

Lithium-Ion Batteries for Hybrid Electric Vehicles: Opportunities and Challenges

Presented at the

National Research Council

Regional Committee on Fuel Economy of Light-duty Vehicles

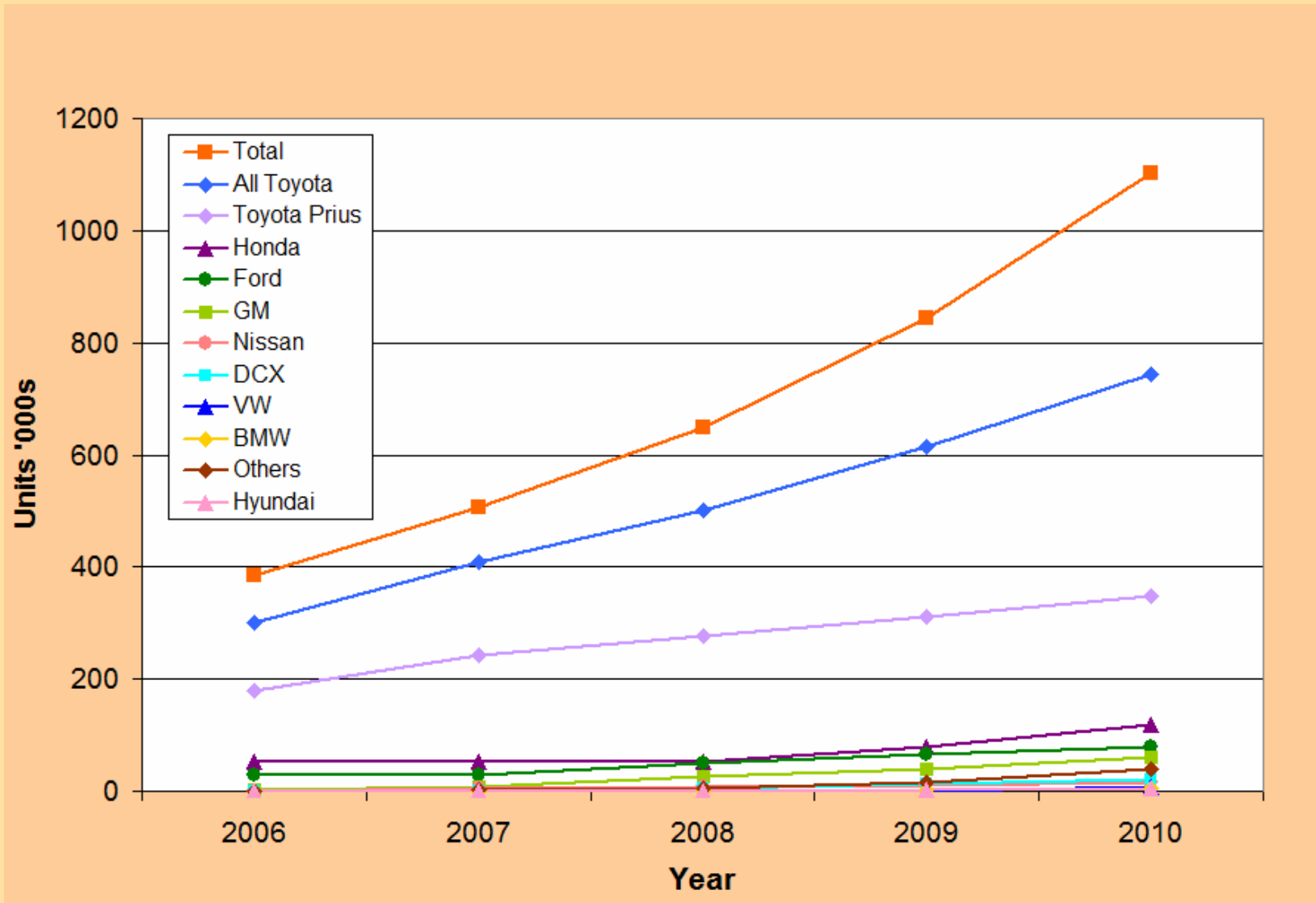
October 2007, Washington DC

Menahem Anderman, President

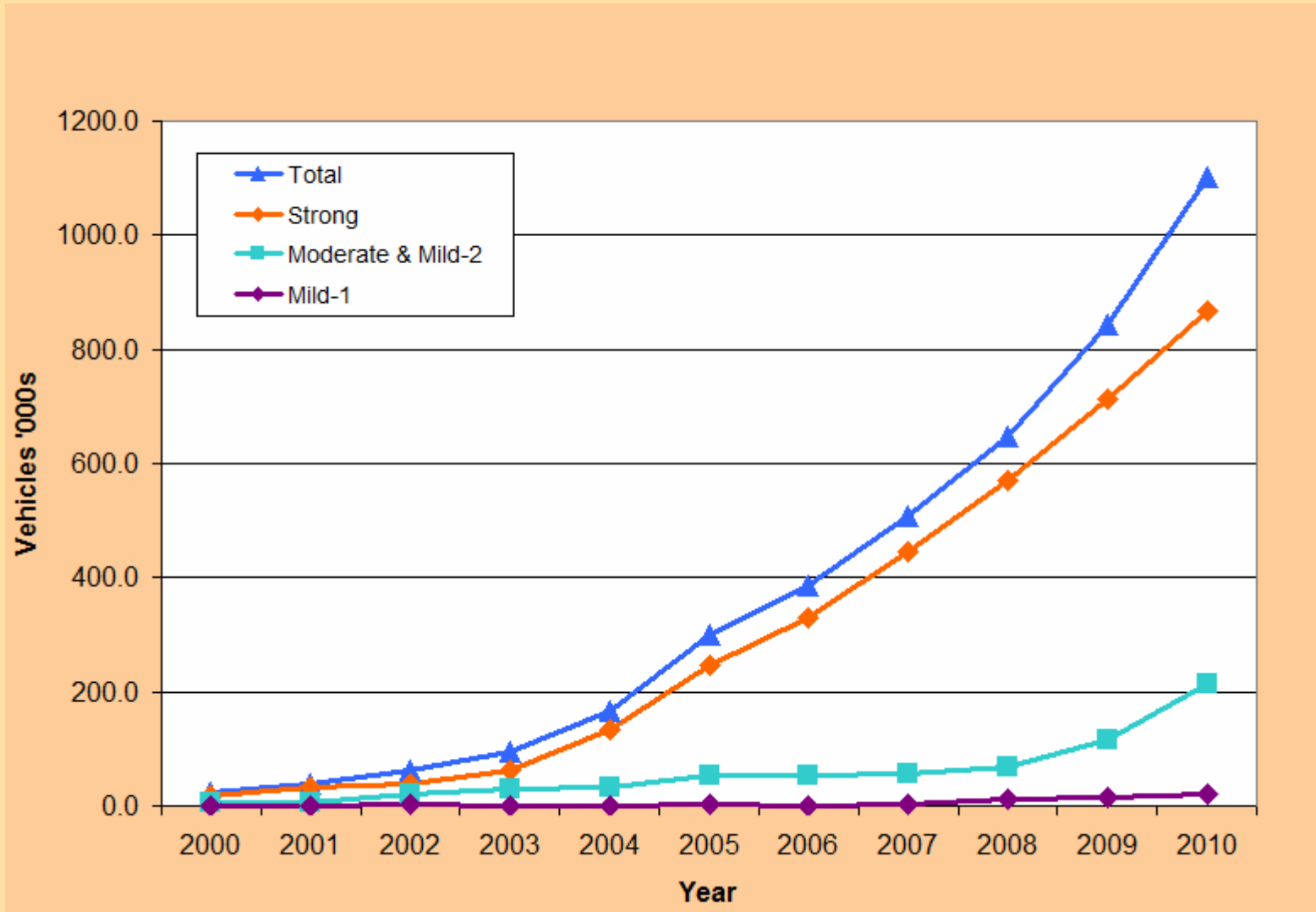
Advanced Automotive Batteries

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HEV World Market Forecast



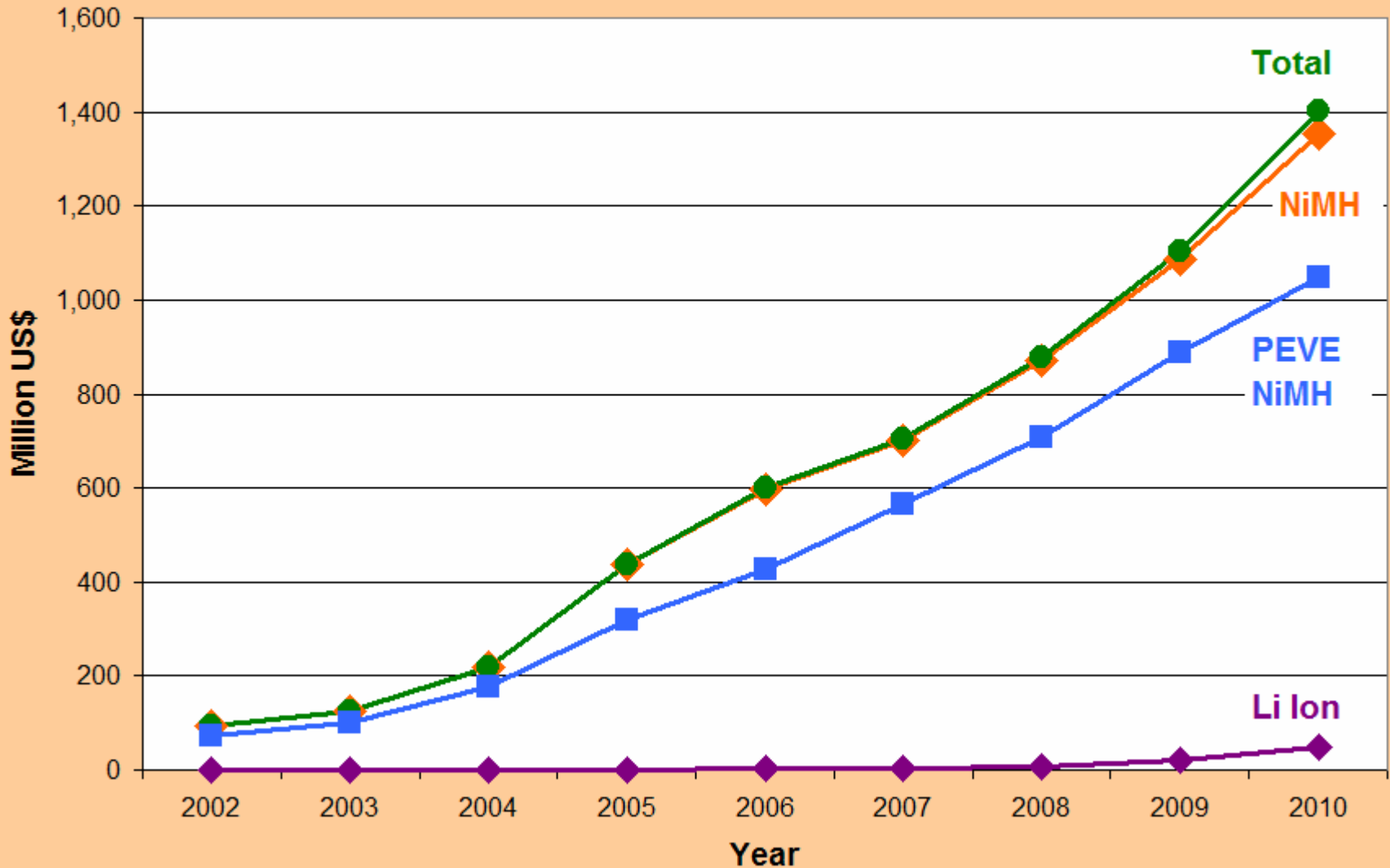
Hybrid-Vehicle Market by Hybrid Category 2000 to 2010 (Excluding micro-hybrids)



Presentation Outline

- **HEV Battery Market & Li-Ion Battery Challenges**
- PHEV Challenges and Gap Analysis
- Conclusions

HEV Battery-Pack Market 2000 to 2010



Drivers:

- Higher power and energy (1.3 to 1.7 times those of current NiMH technology):
 - **Smaller and lighter battery**
- Lower number of cells:
 - **Lower cost, higher reliability**
- Lower metal cost per kWh (Only about 1kg of Ni/Co per kWh versus 7 kg for NiMH):
 - **Lower long-term cost**

Challenges

- **Cost** at initial volumes
- Safety – **Financial Risk**
- Manufacturing reliability – **Cost**
- Life – **Financial Risk**
- Warranty – **Financial Risk**

But long-term cost “should” be lower...

Safety

Safety is a financial risk!



There are many causes to the Li Ion safety problems:

- Flammable and ignitable electrolyte
- Thermally unstable cathode
- Overcharge sensitive cathode
- Overcharge sensitive anode
- Thin fragile separator
- High sensitivity to metallic elements
- High sensitivity to water that can cause Hydro-fluoric acid (HF) formation

There are many attractive ideas to improve safety:

- Thermally stable cathode
- Non-flammable electrolyte
- Improved separator
- **Coated active materials**
- Increased formation and QA
- Anode that will not plate lithium

But safety needs to be enhanced without substantially increasing cost or reducing performance or life, since the value proposition after ensuring safety has to be better than for NiMH!!

To guarantee power, long thin electrodes are needed

➤ To guarantee safety, yield, and reliability, conservative product engineering and manufacturing must be adopted

- Extra-tight coating specifications
- **Ultra-pure environment**
- Conservative winding, welding, etc.

This of course translates to relatively high initial manufacturing costs

➤ **LiNiCoAl₁O₂**

- Most proven (Toyota, JCS, USABC)
- \$25 to \$35/kg
- Most thermally unstable at high SOC
- Moisture sensitive
- Impedance rise at high SOC

➤ **LiNiCoMnO₂**

- Gaining momentum in small cells
- More Cobalt but easier to make
- Less water sensitive
- Various compositions with the 1/3-1/3-1/3 as the most popular
- Not as much (or as good) durability data yet

➤ **LiMn₂O₄**

- High power
- Lower cost
- Life at elevated temperatures is problematic; 15 years of R&D have provided some improvement, at least at intermediate SOC

➤ **LiFePO₄**

- Most thermally stable (safer)
- Should be most stable at high SOC
- Lower voltage - lower energy
- Selectively good data on life at high temperatures
- Cost potential at the cell level similar to LiMnO₂, only slightly better than for NCA-based cathodes

➤ **Blends**

- LMO/NMC (or NCA)
 - **Hopefully $0.5 + 0.5 > 1$; $0.8 + 0.2 \gg 1$**

- *The superior performance over NiMH is notable but not dramatic*

It justifies moving forward, but at a cautious pace

- *Considering the rate of progress with Li-Ion technology, lower cost enabled by lower-cost materials is likely in the longer term*

Provided lower-cost materials meet the life requirements

- *Investment in manufacturing needs to take place when the incumbent technology is about to reach \$1 billion*

The safety cloud and the long-life requirement make this investment a risk to both automakers and battery producers!

Presentation Outline

- HEV Battery Market & Li-Ion Battery Challenges
- **PHEV Challenges and Gap Analysis**
- Conclusions

- *The early hybrid vehicles (circa 1990-95) were of the PHEV configuration*

Commercialization did not materialize due to poor value

- *The power-assist HEVs succeeded technologically and in the market place*

Since they use electric power to only supplement/replace mechanical power where IC engines are very inefficient

- *Using electrical energy for traction is not competitive with ICE, which is mainly due to two limitations:*

- Energy density of batteries is less than one tenth that of gasoline
 - Volume and weight implications
- The \$ value of the fuel savings is considerably lower than the cost of depreciating the battery over its useful life

PHEV – The Requirements for Technical Success

ISSUE:

- The energy density of batteries is less than one tenth that of gasoline

POTENTIAL SOLUTION:

- A significant increase in the battery's energy density,
- A significant reduction in the vehicle's energy consumption per mile,
- Limiting the electric range, and
- A new vehicle design that can accommodate the large battery.

PHEV – The Requirements for Commercial Success

ISSUE:

- The \$ value of the fuel savings is considerably lower than the cost of depreciating the battery over its useful life

POTENTIAL SOLUTIONS:

- Lower battery cost
- Longer battery life
- Larger delta between gasoline and electricity cost
- Government policies (taxation, quotas, incentives) that make up for the value gap

➤ Lead Acid

- Too large and heavy
- Life much too short

➤ NiMH

- Heavy
- Expensive
- Will not meet the life of the car

➤ Li Ion

- The most attractive for the long term but is not even proven for conventional HEVs and operating in PHEV mode is considerably more demanding
 - Reliability and life are not known
 - Safety is a significant reliability/financial risk

- *Retrofitting an existing platform is not really attractive...*
 - Volume restrictions will limit EV range to about 10 miles
 - In comparison to driving an equivalent strong-hybrid vehicle, US drivers of PHEVs with ten miles of electric range will only save about 40 cents per day (\$130 per year) at U.S. gasoline and electricity costs of \$2.8/gallon and \$0.08/kWh, while the difference in the initial cost of the vehicles is estimated at about \$3,000 or more...

- *Designing new platforms for PHEVs is difficult to justify considering the questionable value proposition and the financial risks involved...*
 - No prudent organization will provide long-term battery warranties for the application anytime soon
 - Replacing a \$3,000 to \$10,000 battery during the life of the vehicle is not commercially viable

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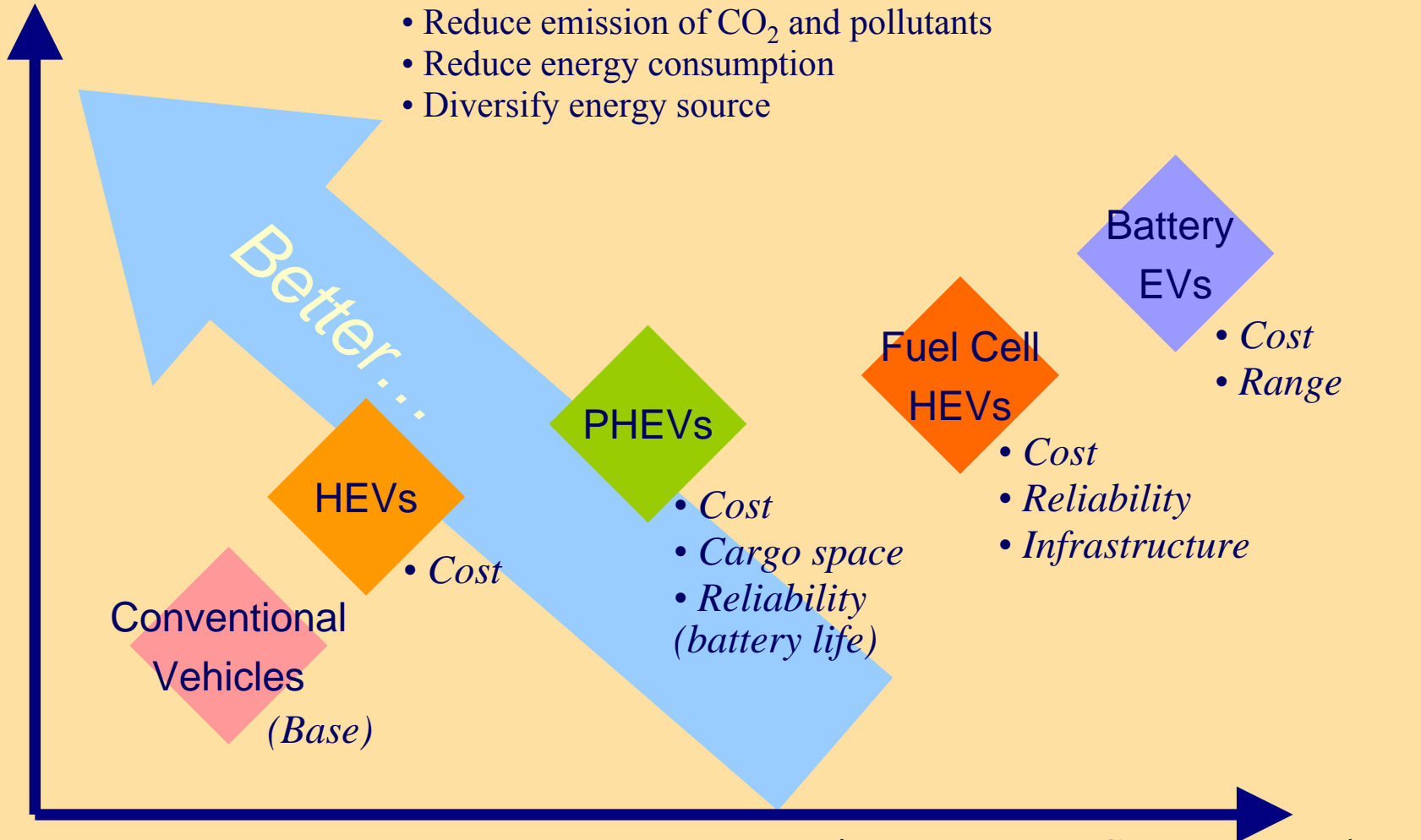
- HEV Market
- HEV Battery Market & Li-Ion Battery Challenges
- PHEV Challenges and Gap Analysis
- **Conclusions**

- NiMH will continue to be the dominant battery technology through 2010
 - 2007 manufacturing investments are still in NiMH
- Li Ion will be the preferred technology at some point in the future
 - Still a risk for short-term implementation
 - Initial introduction expected in 2009
 - Robustness in manufacturing and on the road are key challenges and risks
- No high-volume plug-in hybrid business in the foreseeable future

Value Analysis for Advanced Vehicles

Environmental and Societal Benefits:

- Reduce emission of CO₂ and pollutants
- Reduce energy consumption
- Diversify energy source



- *Cost*

- *Cost*
- *Cargo space*
- *Reliability (battery life)*

- *Cost*
- *Reliability*
- *Infrastructure*

- *Cost*
- *Range*

Negative Impact on Consumer Value:

- Higher costs
- Sacrifice of vehicle attributes

- Not ready for commercial introduction, the business risk is tremendous.
- Considerably more realistic solution than FC vehicles in the 10 to 20-year time scale.
- Heavy incentives for PHEV 5 to 10, which could help gain some technical, reliability, and marketing experience, but the value proposition of PHEV 5 to 10 is quite weak in the longer term.
- In the longer term, PHEV 20 to 30 could become attractive in custom-designed platforms; “life-of-the-car” battery life is a prerequisite.
- Li Ion introduction into conventional hybrids is a prerequisite for PHEV success.
- Government must continue to provide incentives for conventional hybrids to accelerate growth of market share and avoid a retraction. A 10% market share for conventional hybrids in, say, 10-years is a much more realistic scenario than a 1% market share for PHEV, and it will do more for the environment and energy security.
- Government R&D funds for advanced vehicle should better reflect the likelihood of successes and should thus be redirected away from FC vehicles and toward HEVs and PHEVs. Of course, the battery is a key.

The 2007 Industry Report

A comprehensive assessment of an expanding industry on the eve of a technology shift

A detailed analysis and market projection by individual car and battery company

A Multi-client Study

The 8th International

Advanced Automotive Battery Conference (AABC-08) and Symposia

Tampa Convention Center, Tampa, Florida, May 12 -16, 2008

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