Battery Ownership Model: A Tool for Evaluating the Economics of Electrified Vehicles and Related Infrastructure

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Many New Vehicle Technologies, Power Sources, Infrastructure Technologies, and Business Models Are Being Proposed for Transportation

How Do We Make Sense of These Options as They Relate to Component Development, Economics, Energy Use, Greenhouse Gases, and the Role of Government?

Solar Power, Wind Power, Swap Stations, Aggregators, Traditional EVs, PHEVs, City Charge Points, Charge Service, Provider, Smart Grid, Location, Drive Profile, Battery Life, V2G, Cost of Money, Charging Algorithms, Subsidies, Job Creation, Battery Specific Power & Specific Energy, Consumer Behavior, Battery Secondary Use, Future Cost of Gasoline

Model
Battery Ownership Model Multi-Disciplinary Team

Jeremy Neubauer
battery secondary use, project subtask lead

Michael Mendelsohn
economics & financing

John Rugh
vehicle ancillary loads reduction & driving statistics

Terry Penney
advisor on project direction

Aaron Brooker
vehicle systems analysis, optimization & programming

Caley Johnson
carbon markets, policy analysis & fueling stations

Michael O’Keefe
power electronics, EV grid integration & programming

Ahmad Pesaran
energy storage system task lead
NREL developed the **Battery Ownership Model** to answer this question.
Location-Specific Driving Distance Distribution

Price of Gasoline

Baseline US average driving case shown
Vehicle Performance and Sizing Model

Inputs

City

Highway

Acceleration

Results

Component Losses (kJ)

Component Losses (kJ)

Component Losses (kJ)
Baseline technology costs have been calibrated against currently available vehicles.

Equation coefficients can be varied to explore sensitivities and future scenarios.

<table>
<thead>
<tr>
<th>Component</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>$\frac{22.00}{kW} \cdot P_b + \frac{700.00}{kWh} \cdot E_b + 680.00$</td>
</tr>
<tr>
<td>Motor &amp; Power</td>
<td>$\frac{21.70}{kW} \cdot P_m + 425.00$</td>
</tr>
<tr>
<td>Electronics</td>
<td>$\frac{14.50}{kW} \cdot P_e + 531.00$</td>
</tr>
</tbody>
</table>
A simple model for battery degradation has been tied to the driving profile.

\[ \text{SOC Swing} = \text{pow}(n, -0.68) \]

- Case 1
- Case 2
- Case 3
- DOE Target

Note: \( \text{pow}(n, p) = n^p \), \( n \) is number of cycles.
Infrastructure Requirements

<table>
<thead>
<tr>
<th>Swap Fraction</th>
<th>Swap Stations per 10,000 Cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>11%</td>
<td>11</td>
</tr>
<tr>
<td>09%</td>
<td>9</td>
</tr>
<tr>
<td>01%</td>
<td>1</td>
</tr>
</tbody>
</table>

For reference: ~6.4 gasoline stations (~54.7 pumps) per 10,000 cars

Assuming: same “level of convenience” for swap station as gasoline station in terms of cars per “pump” & time per fueling
Electricity Usage

Generation → Efficiency → kWh of Electricity Used → Demand
Traditional EV Ownership Model:

- **up-front costs**
  - dominated by battery cost
  - no infrastructure => large range battery

- **battery replacement**
  - assuming cost reduction in battery over time

- **electric fueling**

...with Service Provider

- **consumer costs**
- **purchase cost**
  - "batteries not included" cost

- **service fee**
  - service provider eliminates risks, provides network & other services for a fee

**KEY**

- up-front costs
- electricity
- service fees
- battery costs
Driver Economics Module

End User

Services and Technology

Cost

battery OEM
auto OEM

Money
Energy
Physical
swap station
battery module
electric vehicle
home charge outlet
city charge outlet
power plants

EV charge service provider

lease

batteries

utility

driver

utility
Greenhouse Gas Accounting

Lifecycle GHG Emissions

- CV: 6.9 tons CO2e
- HEV: 7.1 tons CO2e
- PHEV: 7.5 tons CO2e
- EV US: 8.9 tons CO2e
- EV CA: 21.0 tons CO2e
- EV CO: 8.9 tons CO2e
- EV HI: 8.9 tons CO2e
- EV TX: 8.9 tons CO2e
- EV Renew: 2.0 tons CO2e

Fuel-Well to Wheels
Vehicle Production & Disposal
Levelized Cost per Mile (LCPM)

\[ LCPM = \frac{\sum_{i=1}^{N} c_i \cdot d_i}{\sum_{i=1}^{N} vmt_i \cdot d_i} \]

Present Value
Equivalent initial one time payment

Levelized Cost
Equivalent payment per each period
Validation: The model does well at estimating the cost of vehicle technologies.
We compared the LCPM of the following vehicles:

- **CV**
  Conventional Vehicle (gasoline)

- **HEV**
  Hybrid Electric Vehicle (gasoline)

- **PHEV40**
  Plug-in Hybrid Electric Vehicle [40 mile] (electricity / gasoline)

- **EV100**
  Electric Vehicle [100 mile] (electricity)
...considering the following variable inputs...

<table>
<thead>
<tr>
<th>Variable</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1: GHG Market Cost (2007 U.S. Dollars/Ton CO2e-Year)</td>
<td>0.00</td>
<td>28.53</td>
</tr>
<tr>
<td>D2: Federal Tax Incentive (2007 U.S. Dollars)</td>
<td>0</td>
<td>7,500</td>
</tr>
<tr>
<td>D3: Gasoline Cost Forecast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EIA Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EIA High Oil Price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D4: Annual Distance Driven (Miles/Year)</td>
<td>9,059</td>
<td>15,691</td>
</tr>
<tr>
<td>D5: Vehicle Auxiliary Load (W)</td>
<td>700</td>
<td>2,200</td>
</tr>
<tr>
<td>D6: Battery Energy Cost Coefficient (2007 U.S. Dollars / kWh)</td>
<td>350</td>
<td>700</td>
</tr>
<tr>
<td>D7: Battery Life Coefficient</td>
<td>86</td>
<td>433</td>
</tr>
<tr>
<td>(low cycle life)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(high cycle life)</td>
<td></td>
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</tbody>
</table>
…and found the EV can be cost competitive, but is quite sensitive to changes in assumptions.
Battery Cost And Life Are The Strongest Factors

Cost Ratio Sensitivity

- HEV
- PHEV40
- EV100

Factors:
1. Battery Energy Cost
2. Battery Life Coefficient
3. Federal Tax Incentive
4. Gasoline Cost Forecast
5. Annual Distance Driven
6. Vehicle Auxiliary Load
7. GHG Market Cost
Hawaii: more battery-friendly driving distribution & higher gas prices…

…but higher electricity prices and no effect on dominant battery prices
Service provider costs are dominated by batteries (up to ~92%), allowing charge points and swap stations to be provided at minimal marginal cost.
Summary

• This presentation is meant to give you a quick preview of the “Battery Ownership Model” and its capabilities

• The purpose of the model is to assist the U.S. Department of Energy in understanding how various business plans for EVs compare to other technologies

• The preliminary results presented herein show:
  • EV costs are most sensitive to battery cost and life assumptions within the scope of other parameters considered herein
  • Service provider costs are dominated by battery rather than infrastructure cost; thus one may be able to provide significant added value at minimal additional cost

• Additional application and development of the tool will continue in FY11
Acknowledgements

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