by John H. Day

NiMH batteries CHARGE HYBRID VEHICLES —for now.

Nickel metal hydride is the battery chemistry of choice for hybrid vehicles, but industry executives say that a migration to lithium-ion is inevitable. The question is when.

Nickel metal hydride (NiMH), the prevailing battery technology for hybrid vehicles, is "as durable as the day is long," according to Dave Hermance, executive engineer with responsibility for advanced technology vehicles at Toyota Technical Center. "The downside is that the price of nickel has gone through the roof," he added. "(The price has) about tripled."

Hermance said Toyota and its suppliers have been able to redesign batteries to reduce the quantity of material needed in a hybrid vehicle battery, but he added, "It's hard to get the cost reductions we'd planned on getting."

According to Hermance, the rate of adoption of hybrid vehicles would be greater if batteries were less expensive. Since the battery is one of the most expensive components in a hybrid vehicle, battery technology is a dilemma for automakers and a potential goldmine for suppliers able to deliver a better solution.

Many are trying. The current market leaders in hybrid vehicle batteries include Panasonic EV Energy, a joint venture between Toyota and Matsushita and Sanyo Electric Co., which hhavebeen working closely with Honda, and also supplies batteries to Ford. Panasonic supplies NiMH batteries to Honda, as well as to Toyota. Figure 1 shows a cut-a-way view of a NiMH battery.

Research is under way on Lithium-ion (Li-ion) chemistries, including manganese, cobalt and ion phosphate. Hermance noted that manganese presents durability issues while cobalt raises safety concerns. Ion phosphate, he said, is a lower energy system. "It has a long cycle life, but we don't know about its calendar life," he said, adding that ion phosphate doesn't provide as big an incremental benefit in energy and power compared with NiMH." Table 1 provides some comparison between the two battery technologies.

Valence Technology Inc., which manufactures batteries based on a patent-protected phosphate cathode material called Saphion (safe-ion), and has contracts from manufacturers of electric vehicles, is working to change that perception. It has positioned its U-Charge family of 12 V energy storage systems against traditional lead-acid batteries, claiming twice

Figure 1. Liquid-cooled series 1000 battery modules from Cobasys.

the run time, half the weight, and a lower cost of ownership.

Marc Kohler, Valence's manager of electric vehicle market development, said safety is the primary challenge in developing large-format Li-ion batteries, and the decision of which cathode material to use in a Li-ion battery has a significant effect on a battery's safety behavior.

Kohler noted that Lithium cobalt oxide (LiCoO2) has been the chemical of choice in the Li-ion batteries that power many consumer products, but Lithium nickel oxide (LiNiO2) and lithium manganese oxide (LiMn204) have also been used as cathode materials. LiCoO2 , suffers from poor thermal stability due to oxygen liberation, he said, adding that LiMn204 spinel has better thermal stability than other metal-oxides, but poor electrochemical performance.

Valence describes its Saphion technology as a lithium iron phosphate (LiFePO4) complex that doesn't liberate oxygen even under abusive conditions. Oxide ions form a hexagonal close packing arrangement In the LiFePO4 structure. Fe ions form zigzag chains of octahedra in alternate basal planes bridged by tetrahedral phosphate groups while lithium atoms occupy octahedral sites in the remaining basal planes.

Covalent bonding between the oxygen and P5+ to form (PO4)3- (or-

Table 1. Battery Technology Comparison

Battery System	Negative Electrode	Positive Electrode	Electrolyte	Nominal Voltage (V)	Theoretical Specific Energy (Wh/kg)	Practical Specific Energy (Wh/kg)	Practical Energy Density (Wh/L)	Major Issues
Nickel Metal Hydride	H (as MH)	NiOOH	KOH	1.2	278 – 800 (depends on MH)	70	170	Cost
Lithium Ion	Li	LixCoO2	PC or DMC w/ LiPF6	4.0	766	120	200	Safety Issues, Calendar Life, Cost

H = hydrogen · MH = metal hydride · Li = lithium · NiOOH = nickel oxyhydroxide · LixCoO2 = lithium cobalt oxide
KOH = potassium hydroxide · PC = propylene carbonate · DMC = dimethyl carbonate
LiPF = lithium hexafluorophosphate · Wh/kg = watt hours per kilogram · Wh/l = watt hours per litre

thophosphate ion) units allows for greater stabilization compared with LiCoO2 or other layered oxides that are not as strongly bound. The covalent bonding stabilizes the anti-bonding Fe3+/Fe2+ state through an Fe-O-P inductive effect.

Valence said its technology offers approximately four times the energy/weight ratio, double the energy/volume ratio, and up to five times the cycle life of lead acid batteries, and 2.5 times the energy/weight ratio and up to four times the cycle life of NiMH batteries.

There is, however, plenty of life left in NiMH batteries. "GM is continually evaluating battery technology and Li-Ion shows promise; however, there is a strong base of support for NiMH," said Joe Lograsso, engineering group manager at General Motors' Electrical Product Center. "There will be a crossover point from NiMH to Li-ion, but it's not clear if it will occur within the next three to four years or the next five to seven years."

Lograsso said that GM's priorities for hybrid vehicle battery development are lower cost, better warranty performance, and smaller size.

The 2007 Saturn VUE Green Line hybrid, scheduled to launch in mid-2006, is one of three hybrid systems that GM plans to introduce on up to 12 models. Beginning with the 2006 model year, GM plans nationwide distribution of the parallel hybrid full-size pickup trucks (Chevrolet Silverado and GMC Sierra) it unveiled in 2004. GM is also developing a two-mode full hybrid system that will debut on the Chevrolet Tahoe and GMC Yukon (full-size SUVs) in 2007.

The Saturn VUE hybrid design uses a Panasonic NiMH battery pack said to deliver/receive more than 10 kW of peak power, a precision electric motor/generator, and a 12 V lead acid battery for starting, lighting and ignition (SLI) functions.

Lograsso explained that the Saturn hybrid captures kinetic energy during deceleration to help charge the battery, charges the battery when it's most efficient to do so, and provides an electric power assist during acceleration. It also maintains accessory functionality and passenger comfort when the engine is stopped, so hybrid operation is transparent to the driver and passengers.

In motoring mode, the NiMH battery converts its stored chemical energy into dc power to start the engine quickly when the brake pedal is released, and to provide acceleration assist. The hybrid's power electronics then converts dc power to three-phase ac to run the motor/generator unit as a motor and to generate 12 V vehicle accessory power.

In generating mode, the engine powers the motor/generator unit, which provides a three-phase electrical output. The energy required to drive the engine can come either from gasoline, when accelerating, or from kinetic energy when the vehicle is decelerating with the fuel cut off.

Automotive and battery industry executives predict that Li-ion batteries will dominate the hybrid market a decade from now; however, they are less certain when the migration from NiMH will begin, or when the price/performance crossover point will be reached. "The manufacturing technology (for Li-Ion) is not as mature (compared with that for

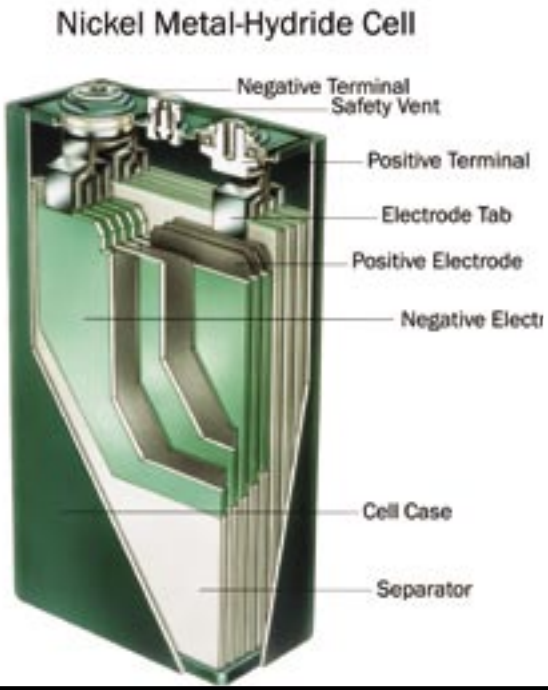

Figure 2. NiMH battery cut-a-way view.

NiMH), but the cost of materials is lower," said Toyota's Hermance.

Cobasys, a joint venture between Chevron Technology Ventures LLC and Energy Conversion Devices Inc., designs and manufactures proprietary NiMH battery systems for hybrid electric vehicles (HEV), electric vehicles (EV) and 42 V applications, among others. Its batteries powered the GM EV1 and the Chevrolet S10, among other HEVs. Cobasys holds the fundamental patents for NiMH technology, and recently extended a cross-licensing agreement with Panasonic EV Energy. It is also working with Motorola, Inc. on the development and manufacture of HEV battery control system components. Its liquid-cooled series 1000 battery modules (Figure 1) target light duty to large SUV power assist applications.

"NiMH batteries evolved from the nickel hydrogen batteries used in aerospace applications, but nickel hydrogen batteries have poor volumetric efficiency and require tanks of compressed hydrogen gas and platinum catalysts," said Ray Wagner, Cobasys' vice president of marketing.

"NiMH batteries were mere laboratory curiosities before the development of advanced metal hydride electrodes that were capable of being charged and discharged in a cell environment without failure," he explained. "The basic work performed in multi-component metal hydride alloys paved the way for the NiMH batteries in use today."

Wagner said other elemental metal hydride materials were not practical for battery applications due to the high equilibrium pressure the materials exhibited at room temperature. "This changed when intermetallic compounds were developed that combined strong and weak hydride forming materials," he said. "Tailoring the metal hydrides for the desired equilibrium pressure and other chemical properties is achieved by adjusting the ratio between these two types of material components.

The NiMH battery is termed an alkaline storage battery due to the use of potassium hydroxide (KOH) as the electrolyte. "The active materials in NiMH batteries are composed of metal compounds or metallic oxides, which are relatively good conductors," Wagner said.

"The positive electrode of the NiMH battery (Figure 2) is nickel hydroxide, and the active material for the negative electrode is hydrogen. The nickel hydroxide electrode only exchanges a proton in the charge-discharge reaction and the electron transfer is very rapid, which contributes to high power capacity. The small change in size of the electrode between charge and discharge also results in greater mechanical stability and longer cycle life."

Wagner noted that the electrolyte does not enter into the electrode reaction, so conductivity remains at a high level throughout the usable capacity of the battery. "The nickel active material is insoluble in the KOH electrolyte, which leads to longer life and better abuse tolerance," he said. "Nickel-based alkaline batteries are also attractive since the nickel electrode can be fabricated with very large surface areas, which lead to high capacities and high current densities."

Cobasys' NiMH batteries are capable of supplying powers of 200 W/kg to greater than 1000 W/kg to a load. They have demonstrated cycle life of greater than 1000 80% depth of discharge (DOD) charge discharge cycles. And in HEV applications, with very shallow charge-discharge cycles, they have achieved 200,000 to 300,000 cycles.

The integrated motor assist (IMA) system in Honda's 2006 Civic hybrid consists of an engine connected to a high-power electric motor and a continuously variable transmission. A NiMH battery pack is used to capture and store electricity for the electric motor. The gasoline engine is the system's primary source of power with the electric motor providing additional power and regeneration capability. During braking, the

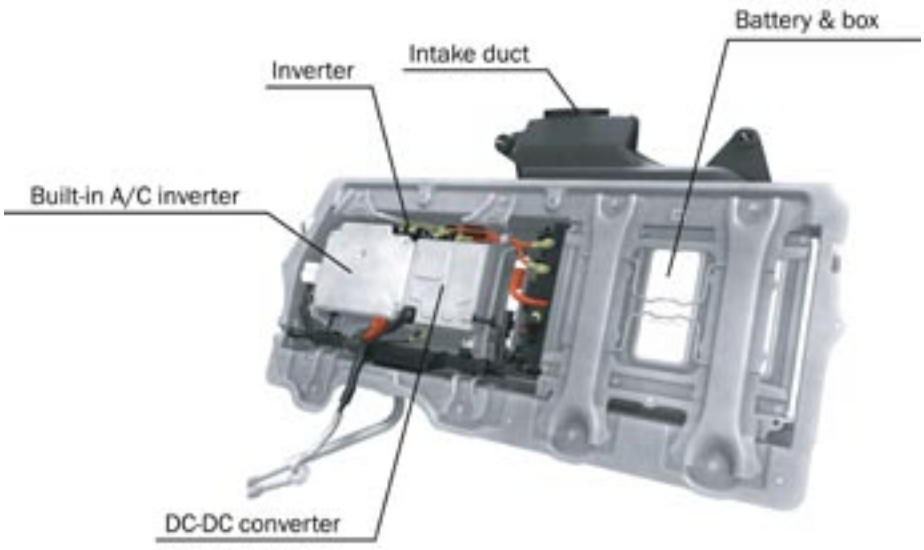

Figure 3. The IMA intelligent power unit comprises a power control unit, a NiMH battery module, and an integrated cooling unit.

engine deactivates the motor and acts as a generator to replenish the battery pack. The IMA intelligent power unit (Figure 3), located behind the rear seatback, consists of a power control unit, a NiMH battery module, and an integrated cooling unit. The power control unit, which also includes an inverter and a dc-dc converter, controls the flow of energy to and from the IMA electric motor. A bank of 132 1.2 V NiMH cells stores up to 158 V for the IMA motor. A Panasonic dual module casing makes the unit smaller and lighter than those on previous Civic Hybrid models.

Johnson Controls, one of the automotive industry's largest suppliers of lead acid batteries, last year received a contract for Li-ion battery development by the United States Advanced Battery Consortium (USABC), which includes the U.S. Department of Energy, DaimlerChrysler, Ford and General Motors. Johnson Controls was selected to develop an abuse-tolerant, Li-ion battery able to offer extended life and improved power-to-weight performance over NiMH.

Johnson Controls recently announced that it is investing approximately $4 million in an advanced Li-ion battery development laboratory in its Battery Technology Center in Milwaukee, and last month it formed a joint venture with Saft to accelerate development of both NiMH and Li-Ion hybrid and electric vehicle batteries.

Al Mumby, vice president and general manager of Johnson Controls' HEV battery business unit, noted that "the rapid rise in fuel prices has substantially increased the outlook for hybrid vehicle production." According to industry projections, sales of HEVs in the United States and European automotive markets could reach six million units within a decade. HEV sales currently account for about 0.5% of total world vehicle production.

"At this time, most HEVs rely on NiMH batteries. Lithium-ion batteries have significant potential for near-future HEV applications, because they have the capability of offering major advantages in power-generation, size, weight, cycle life and cost," Mumby said.

"At one time NiMH batteries were unaffordable; considered exotic," noted William G. Rankin, president and chief executive officer of UQM Technologies, a developer of high-efficiency electric motors, generators and power electronic controllers for automotive and other applications. "Eventually, after enough experimentation, NiMH batteries were able to prove themselves in terms of energy density, and with volume production, prices came down. Li-Ion is going to have to go through the same process." ■

ABOUT THE AUTHOR

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