My Electric (Car) Journey: Update

Stanton Zeff, PE
# Total EV Sales: 2013

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<th>Mar</th>
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<th>May</th>
<th>Jun</th>
<th>Jul</th>
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My criteria for owning an EV
(or why it took me 20 years to buy one)

- More than a “2 seater”
- Able to travel at highway speeds (>60 mph)
- Sufficient range (>75 miles)

Leaf was the first EV to meet these 3 criteria
2011 Nissan Leaf

- 100% electric Zero Emissions Vehicle (ZEV)
- Range: 100 miles/charge based on US EPA LA4 city cycle
- Top Speed: 90 mph
- 80 kW AC synchronous motor with 24 kWh lithium-ion battery
- Weight: approximately 3500 lbs (including 600 lb battery pack)
- Full charge: 7 hrs (240v), 20 hrs (120v), 30 minutes (480v DC)*
How far do you *need* to go?

>75% of population drive <40 miles/day!

**Typical U.S. Commute Distances**

- 1-10 miles: 29%
- 11-20 miles: 22%
- 21-30 miles: 17%
- 31-40 miles: 10%
- 41-50 miles: 7%
- 51-60 miles: 5%
- 61-70 miles: 3%
- >70 miles: 8%

*Round-Trip Miles Traveled*
How far can you go?

Range vs. Speed (Nissan Leaf)
Charging on the “grid”

[Graph showing system load with and without 5 million PHEVs on the grid]
Hybrid vs Electric

- Two types of hybrid vehicles (HEV)
  - Parallel (e.g. Prius)
  - Serial (e.g. Volt)
- Pure Electric (BEV) vehicles have *no internal combustion engine* (ICE)
Regenerative brakes

- Unique to HEVs/BEVs
- Extend range with little or no effort on the part of the driver
Leaf Lithium (LiOn) battery pack

- 2p,2s configuration (2 cells wired in parallel and then each pair is wired to the other pair in series)
- Module rating 7.4v and 33AHr
- Pack rating ~400v (full) and 24kWh
- Excellent shelf life (months)
Role of Battery Management Systems (BMS)

Lithium Ion Cell Operating Window

- Thermal Runaway
- Cathode Active Material Breakdown
- Oxygen Release and Ignition
- Possible Venting
- Exothermic Breakdown of Electrolyte
- Release of Flammable Gases
- Pressure and Temperature Increase
- Separator Melts
- Copper Anode
- Current Collector
- Dissolves
- Cathode Breakdown
- Short Circuit
- Lithium Plating During Charging
- Lithium Plating During Discharging
- Breakdown of SEI Layer
- Temperature Rise

Capacity Variation with Temperature

- Full @ 4.2 Volts
- Empty @ 2.5 V
- Empty @ 2.5 V & 0.2 C Rate
- Empty @ 2.5 V & 1.0 C Rate

Cell Voltage (V)

Temperature °C
Importance of discharge rates

- "C" rate is time to total discharge (e.g. 1 hour = 1.0C, 5 hours = .2C)
- Hybrid (HEV) and pure electric (BEV) battery packs are managed differently
  - BEV have lower discharge rates (<1C) for longer battery life
  - BEV have greater depth of discharge (DOD) for higher capacity
- This is why speed directly impacts range (see “range vs. speed” graph)
Battery degradation factors

There are 2 sources of battery capacity loss:

- Calendar
- Cycling (charging)

These sources are impacted by:

- Temperature
- State of Charge (%)

Temperature has a compounding affect on both types of capacity loss.
According to the U.S. government, LiOn batteries are not an environmental hazard. "Lithium Ion batteries are classified by the federal government as non-hazardous waste and are safe for disposal in the normal municipal waste stream," says Kate Krebs at the National Recycling Coalition. While other types of batteries include toxic metals such as cadmium, the metals in LiOn batteries--cobalt, copper, nickel and iron--are considered safe for landfills or incinerators.
Thermal aging affects

Geographic Impact on Battery Life

Thermal Management Impact on Battery Life

Li-Ion graphite/nickelate life: PHEV20, 1 cycle/day 54% ΔDoD

Phoenix, AZ ambient conditions
33 miles/day driving, 2 trips/day

Liquid cooling, chilled fluid

Air cooling, low resistance cell

No cooling

Minneapolis

Houston

Phoenix

0
5
10
15

0
1
0.95
0.9
0.85
0.8
0.75

0
1
0.95
0.9
0.85
0.8
0.75

Time (years)

Relative Capacity

Time (years)

Relative Capacity
Petroleum consumption
(Millions of Barrels per Day)
U.S. retail gas prices

Texas Super-Unleaded Gasoline Price History

Adjusted for inflation (current dollars)

Actual price paid

Global carbon (CO$_2$) emissions
Cost of owning a car: exhibit A
based on data compiled by Electric Auto Association
for 10yr life (@12k mile/yr) of RAV4 vs RAV4-EV

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<th>Maintenance</th>
<th>Items</th>
<th>Lifetime</th>
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<tr>
<td>Electric</td>
<td>Tires+ brakes</td>
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<table>
<thead>
<tr>
<th>Fuel Costs</th>
<th>Miles/GGE*</th>
<th>$/mile</th>
<th>$/month</th>
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<td>$139    @$3.75/gal</td>
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<tr>
<td>Electric</td>
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<td>$0.023</td>
<td>$23     @$0.08/kWh</td>
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*GGE=gallon of gas equivalent

- Initial purchase price ($20k+ vs. $30k+)
- Fuel/electrons: assume 1 gallon of gas = 33.53 kWh of electricity

Savings=$100/month x 120 months = $12,000
Cost of owning a car: exhibit B

based on data compiled from Cars.com for 15yr life (@12k mile/yr)
including Pricetag + Maintenance + Fuel – Tax Rebates

$50,500 Leaf (EV)
$57,900 Volt (EV with range extension)
$61,100 Prius Plugin (EV with range extension)
$59,900 Prius C (hybrid)
$65,800 Civic (hybrid)
$70,300 Fusion (hybrid)
$66,700 Versa
$67,400 Fiesta
$71,000 Jetta
$76,900 Jetta (diesel)
$77,100 Cruze
$82,300 Cruze (diese)

EV lower cost than ICE even with addition of tax rebates
EV vs. ICE

Fuel price, $/gal

Battery-electric vehicles are competitive
PHEVs\(^2\) are competitive
Hybrid-electric vehicles are competitive
ICE vehicles are competitive
Recent US conditions

Battery prices, $/kW-hr

2011 average

1 Assumes 240 watt hours per mile (as may be achieved with lightweight, efficient air conditioning) compared with today's 305–322 watt hours per mile.
2 Plug-in hybrid-electric vehicles.

Source: US Energy Information Administration; McKinsey analysis
My EV data

1) Fuel savings
2) Battery degradation
3) 12v starter battery replacement (Lithium)
4) Leaf DD
Fuel savings

Before Leaf ~ $325/month

After Leaf ~ $125/month
Battery degradation model

### City Information

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<th>Metric</th>
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### End of Life Information

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### Yearly Prediction

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<th>Calendar Plus Cycling Loss</th>
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12 Volt starter battery replacement
“get the lead out”

12v Lead Acid
12v LiFePO4

Even better: the Lithium battery only requires half the Ahr rating of the Lead Acid battery
Leaf Dash Display
EV-CAN bus display
Why I own an *electric* car

“Fuel” costs for the Nissan LEAF:

- Assume I get 100 miles per full charge of the car
- The battery pack is 24kWh; I pay 10 cents per kWh at my house
- So to go that 100 miles, it costs $2.40 to charge the 24kWh battery

Let's compare this to my Ford Expedition:

- Assume I get 12.5 mpg, so to go 100 miles would take about 8 gallons
- With gas at $4 per gallon, it costs $32 to go 100 miles

*For the same 100 miles, LEAF costs ~$2.40 while Expedition costs ~$32*

Over the lifetime of ownership, Operational Expenditures (OpEx) for gasoline powered cars *far exceed* that of electric powered cars (by as much as 10:1), eventually erasing the initial Capital Expenditure (CapEx) advantage. Eventually, electric cars *will reach initial cost parity*...with no trips to the gas station!
Q&A

http://stantonzeff.com/my-nissan-leaf.html
http://stanton.myevblog.com/

I quit!
ask me how

Nissan LEAF
100% electric