Should Next-Generation Hybrids Use Li-Ion or NiMH Batteries?

- **Fixed Plan:** Design new platform using NiMH Batteries
  - Currently cheaper
  - Chemistry is close to limits imposed by fundamental material properties

- **Flexible Plan:** Design new platform using Lithium-Ion Batteries
  - Enables a flexible platform: Limited electric range (plug-in hybrid), conventional hybrid, or a mild-hybrid
  - Costs likely to drop over time, but may stay higher than NiMH throughout the life of the project
  - Technical risk due to questions about battery durability
Model Overview

- Project Lifetime: 18 Years

- Demand for a vehicle is a function of its NPV
  - NPV = (Lifetime savings on fuel - HEV Price premium)

- Vehicle Parameters (Shaded = Flexible Options):

<table>
<thead>
<tr>
<th>Vehicle Config</th>
<th>FC. Imp</th>
<th>% of MI Electric</th>
<th>MPG</th>
<th>Gallons Saved/Yr</th>
<th>Price Premium</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHEV-20, NI</td>
<td>25%</td>
<td>0%</td>
<td>40.0</td>
<td>125</td>
<td>$2,500</td>
</tr>
<tr>
<td>Full Hybrid, NI</td>
<td>15%</td>
<td>0%</td>
<td>36.6</td>
<td>90</td>
<td>$2,500</td>
</tr>
<tr>
<td>Full Hybrid, LI</td>
<td>25%</td>
<td>20%</td>
<td>67.1</td>
<td>238</td>
<td>$6,000</td>
</tr>
<tr>
<td>PHEV-10, LI</td>
<td>25%</td>
<td>30%</td>
<td>50.0</td>
<td>200</td>
<td>$5,000</td>
</tr>
</tbody>
</table>

Key Uncertainties

1.) Gas Price Volatility:
- Assume $2.75 start point
- 0.5% growth per year
- 10% volatility

2.) Technology-driven cost reduction:
- Assume 1.75% per year baseline
- Analyze sensitivity to different rates
- Analyze effect of volatility using Monte Carlo

3.) Regulatory Structure: Subsidy/Rebate Programs
- Test 0, $0.25/gal, and $0.50/gal rebates
Demand Model

Sales volume is normally distributed around NPV = $1000, with Std Dev = $1200. Max. Sales = 1,000,000 vehicles

Integrated System Model: (Shaded = Model Inputs)
Build Strategy as a Function of Gas Price

Lattice Calibration: Models Fuel Price Volatility

<table>
<thead>
<tr>
<th></th>
<th>Initial Value of gas (per Gal):</th>
<th>Volatility (per year):</th>
<th>Rate of Appreciation (per year):</th>
<th>Project Duration</th>
<th>Length of 1 period:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$2.75</td>
<td>10%</td>
<td>0.5%</td>
<td>18 yrs</td>
<td>3 yrs</td>
</tr>
</tbody>
</table>

PDF for Lattice

EV, Pd 1 = $2.83 EV, Pd 6 = $3.29
Results: Lattice Evolution of Fuel Price

- NiMH is the best option: It has a sizeable advantage over mid-range price scenarios.
- Li does better at high-gas prices, but the advantage in terms of sales is slim

At Li-Ion price reduction >2.5%/Yr, Flexible strategy is better…
At >$0.40/gal rebate, flexible strategy is better…

Conclusions

- Under most moderate scenarios, the NiMH strategy is preferable

- If lithium-ion batteries drop in cost at higher-than-expected rates, or if aggressive regulatory structures are implemented, the flexible strategy becomes a better choice.