Brief Assessment of progress in EV Battery Technology since the BTAP June 2000 Report

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This report is a brief evaluation of changes in EV battery technology since the June 2000 submittal of the Battery Technical Advisory Panel (BTAP 2000) report. While this report is authored by a member of the BTAP, its conclusions are those of the author and do not represent additional BTAP work.

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Sources of information

- Over 50 site visits to major developers of advanced vehicles and advanced vehicles power sources during April 2001 to March 2003
- Participation in about six conferences on the above subject
- Short survey on EV batteries with major EV battery developers for this report during February 2003

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Highlights

- Direct efforts to develop EV batteries have generally declined over the last 3 years
- Battery development for HEV applications continues to gain momentum
- Steady predictable progress but no breakthrough in battery technology
- Improvements made through the HEV battery effort will have significant positive effects on the cost/performance of EV batteries

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BTAP 2000 Report Conclusion 1:

- NiMH batteries show good characteristics and reliability in EV applications with a life expectancy exceeding 6 years
- Specific energy approaching 70 Wh/kg
- Real-life range of practical midsize cars is limited to 70-100 miles
- Prices for a typical 30-kWh pack are projected to drop from about $15,000 at production volumes of thousands per year to about $9,000 at volumes of hundreds of thousands per year. 30.

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Comments for 2003:

- NiMH batteries continue to show good performance and life
- Improvements in specific energy are only incremental
- While life may be longer than 6 years, there is no data yet to support a battery life as long as the life of the car
- For lower pricing than the BTAP 2000 estimate at high volumes, the following would be required:
  - A significant reduction in nickel metal pricing (which is independent of the battery market), and
  - Relocation of production to China or equivalent low-cost/labor area

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BTAP 2000 Report Conclusion 2:

- Current Li Ion EV batteries do not have adequate durability
- Safety under severe abuse is not yet fully proven
- Early cost of these batteries is expected to be considerably higher than that of NiMH EV batteries
- Even in true mass production, the cost of Li Ion batteries is unlikely to drop below those of NiMH without major advances in materials and manufacturing technology

Comments for 2003:

- **Improvements in life are occurring but are too early to quantify**
  - $LiNiO_2$-based cathode shows potential for increased life
  - $LiMn_2O_4$-based cathode still suffers from short life at moderately elevated temperatures
- **Abuse tolerance works mostly for HEV application with steady progress**
  - $LiMn_2O_4$-based cathode seems manageable
  - $LiNiO_2$-based cathode not satisfactory yet
- **Cost is dropping,** though **no major breakthrough in material selection or processing** has occurred to support lower prices than those of NiMH

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Key Characteristics of EV Batteries

Battery technology	Specific Energy	Operating life	Cost for 30-kWh Pack ($)		Safety	Status
	Wh/kg	*At 200 cycles/year*	*At 1000's*	*At 100,000's*		
Valve Regulated Lead Acid	35	2 to 5 years	4,500 to 6,000	2,500 to 3,500	OK	Mature
Nickel Metal Hydride	65	5 to 10 years	15,000 to 25,000	9,000 to 11,000	OK	Maturing
Li Ion (LiMn2O4 Cathode)	90	2 to 5 years	30,000 to 40,000	8,000 to 13,000	OK	Development
Li ion (LiNiMO2 Cathode)	130	4 to 10 years	30,000 to 50,000	9,000 to 15,000	Concern	Development

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Implications of the Development of the HEV Battery Market for EV Batteries

Quote from Executive Summary of the BTAP 2000 report:

"There is little doubt that the development of NiMH and Li Ion battery technologies for HEV applications has benefited directly and substantially from EV battery development. Conversely, the successful commercialization of HEVs can be expected to result in continued improvements of advanced battery technologies. Over the longer term, these advances—together with likely advances in electric drive technologies and reductions in vehicle weight—might well increase performance and range, and reduce costs, to the point where electric vehicles could become a widely accepted product."

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Comments for 2003:

It is clear that the continued research and development work on HEV batteries by automakers, battery producers, material developers, and research organizations around the world, along with the increasing HEV application experience, will improve the key characteristics of these batteries, which in turn will improve their future viability for EV applications.

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Table 1. EV versus HEV NiMH Battery Development

Area		EV Battery	HEV Battery
1) Material cost drivers			
	1	Nickel foam	Nickel foam
	2	Metal hydride	Metal hydride
	3	Nickel hydroxide	Nickel hydroxide
	4	Cobalt compounds	Cobalt compounds
	5	Packaging	Packaging
	6	Thermal management	Thermal management
2) Life driver			
	1	Metal hydride corrosion	Metal hydride corrosion
	2	Venting	Venting
3) Performance drivers			
	1	Improved charge efficiency at high temperatures	Improved power at low temperatures
	2	Improved specific energy	Improved charge efficiency at high temperatures

Table 2. EV versus HEV Li Ion batteries

Area	EV battery	HEV battery
1) Cell design		
Cathode	$LiMn_2O_4$ or $LiNiCoO_2$	$LiMn_2O_4$ or $LiNiCoO_2$
Anode	Carbon / Graphite	Carbon / Graphite
Separator	UHMW PE/PP	UHMW PE/PP
Electrolyte	$LiPF_6$ in mixed carbonates	$LiPF_6$ in mixed carbonates
Configuration	Spirally wound	Spirally wound
1) Cell material cost drivers		
1	Positive active mass	Separator
2	Separator	Positive active mass
3	Electrolyte	Electrolyte
4	Negative active mass	Negative active mass
5	Copper foil	Copper foil
2) Life driver		
1	Positive electrode decomposition	Loss of ionic lithium
2	Negative electrode passivation	Positive electrode decomposition
3	Loss of ionic lithium	Negative electrode passivation
3) Performance drivers		
1	Safety	Safety
2	Specific energy	Specific power

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There are many different approaches to vehicle hybridization:

- 12V single/dual battery system with stop/start and possibly launch assist
- 42V with stop/start
- 42V with launch assist
- 42V with mild power-assist hybrid
- High-voltage power assist
- Plug-in hybrid (with electric range at full power)

Car companies are struggling with establishing business cases for all or any of the above

Environmental Value of Vehicle Electrification

- Electric power and drive-train
- Electrically assist turbocharger and electrical valve actuation
- Electrical power steering, air conditioning, ABS, 4-wheel drive, fans, and pumps

All above auxiliaries contribute to reducing emissions, and their mass introduction in HEVs will increase the value proposition of batteries or Fuel Cell EVs.

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U.S. and European Hybrid Vehicles Programs as of January 2001

And their status at the end of 2002

Manufacturers	Vehicle	Vehicle category	Planned launch year	Status Oct 2002	Date of change
DaimlerChrysler	Mercedes S	42V ISS	2004	**2006 or later**	**Q1-02**
DaimlerChrysler	Durango	High-voltage power assist	2004	**Cancelled**	**Q2-02**
Ford	Volvo	42V mild power assist	2003	**Cancelled**	**Q2-01**
Ford	Escape	High-voltage power assist	2003	2004	N/A
General Motors	Silverado	42V Launch assist	2004	2004	N/A
PSA	Xsara	42V mild power assist	2003	**Cancelled/delayed**	**Q2-02**

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The following companies were visited during April 2001 to March 2003:

Automakers:

- BMW
- DaimlerChrysler
- Fiat
- Ford
- GM
- Honda
- Nissan
- PSA
- Renault
- Toyota
- Volkswagen
- Volvo

Battery Developers:

- Delphi
- JCI
- JSB
- MBI
- PEVE
- Saft
- Sanyo
- Shin-Kobe
- Varta
- Yuasa

Others:

- CARB
- Continental
- European Commission
- Hitachi
- LIBES
- Siemens
- USABC
- UC Davis
- Valeo
- Visteon

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The following major EV battery developers have answered the survey:

- Japan Storage Battery - (Kyoto, Japan)
- Johnson Controls - (Milwaukee, WI, USA)
- Matsushita Battery Industry (Panasonic) - (Kosai City, Japan)
- Panasonic EV Energy (Kosai City, Japan)
- Saft (Bordeaux, France, and Cockeysville, Maryland, USA)
- Shin-Kobe Electric Machinery (Saitama, Japan)