightweight materials and other load reductions
- PHEVs will always command a significant cost premium, while incremental fuel savings will diminish
- BEVs will penetrate market quicker than fuel cells, but fuel cells more likely to be accepted by the mass market in the long run
- Incentives are essential to overcome early barriers to market transformation