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Zebra-Candidate for Low Cost Transportation?
The front cover photo... BD Editor Shirley Georgi shows the size of a Zebra Battery on the floor in the Exposition Hall at EVS 20. See an overview of the Zebra Paper on page 4.

The ZEBRA battery is based on the electrochemical couple Sodium/nickel chloride and has a high specific energy (~125Wh/kg) battery which provides electric vehicles with an range of approximately 120 - 180 miles. The specific power is greater than 150 W/kg which gives the vehicle performance similar to the IC (internal combustion) vehicle. There are no gassing reactions, the battery is fully sealed and it is purported to maintenance free. Because it has nearly 100% coulombic efficiency (the recharge energy = the discharge energy), accurate state of charge can be provided to the operator.

Other characteristics of the battery and cells are:
- The cells operate at greater than 270°C (270 °C to 350 °C)
- The outer surface of the cell is ~15°C above ambient. Performance is independent of ambient temperature (-40°C to +70°C).
- Less than 2 kg of nickel is used per kWh.
- The battery has indefinite storage life at ambient temperature.

EVS 20 Presents
Eclectic Battery And Ultracap Roles
A review of Battery and Double Layer Capacitor presentations at EVS 2003

by Donald Georgi

EVS 20 was a cornucopia of concepts for new generation transportation power, not the least of which was the myriad of battery sessions covering multiple chemistries for many applications.

In this installment, battery sessions are summarized, by paper, to provide the reader with the state of technical thinking and capabilities of battery power in transportation. Batteries and ultracaps for transportation are very important to the quest for cleaner air, greater efficiency and energy independence. In the case of the pure EV, the battery is the only power source, but in hybrids, whether internal combustion powered or fuel cell powered, the battery works in a synergistic mode to absorb braking energy, add performance and provide for the most efficient operating region of the primary power source. In this meeting we see an emergence of serious applications of ultracaps in hybrids.

The following thumbnail summaries of presented papers are organized by chemistries. Further details on presentations referred to here are available from The Electric Drive Transportation Assn. at www.electricdrive.org or from the organizations which provided the papers.

Double Layer Capacitors (Ultracaps or Supercaps)


Ultra capacitors for hybrid transportation, developed by Okamura, have been supplied by Power Systems to Honda for the FCX and to Nissan for their diesel hybrid truck. At the time the capacitors were delivered, the energy density for the
FCX was 5.2 Wh/kg and 6.3 Wh/kg for the Nissan truck. Today, ultracaps are being produced with 10 Wh/kg energy density and 5.8 kW/kg of power density.

Current concerns or considerations for the choice of ultracaps in hybrid vehicles include serial charge control, electrolyte safety and design trade-offs of internal resistance and energy density.

Ultracaps require many cells in series to develop the useful bus Voltages for vehicles. Ideally, the charging of multiple serially connected cells would only require a single bus Voltage charger, but on reality, differences in cell characteristics beyond the control of manufacturers can cause cell Voltage imbalance and lead to degraded cell performance or failure. To use bypassing circuits, which handle the heavy charging currents, would add unacceptable costs. Applying switching converters to individual cells would again add bulk, cost and reduce reliability.

The problem of electrolyte safety has led manufacturers away from the more dangerous acetonitrile (AN) which has a flash temperature of 200°C. It also generates cyanide gas when burning, and thereby is a poor choice for use in an ultracap which would be placed in public transportation. The comment was made that although AN has these safety deficits, it is safer than Lithium-ion batteries, which have failed to produce the catastrophes envisioned in the last decade of the twentieth century, although many safety recalls have been required.

The safer, propylene carbonate (PC) has about one half the capacity of AN and three times the internal resistance of AN. PC also has reduced performance at low temperatures. For a temperature of 20 °C, the internal resistance of an ultracap increases 12 times in cooling to -35 °C. In a pack of ultracap cells, which were cooled, the Voltage would increase inversely proportional to the capacitance because charge would be conserved. Such an increase would not be a desirable feature of the pack.

The present solution of using the PC electrolyte with higher internal resistance, it is important to notice that the mathematics of both charge and discharge provide for the internal resistance as a limiting factor of the power, but the power is also dependent on the charge or discharge time in the relationship RC/t. Cells charged for the proper amount of time, based upon the design with an appropriate current source, can achieve good performance. In summary, to achieve desired performance, accept the internal resistance and increase the energy density of the cell for the application. Increasing energy density twofold will provide the same results as decreasing the internal resistance by half.

Long term results of using the ultracaps by Honda and Nissan will be anxiously awaited by others considering ultracaps, especially as their capacity continues to increase.

“Application Studies of Electric Double- Layer Capacitor System For Fuel Cell Vehicle,” Honda

Honda’s first commercialized fuel cell powered vehicle, the FCX, is a hybrid which uses an 80 cell, 216 Volt, ultra capacitor instead of a battery as Toyota does on its Prius. This approach is not new with Honda. They had configured the Insight hybrid with an ultracap until the augmentation power from the ultracap was deemed insufficient, requiring a return to battery power.

The 28 kW (max), Ultracap chosen for the FCX has a specific power density of over 1500 W/kg and a specific energy density...
of 3.9 Wh/kg. The Ultracap has 30% more output power and twice the power density of Nickel-metal hydride batteries commonly used in hybrid vehicles.

The addition of an ultracap was required principally to provide peak power beyond the performance capability of the fuel cell. By comparison to the Honda Civic IC/battery hybrid, the FCX requires 3 times more assist power. The FCX ultracap produces twice as much power for the equivalent weight of battery used in the Insight.

Although the ultracap output voltage linearly tapers, it can be placed in parallel with the fuel cell, eliminating the cost and complexity of a Voltage regulator. Regenerative braking is also employed to both replace charge in the ultracap and recuperate energy to improve overall efficiency.

Another benefit of the ultracap is its relatively low internal resistance. It has about 7 to 8 percent greater energy efficiency than Nickel-metal hydride batteries during charge and discharge.

Overall system complexity is reduced with the ultracap when considering its lack of memory effect and Voltage proportional to terminal Voltage. Because of the Ultracap’s long cycle life, it might be considered to last the life of the vehicle (when fuel cell endurance builds to a level commonly provided by today’s IC engines.)

To achieve the greater power performance, Honda focused on improving the fill density and collector structure so that direct connections could be made between collector plates and the case. No information was offered regarding inner cell chemistry.

**Lithium-ion**

“Distributed Modular Lithium-ion with Intelligent Device For Hybrids,” Industrial Technology Research Institute (ITRI), (Taiwan)

To implement Taiwan’s year 2000 mandate to produce 2-wheel zero emission vehicles, the ITRI has consolidated this program with lean-burn IC engine technology to pursue hybrid configurations for metropolitan light-duty vehicles.

A parallel hybrid with a 375 cc IC engine and a 24 cell series-connected 8.4 kW Lithium-ion battery is controlled via an intelligent CAN bus. Balancing of all cells is performed to promote performance, 2000 cycle life, and safety. Lithium-ion has been chosen because of low internal resistance, reasonable power, durability, safety and acceptable cost.

From a system performance profile specification, the engine and battery requirements were set to include 20 Ah capacity, 1000/kg power density and 65 Wh/kg energy density. The power output is to be 8.4 Kw above a 50 percent state of charge. Taiwan is apparently a warmer climate so temperature performance has only been evaluated down to +5 °C.

The battery management system consists of one control unit and four sensing modules which can be expanded for additional pack control. With the CAN bus, the electric motor, integrated starter, generator and vehicle control is rapidly interconnected with simple wiring and good noise immunity.

The battery system is being tested and integrated with the power train. Although battery cost is still a problem, the acceptance in the hybrid community should increase volume and reduce costs.

**Lithium-ion for Light Hybrid, Industrial Technology Research Institute (Taiwan)**

‘Home brew’ batteries and vehicles are the goal within Taiwan. At the center of their work is a planned hybrid two seat auto with a lean burn engine and Lithium-ion batteries. The vehicle is to have a range in excess of 200 km and carry batteries which drop in cost.
from $700-$800 to $300-400 per kWh per kg. Using experience from Ultralife, Taiwan, an 88.8 Volt three pack consisting of a total of 24 cells has been constructed to begin the design. Characterization and capacity testing with cycling at 60-80% state of charge is being performed. Cells have passed safety testing, consisting of nail penetration, overcharge and external short circuits. Final battery pricing of $109/kWh, including controller, are anticipated in high volume. Based on the past ability of Taiwan’s to compete in world markets with high tech products, there is the possibility of seeing another global hybrid manufacturer emerge. (Ed. note: the next question may be whether they would be sold at Wal Mart?)

“Impedance Studies of High-Power Lithium-ion Batteries for HEV Applications,” Samsung SDI Co., Ltd.

The Korean influence on the choice of future HEV batteries continues to support Lithium-ion. The work by Samsung in preliminary, with prismatic 3.6 Ah cells using Lithium cobalt oxide in the cathode, artificial graphite for the anode, a 20 micrometer thick polyolefin separator and an organic carbonate electrolyte with LiPF6 salt.

In the development process, the performance relative to the need for improvements was analyzed with cycling tests using pulses to determine performance. Cells at 50% state of charge were discharged at a 5C rate for 18 seconds, then rested for 32 seconds before recharge back to the 50% SOC. During testing, an ac Ohmmeter was used to provide data for determining the major sources of impedance.

Testing was carried out for 180,000 cycles, to determine various components of the change in cell impedance. Results showed that the major contributors were the current collectors and the cell polarizations. Because this testing was done to find these areas which require improvement, it is assumed the next part of the development program will be to improve these impedance components.

“Lithium-ion for Idling Stop Vehicle,” Toyota

Today’s popular hybrid vehicles are almost exclusively powered by Nickel-metal hydride batteries. But, Toyota is offering a special concept ‘Idle stop’ control which uses Lithium-ion technology. This is one step below the hybrid drive in that the battery is only used to restart the engine and provide accessory power while the vehicle engine is off. Looking at the Los Angeles freeway during rush hour, it is easy to see how the Idle Stop approach can drastically reduce emissions as all those vehicles sit parked six-wide, across the I-10. According to Toyota which has demonstrated the system in a vehicle designated the “Vitz,” This model has the lowest fuel consumption of vehicles except for those under 660 ccs and hybrids.

The system provides power when the driver applies the brake and the vehicle comes to a stop. The engine shuts off and the heater, air conditioner, radio and lights are powered by the 14.4 Volt, 12 Ah, 4-cell Lithium-ion pack. When the driver releases the brake, the Lithium-ion battery restarts the engine which is the only prime mover in the vehicle, separating it from the ‘hybrid vehicle’ classification. The Lithium-ion battery is recharged from the alternator while the engine is running and can also absorb regenerative braking energy. When the battery charge is low or the temperature too high, the system does not stop the engine.

Lithium-ion polymer

“Advances in State of Charge Estimation for Lithium-ion polymer Battery Packs,” Compact Power & University of Colorado

This presentation is an excellent example of evolutionary
progress in the development of a model to predict the state of charge of a Lithium-ion polymer battery in a HEV application. The presenters began the work with a model based on extended Kalman filtering and reported results in 2001. Improvements and limitations were continually evaluated with better results, but often did not extend from cell level to battery management in the pack. Complexity also extended the execution time to limit usefulness.

With the latest level of development, the model error has been reduced and execution time has been cut by a factor of 50. The current version considers the effects of open circuit Voltage, cell relaxation, cell internal resistance and hysteresis.

“As Lithium-ion Polymer for Transportation Applications,” LG Chemical

As the rechargeable Lithium-ion chemistry unfolded in the last decade, the design and manufacturing excellence of the Japanese

insured the success through safety and performance. After the market was established, the Chinese began to become a major supplier with cost being a large incentive in their acceptance.

Korean influence in Lithium-ion has been added to the list of suppliers and the thoroughness of their presentation at EVS supports their inclusion in the membership of serious suppliers. LG Chemical has provided large size Lithium-ion polymer batteries for transportation applications and is expanding the offering with new sizes and improved performance. Details of the performance was extensive with only the calendar life and low temperature data left out. In the case of calendar life, there may be difficulty in providing accurate information at the outset of such a new program.

LG emphasizes its focus on safety by choosing a manganese spinel with graphite chemistry. The spinel has long been accepted as having superior thermal safety over cobalt electrodes. Additionally, the Mn based cathode material is abundant, with relatively low material cost. In the new 7.5 and 5 Ah cells, a blended carbon provides improved power density both in charge and discharge. At discharge rates to 30 C, the cell delivers over 85% of its 1 C rated capacity.

Detailed performance at 1 and 2 C rates shows initial peak power densities over 5000 W/kg at State of charge between 80 and 20%. Cycle life in the PNGV life cycle pattern produced 160,000 pulse cycles with only a 20% reduction in initial power.

The combination of inherent safety and reasonable costs of the spinel and polymer materials with the high power performance can make this supplier a force in power for HEVs, electric bikes, scooters and wheelchairs.

Lithium Metal-polymer

“Integration of a Lithium-Metal Polymer Battery Pack into an Electric Vehicle,” Avcestor

This is one of the chemistries which has been under development for many years but continues to be pursued as a high energy density, potentially low cost battery. Since electric and hybrid vehicles are still experimental or of low volume, Avcestor has directed the immediate applications to telecom backup where the tolerance to low and high temperatures allows it to be offered with a 10 year warrantee. The telecom experience will allow reliability and cost performance data to determine the acceptability to EV and HEV applications, which will hopefully emerge in the next decade.

Multi-Chemistries

“Improving Battery Thermal Management Using Design for Six Sigma,” Advanced Engineering Solutions & the National Renewable Energy Laboratory

The level of understanding needed to implement such design is formidable, but the overview of the approach can be made understandable to those not statistically well versed. First, one must admit to the complexity of battery utilization which includes battery performance and life. To put a single battery in a test device, measure its power and energy delivery, and then cycle it under appropriate load conditions are only the first steps in determining the battery’s capabilities. If we need only one cell at standard temperature, pressure and accelerations, one additional ‘g’ test might be in order. But, when the battery will be designed into tens of thousands of hybrid vehicles encountering a variety of operational and environmental conditions, much more understanding is needed to assure performance and life.

Central to the performance/life issue is the thermal management. While either charging or discharging, the current flow in batteries...
creates heat. High rates of charge or discharge, often desirable in an HEV battery, leads to excessive cell temperatures. Internally generated heat interacts with the heat of the ambient surroundings because other parts of the vehicle are producing heat, and the air surrounding the vehicle may either be adding or subtracting heat from the battery. If these conditions do not make for enough complexity, added variances occur due to manufacturing tolerances of battery parts, and assembly dimensions which restrict airflow.

To make the process accurate, the Panasonic prismatic Nickel-metal hydride cells in a Toyota Prius were chosen because of the extensive testing which has been accomplished on this vehicle at the National Renewable Energy Laboratory (NREL). Finite element modeling defined the geometry of the cell, which included the physical characteristics such as thermal conductivity, heat capacity, internal resistance and module placement gap.

A parametric deterministic model used three variables of thickness, resistance and flow rates with assigned normal distribution probability densities representing variations as quantities in production increase.

To quantify the quality of the design, a level of six sigma was selected corresponding to 3.4 defects per million. While this may seem excessive in auto transportation, it must be remembered that Toyota and Honda have established their overall quality performance with major attention to subsystem reliability.

Responsibilities for advance Lithium-ion battery research is achieved.

The degree of sophistication in this approach may lead the way to better understanding of battery performance and ultimately could improve quality for optimal design and manufacturability in stationary, portable and transportation applications.


For the person wanting to see the big picture of battery development now and in the future, this presentation is both detailed and yet complete in less than 12 pages which include 1 1/2 pages of credits and references. To make the subject identification simpler, it should be noted that this presentation does not mention double layer capacitors specifically.

The DOE supports R & D for innovative auto technologies through the FreedomCAR Partnership. This includes hybrid electrics, battery electrics, 42 Volt systems and fuel cell vehicles. The goals are to establish and reaffirm performance and cost targets, develop hardware, and accelerate development of applied and long-term advanced battery technology. Over the last decade, development of Lithium-iron sulfur, Nickel-metal hydride and Lithium-ion chemistries has progressed.

Today, their work focuses on technical barriers associated with cost, performance, life or abuse of battery systems. Targets have been established for hybrids, EVs, 42 Volt systems and fuel cell vehicles. Costs, however determined, are big barriers to the implementation of battery power. Separator costs are a big part of the continuing work. (Ed. note: Units of measure are not consistent in that the long term production price of a HEV battery is a maximum of $800, whereas the selling price of a 42 Volt system battery is listed at $360. Based on past experience, better measures are needed. Motorists have been the brunt of vicious markups in selling price as the product passes through the chain of price buildup and distribution. Ultimately, the final retail price becomes whatever the market will bear.)

Today, specific programs include liquid-cooled Nickel-metal hydride packs, Lithium-ion battery life and development of Lithium-sulfur battery systems. Benchmark testing of emerging technologies is accomplished at independent test facilities, although results are held in confidence between the DOE and developers.

Using information from this model, transient response can be determined for applications such as the 40 kW Freedom car profile. Performance to establish the time to reach steady state temperatures can be determined, and choices of input parameters and design constraints are factors which contribute to the quality level.
spectroscopy and microscopy diagnostics and Sandia is in charge of abuse, accelerated life testing and statistical analysis. The presentation describes programs within each of these Laboratories in greater detail.

With the well structured approach of the DOE battery program, additional strength is added through cooperation with other international agencies such as the International Energy Agency, and Japan’s Lithium Battery Energy Storage Research Asn.

“Energy Management System for Combined Storage System,” University of Bremen

Initially the vehicle power system seems most unusual. It is composed of an electric van with three independent storage systems - Zinc-air batteries, Nickel-metal hydride batteries and an ultra capacitor. These power sources are all connected to a 230-360 Volt bus which powers a nominal 40kW, (65 kW peak,) drive motor.

The large energy storage is in the 105 kWh Zinc-air battery which provides the highest energy density of 125 Wh/kg but only a low power density of 26 W/kg. This is the ‘long range’ power supplier. The 3 kWh Nickel metal-hydride battery is the power boost for hill climbing and meets larger profile assist requirements, providing 300 W/kg.

Finally, the 150 Wh ultracap provides additional short bursts of power for acceleration and passing.

The energy management system recharges the ultracap first from regenerative braking and then adds other regenerative energy to the Nickel-metal hydride battery. When insufficient regenerative energy is available, the Nickel-metal hydride battery is brought up to a 70% state of charge by energy from the Zinc-air battery.

The vehicle provides not only an experimental test bed for identifying the best control schemes, but also a real world road vehicle to determine if the performance is suitable for driving conditions. Unfortunately, the Zinc-air battery requires removal for regeneration of the zinc anodes which is not conveniently available.

Rather than define this vehicle configuration as an end design, the concept is being extended to a minibus which will take advantage of higher performance batteries and ultracap. Beyond that, the concept of management of combined systems provides a base for other combinations of power including IC engines, fuel cells and photovoltaics.


This program was initiated in 1997 and involves Honda, Toyota, Isuzu, Mitsubishi, Nissan and Hino in contracts with the New Energy and Industrial Technology Development Organization. The goal has been to develop technologies and vehicles which have increased efficiencies.

Now seven years into the program, experimental vehicles are in the final building stages. Already, Nissan’s Diesel bus has been completed and tested to demonstrate that fuel efficiency of 2.1 times that of the base vehicle has been achieved.

Regenerative efficiencies of baseline series and parallel HEVs were under 40%, requiring doubled targets of 80% regenerative efficiency for the experimental vehicles. In this report, the performance of capacitor storage was highlighted. From an earlier design, a second capacitor was developed which boosted charge and discharge efficiency by 5 to 10 percent over the 80 to 40 percent state of charge region. With this performance compared to the lesser efficiency of a Nickel-metal hydride hybrid, it was determined that fuel economy can be improved by 19% if capacitors are used in place of the Nickel-metal hydride batteries. This may be one reason we see the emphasis by Honda to use the ultracap in the FCX vehicle and may see further considerations of double layer capacitors in other hybrids.

“The Future of Traction Batteries and the EV, “ PSA Pugeot Citroen

This presentation is an excellent status report and forward looking
Batteries Digest Newsletter

March 2004

PSA is able to provide such a view because it is the world’s leading manufacturer of volume produced electric vehicles since 1995. It accounts for 65% of the electric vehicles currently on the road in Europe. Testing and prototype development continues within the company.

Of the available battery chemistries, Nickel-cadmium is considered obsolete because of its environmental problems upon disposal and because the Nickel-metal hydride battery has brought higher energy density and acceptable power density. Loss of capacity at temperatures of -20°C is a problem. Concerns still exist in the generation of hydrogen as a safety factor. Lithium-ion and Lithium-ion polymer have made solid improvements although low temperature operation is a problem, especially with the solid polymer version which must be maintained at temperatures of 60-80 °C.

Despite lab testing, there are safety concerns for these batteries in vehicles.

Because pure electric vehicles would be best operated from 100% state of charge to close to zero, the cycle life of Lead-acid under such conditions would only provide 180 cycles. Nickel-metal hydride is good for over 1000 cycles and Lithium-ion for 500-900 cycles.

Recent road testing of Lithium-ion powered sedans has provided better understanding of performance such as operation in cold climate conditions. Average driving ranges have been 165 km.

The performance capabilities of the electric vehicles, with many choices of battery chemistries, can provide suitable performance, but the shadow over all of them is the cost of the batteries. The technical advantages of Lithium-ion (& polymer) continue to build, but the costs which have dropped from 330 Euros/kWh to 150 Euros/kWh remain the penalizing barrier to EV acceptance.

As technical and cost barriers are resolved, the principal applications of EVs appears to be for urban vehicles and fleet applications.

At Japan’s Advanced Research Institute, improvements in capacitor charge/discharge efficiency have been significant as shown by the second capacitor data above. Measurement was carried out under fixed power conditions rather than fixed current conditions, taking power density as a parameter. The second capacitor has lower internal resistance which contributes to the higher efficiency. Special assistance in obtaining the graphic was provided by Kenji Morita. (Copyright permission by EDTA.) +

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Nickel-metal hydride

“Development of Prismatic Nickel-metal hydride for HEV,” Panasonic

The casual observer focuses on the dramatic commercial hybrids produced by Toyota and Honda, but a third player in this exclusive club is the battery supplier Panasonic which has supplied battery packs to over 200,000 HEVs. As Toyota and Honda vehicles have collected hundreds of thousands of hours of road experience, Panasonic has shared in the experience with its batteries. The direction Panasonic takes in new developments will be reflected by the road experience and the direction of new designs by their countrymen.

Prior to 2003, Panasonic has developed a prismatic Nickel-metal hydride battery which provided a 25% increase in specific power over their cylindrical design. In the 2003 Panasonic paper, discussion continued on an even higher specific power prismatic cell with an increase from 1000 W/kg to 1300 W/kg. This increase was accomplished by reducing the resistance of internal current pathways and changes in material of the positive electrode. New intercell current pathways provide lower internal resistance, and solid solution additives (to the positive active materials) show higher terminal Voltage from very low to maximum currents. Data presented shows approximately 30% increase in specific power in the compete range of state of charge and maximum ambient temperatures.

Concurrent with the above changes, the new cells utilize an improved separator which should lead to longer cycle life. To date with only 8500 normal driving cycles reported, there is no reduction in cycle life, but the testing is continuing to hopefully show the improvement for the new separators.

‘Hybrid Bus In A Large City,’’ Saft

Busses and trams are the focus of the design of the model NHP battery which must recognize the large number of cycles imposed by a hybrid system powering a public transportation vehicle. By sizing the battery properly, depth of discharge can be limited to 20%. Under these conditions, prismatic Nickel-metal hydride batteries are being produced which have an anticipated life of six years. Under operational conditions, thermal management becomes a major concern. After considering the advantages of air and liquid cooling, the liquid cooling has been implemented with circulation chambers integral to the cell design. This produces a compact battery which allows uniform heat removal. Cycle testing of 20% depth of discharge from 60% peak power has shown no significant fading at 43,000 cycles. Relating the cost of the battery to the passenger, Saft estimates that the premium of the battery hybrid would only be $0.15 per passenger per ride. (Ed note: This may be a small price to pay for a healthier air quality for all the people in congested cities.)

Sodium/Nickel-chloride

“The Zebra battery” , MES-DEA Sa

The name of the “Zebra” battery may be appropriate for this chemistry since the actual chemistry is a bit complicated. A cell is built from nickel and iron powders, sodium chloride, beta-alumina (boehmite) a ceramic electrolyte and a stainless steel case.

The reaction is:

\[ 2NaCl + Ni \iff NiCl_2 + 2Na \]

When charged, a negative electrode of sodium forms from the sodium chloride making construction in the uncharged state safe. The sodium reacts with nickel chloride to produce current. Cell Voltage is a healthy 2.58 Volts, leading to a lesser number of individual cells in a high Voltage pack. It may be that the presence of sodium in the charged state is the major safety concern for the battery, but no safety information was presented.

The desirable features for the Zebra battery includes its high energy density of 120 Wh/kg, its economical and easily available materials (nickel, iron, sodium chloride) and its friendly recyclability. Calendar life is claimed to be more than 10 years, and 1000 to 2500 cycle life is anticipated. It has high energy density of 1230 Wh/kg. Compared to other nickel based chemistries, the Zebra requires only 1.53 kg of nickel to produce one kWh of energy while Nickel-cadmium and Nickel-metal hydride require between 3.5 and 6.8 kg of nickel per kWh.

As of the latest report, November 2003, at EVS 20, the ZEBRA battery is said to have achieved:

• More than 4 million miles in road vehicles
• More than 60,000 miles in one vehicle with no maintenance
• More than 5 years life in a car
• More than 12 years demonstrated calendar life
• Performance independent of ambient demonstrated in arctic and desert conditions
• Proven safety

More information on the battery can be obtained at Beta Research and Development Ltd. at their website at www.betard.co.uk

Lead-acid

“Lead-acid Battery for HEV Applications,” European Advanced Lead-acid Battery Consortium

This is an update of the saga reported in detail in BD’s May 2003 issue. While Nickel-metal hydride has captured the HEV production offerings of Toyota and Honda, efforts as mentioned above show aggressive consideration of Lithium-ion and Lithium-ion polymer as the ‘other source’ in future hybrids whether they be with IC or fuel cell engines.

Where does that leave Lead-acid? The perception is that the low-cost battery has neither the energy density nor the cycle/calendar life to compete in this modern HEV world. Pundits can expound on the subject until the public is as tired of hearing about it as they are tired of reports of the political elections. Talk is cheap; it will
take road experience, production capability and cost to the consumer to decide if Lead-acid can be a player.

That is exactly the path being pursued by the European Advanced Lead Acid Battery Consortium in their Rholab program(me). This three year program is dedicated to determinet the road capabilities of a currently manufactured Lead-acid battery in a well characterized vehicle, the Honda Insight. Hawker, pure lead, starved electrolyte cells with improved double ended terminals to reduce resistance are bench tested, and then installed in the Insight to determine performance capability. This venerable battery, which has been around since the dawn of the VRLA era, has nothing to prove in its basic performance. However it needs to perform on the road with vibration and high cycling in partial state of charge conditions which require high charge and discharge rates to accommodate acceleration and regenerative braking.

At this point in the program (Nov 2003), the cells have been assembled into packs, after having good results from the bench testing. Reduced Voltage drops in 1000 second pulse discharge have shown the viability of the twin tab design. A decline in the pack Voltage was observed after 65 Rholab cycles which has led the team to consider modifying the negative active material with added carbon and a second approach of conditioning the cells by bringing them up to full state of charge after every 10 Rholab cycles. Such a pattern can be easily implemented in an automatic battery management system, and if successful in the long run, could be a transparent ‘fix’ for the Voltage dropoff problem.

Before installing the Lead-acid battery, the Insight has been bench marked with the Nickel-metal hydride battery pack. This adds performance data to the well investigated Honda and allows the Rholab data acquisition package to be validated prior to use with the Lead-acid power.

Work is in process to convert the Insight over to the Hawker battery. A 50,000 mile test comparable to the Rholab bench cycle test will be performed. One might say that such a driving distance would be less than that experienced by the Insight or Prius with Nickel-metal hydrides, but then there is the need to consider the comparable initial and replacement costs. A motorist with saved dollars in his/her wallet/purse probably would accept a Lead-acid battery replacement at 50,000 miles if it was scheduled (not traumatic) maintenance. Other factors such as calendar life and suitability to temperature extremes not only need to yet be presented to the automotive public for Lead-acid but also for Nickel-metal hydride, Lithium-ion, Ultracapacitors and any other candidates. Driving 100,000 miles in two years is not the same as driving 100,000 miles in 10 years.

The viability of hybrids in reusing braking energy and tuning of the engine for optimum performance has been established. It is real world road performance such as Rholab’s work which will help to bring this vision of battery suitability into focus.

“Vehicle Integrated Monitoring with SOC/SOH Intelligence,” Midtroncs

Lead-acid batteries have often been left out of consideration in hybrid applications, but the real world may still be a domain for the venerable heavyweight if sophisticated battery condition is needed in applications such as idle-stop or start-stop. Such an application needs to know if the capability of the battery is sufficient to restart the engine each time it is shut off. While such information may be easy to get for a new, cool fully charged battery, the repeated engine on-off regimen of an ordinary driving cycle, with variable demands for engine-off power, requires managing the load priorities so that sufficient cold cranking Amps will be available as the engine is brought back to life.

The intelligent Battery Monitoring System (iBMS) uses microprocessor control to measure battery conductance. The system also considers Voltage, charge/discharge current and temperature to arrive at battery state of charge and the state of health (in percent) which should constantly decline with use and age. No longer is the power capability idealized for a battery. The vehicle intelligence must know if the remaining power/energy will restart the engine, and if so how long can it provide power to drive components with prevailing temperatures, yet still fulfill the restart mission.

A new term was mentioned, ‘State Of Life’, which is computed from the measurements, but left undefined. Perhaps BD can find additional information on this in future issues.

In 2005 the inGEN system will be offered in a European passenger vehicle and other systems are used in military vehicles and heavy-duty trucks.

Perhaps with appropriate intelligence tailored to sophisticated and hybrid applications lead is not dead after all.
Batteries/Alkaline

Matsushita Electric Industrial Co. is planning to announce a new product, Oxyride, to compete with Alkaline batteries. According to Japan Today’s January 29th edition, this is the first new dry battery to be introduced by a Japanese manufacturer for 40 years. Oxyride is reported to be more powerful and durable than Alkaline.

Batteries/Business

GP Batteries International and Energizer Holdings agree to a patent cross-licensing. The cross-licensing provides all parties to operate freely throughout the world. This ends the legal dispute over zero mercury-added Alkaline batteries.

Last June Energizer Holdings and Eveready Battery Company initiated a U.S. International Trade Commission action against a number of companies, including GP Batteries, for allegedly infringing on their battery patent.

Batteries/Lithium/Lithium business

Aerotech acquires Epsilor Electronic Industries, Ltd. Epsilor has developed and sold rechargeable and primary lithium batteries and smart chargers to the military and private industry in the Middle East, Europe and Asia. Aerotech plans to introduce the acquired lithium-based battery technology to its Auburn, Alabama battery plant, as a base for broadening its US. military battery market. Aerotech wants to be well-positioned in three important military battery markets; non-rechargeable Zinc-air, primary lithium, and rechargeable lithium along with associated smart chargers.

Batteries/Lead-acid/Business

TBS Engineering Ltd. purchases all assets of Tekmax, Inc. Tekmax is the world’s largest provider of battery plate enveloping and automated transfer equipment. TBS Engineering bought Tekmax because it complemented the range of Lead-acid battery assembly equipment.

Batteries/Lithium/Lithium business

Oak Ridge Micro-Energy is developing a thin film medical rechargeable microbattery. The battery-powered device will be implanted deep inside the body and enable physicians to assess and treat a variety of medial conditions in a noninvasive manner. The devices can either serve as a sensor for measuring parameters such as temperature and radiation dosage, or as an activator for localized drug therapies and nerve or tissue stimulations. The battery for this family of devices is about 0.25” X 0.08” X 0.0003” thick. According to Mark Meriwether, president and chief executive officer, this battery is being developed in a joint project with an unnamed company. He said, “(This project) will lead to the world’s first miniature implantable medical device of extremely small size that is fully contained and self-powered by our thin-film battery.” Mr. Meriwether says that...
this project will provide a significant revenue stream as soon as the third quarter of 2004.

Batteries/Manufacturing

Philips Lithylene™ Technology offers manufacture of batteries for operation space. In the fabrication of the battery there is no need of outside pressure to keep electrodes together. Batteries assembled by this technology can operate under vacuum conditions, but they do not generate a magnetic signal owing to lack of loop current. The design and creation of any free form battery can be done with any electrochemistry. Information on this technology is found on the website: www.stonebattery.com

Fuel Cells/direct methanal

Medis’s CEO tells World Economic Forum audience that microfuel cells cannot be scaled up to run automobiles. At the Switzerland conference in January, CEO Robert Lifton says governments should focus on energy preservation and not hope that fuel cell technology will be soon catching up to meet energy needs.

He also told that audience that Medis’s working prototypes of the Power Pack fuel cell for powering portable devices would be introduced in May 2004. Initial pricing for the product is $29.99. Refuelable methanol cartridges would be priced at $1.50. Each cartridge should power a cell phone for about 12 hours.

PolyFuel announces breakthrough in a membrane specifically designed for the direct methanol fuel cell (DMFC) applications. The newly developed membrane is said to lower methanol and water crossover, have higher fuel efficiency and stability in high levels of methanol concentration. Leading consumer electronics manufacturers and other developers of DMFC systems are currently are receiving samples.

Batteries/Nickel-zinc

Evercell plans to deregister its common stock on the NASDAQ. “The board of Directors of the Company has been examining the question of whether remaining a publicly-traded company merits the associated costs and regulatory burden,” stated Garry Prime, CEO. Shareholders who wish to sell or buy stock can continue to do so in the public market prior to the filing of the Form 15 for delisting.

In addition to the loss of liquidity that will occur upon deregistration, the specific disclosure requirements intrinsic to the period and current reporting requirements of the Exchange Act will no longer apply to the Company. Although the Board of Directors can continue to communicate with existing shareholders, the Company will no longer be required to observe the specific form, frequency or priority prescribed by the Exchange Act.

Evercell, Inc. manufacturers Nickel-zinc rechargeable batteries for applications in light electric vehicles, trolling motors for boats and lawn mowers.

Fuel Cells/Automotive

The California Fuel Cell Partnership (CAFCP) goals emphasize placement of additional zero-emission fuel cell vehicles (FCVs) into fleet demonstration sites and more hydrogen fueling stations. Over the next four years, its 30 members will work to facilitate the placement of up to 300 fuel cell vehicles in independent, fleet demonstration projects within the state. Fuel cell buses will operate in regular passenger service in at least three transit districts.

As of January 15, 2004, 58 FCVs have participated in CAFCP demonstrations. Cumulative miles driven by these cars for the demonstration is over 145,000. Members with current FCV fleet programs in place in California are Honda in the cities of LA and San Francisco and Toyota at the University of California at Davis and the University of California at Irvine.

Fuel Cells/Hydrogen

Business Communications publishes information on steady growth in hydrogen generation for the fuel cell market. The Company has published “RE-107 Hydrogen Generation for Fuel...
Cells.” The report predicts that the market will reach nearly $1.5 billion as it grows at an average annual growth rate of 15.8% through 2008. For more information see the website - http://www.bccresearch.com.energy/E107.html

The National Academies’ National Academy of Engineering and National Research Council report on study of the future hydrogen economy. “Our study suggests that while hydrogen is a potential long-term energy approach for the nation, the government should keep a balanced portfolio of research and development efforts to enhance U.S. energy efficiency and develop alternative energy sources,” said committee chair Michael Ramage, retired executive vice president at ExxonMobil Research and Engineering, Moorestown, N.J.

Some highlights from their press release are:
• Today, 10 percent of natural gas is imported and the percentage is increasing. Thus, while natural gas is the most cost-effective source of hydrogen for the long run, its long-term use as a source of hydrogen would not increase U.S. energy independence.
• Although positive about DOE leadership, the DOE has tried to establish activities in too many areas.
• The DOE should increase research in more exploratory work in such areas as distributed hydrogen production systems, hydrogen storage and solar energy for hydrogen production.
• The DOE’s program success will be greatly increased if the DOE partners with a broader range of academic and industrial organizations.
• The DOE program should accelerate development and early evaluation of carbon capture and storage technologies and further investigate production methods that do not result in emissions, such as wind, the sun and nuclear heat processes.

For more information, see website, http://national-academies.org.

Fuel Cells/Materials

Fujitsu Laboratories develops new material technology. The company has developed new fuel cell material technology which enables the use of 30 percent methanol as a fuel source as well as a prototype power unit that incorporates the technology. The technology comprises an aromatic hydrocarbon solid electrolyte material covered with a high density of highly active platinum-based nanoparticle catalyst with methanol blocking properties.

California Institute of Technology builds new fuel cell that uses a solid acid-electrolyte which can use either hydrogen or methanol as a fuel. The new phosphate-based electrolyte material has possible advantages over the current polymer solid electrolytes; some advances are the ability to produce electricity at temperatures over 100°C and less chance of fuel leakage. To keep the material from dehydrating, the solid acid electrolyte must have enough water vapor pressure - approximately 10 percent relative humidity. Possibilities exist that some day, this technology would be used to power cars.

Fuel Cells Solid Oxide

Current Global Market for Solid Oxide Fuel Cells (SOFCs) is $123 Million.

North American Market = $76 Million
Global Market Outside North America = $47 Million

Over half of the global market for solid oxide fuel cells is in North America.

Miscellaneous/Automotive/Transportation

SunLine Transit in Cochella Valley, California shifts gears from striving to become a world leader in alternative-fuel research to improving bus service.

For the past several years, SunLine Transit has received various grants to offer alternative transportation to the Valley residents. It was one of the first transit agencies to receive a Ballard-powered fuel cell bus and had a number of transport vehicles powered by hydrogen as well as natural gas.

But, changes are taking place because for the past several months, “auditors have been poring over management and financial practices at the agency and making recommendations for improvement.” (Quote from “SunLine reshuffles priorities,” by Kimberly Trone, The Desert Sun, 01/29.04, p.1 Section B). Both SunLine’s General Manager, Richard Cromwell III, and chief financial officer, William Mair, resigned in August amid disclosures of conflict of interest and financial management.” According to the article in The Desert Sun there is evidence transit funding had been shifted to non-transit expenses and that contracts had been made without board approval.
This past year, China surpassed Japan as the No. 2 petroleum user after the U.S. In an article, “China’s Huge Thirst for Oil Set to Change World Energy Flows,” Sydney Morning Herald, 12/03/03, the statement is made that China’s purchases are an important reason the Organization of Petroleum Exporting Countries has been able to keep the cost of a barrel of oil at or above $30 US a barrel for much of this year. Data in this graph is based on expectations of the International Energy Agency. (BD note: An important question to ask is - “What will China’s rise as a leading buyer of oil mean in the future for prices and availability?)

Photovoltaics/Business

Astropower files for bankruptcy in early February 2003. The company has also reached an agreement to sell “certain” of its U.S. business assets to GE Energy (formerly GE Power Systems). The transaction with GE Energy will be subject to competitive bidding and Bankruptcy Court approval. The company said filing for reorganization under Chapter 11 of the Bankruptcy code of the U.S. is at least partially designed to facilitate the sale of assets of GE Energy.

Sanyo electric Company will double its solar cell production at its plant in Osaka Prefecture in Japan by January 2005. The expansion will make it the second largest solar cell manufacturer in Japan. With Shimane Sanyo Industrial Co., a Sanyo subsidiary, capable of producing 63 megaWatts, the Sanyo Group will be able to increase its annual capacity to 133 megaWatts. Sanyo says it will manufacture the industry’s highest cell conversion efficiency 19.5% in mass production.

Photovoltaics/Manufacturing

Shell Solar and the Fraunhofer Institute for Solar Energy (ISE) address new procedures to improve cell efficiencies and make production of thinner and cheaper cells. Their research work will center on a new dry, plasma etching process to remove the phosphorous glass from the cell surface after diffusion, a process in the past which has been expensive. The new plasma development etching process is intended to incorporate passivation of the cell front and back with nitrogen gas and hydrogen. This passivation method will also permit the use of thinner, cheaper wafers.

Photovoltaics/Efficiency

Konarka Technologies in Lowell, Massachusetts, U.S.A., develops prototypes of its photovoltaic cells that have achieved more than seven percent efficiency. Howard Berke, Chairman, Konarka Technologies, Inc., said, “Konarka is focused on the development and commercialization of cells that are lightweight, flexible and more versatile than previous generations of products. Konarka’s chemistry-based cells represent a new breed of coatable, plastic flexible photovoltaics that can be used in many applications where traditional photovoltaics can’t complete. We have now built functioning, full-size production cells that have achieved close to eight percent efficiency and we expect to exceed 10 percent in the coming months.”

Konarka says it will be the first company to manufacture and commercialize highly efficient, flexible photovoltaics. The company will have pilot-scale production later this year and begin scaling-up production capacity in 2005.

You only get the latest Batteries Digest Newsletter when you request your free monthly subscription to BD as an Acrobat file by email. Just send us an email request to Staff@BatteriesDigest.com. Include your name, position, organization, and phone number. This information will be held in confidence. No junk email will ever be sent nor will the information be sold to others.
Battery research is focusing heavily on lithium chemistries, so much so that one could presume that all portable devices will be powered with Lithium-ion batteries in the future. In many ways, Lithium-ion is superior to nickel and lead-based chemistries and the applications for Lithium-ion batteries are growing as a result.

Lithium-ion has not yet fully matured and is being improved continuously. New metal and chemical combinations are being tried every six months to increase energy density and prolong service life. The improvements in longevity after each change will not be known for a few years.

A Lithium-ion battery provides 300 to 500 discharge/charge cycles. The battery prefers a partial rather than a full discharge. Frequent full discharges should be avoided when possible. Instead, charge the battery more often or use a larger battery. There is no concern of memory when applying unscheduled charges.

Although Lithium-ion is memory-free in terms of performance deterioration, engineers often refer to “digital memory” on batteries with fuel gauges. Short discharges with subsequent recharges do not provide the periodic calibration needed to synchronize the fuel gauge with the battery’s state-of-charge. A deliberate full discharge and recharge every 30 charges corrects this problem. Letting the battery run down to the cut-off point in the equipment will do this. If ignored, the fuel gauge will become increasingly less accurate. (Read more in ‘Choosing the right battery for portable computing’, Part Two.)

Aging of Lithium-ion is an issue that is often ignored. Lithium-based batteries have a lifetime of two to three years. The clock starts ticking as soon as the battery comes off the manufacturing line. The capacity loss manifests itself in increased internal resistance caused by oxidation. Eventually, the cell resistance will reach a point where the pack can no longer deliver the stored energy, although the battery may still contain ample charge.

The speed by which Lithium-ion ages is governed by temperature and state-of-charge. Figure 1 illustrates the capacity loss as a function of these two parameters.

There are no remedies to restore Lithium-ion once worn out. A momentarily improvement in performance is noticeable when heating up the battery but the high internal resistance will revert to its former state with normal temperature.

If possible, store the battery in a cool place at about a 40% state-of-charge. This reserve charge is needed to keep the battery and its protection circuit operational during prolonged storage. The most harmful combination is full charge at high temperature. This is the case when placing a cell phone or spare battery in a hot car. Running a laptop computer on the mains has a similar temperature problem. While the battery is kept fully charged, the inside temperature during operation rises to 45°C (113°F).

In spite of the high operating temperature and the harm inflicted to the battery during the use in a laptop, removing the battery when running on fixed power poses some risk to the laptop and manufacturers caution against it. There are issues of dust and moisture accumulating inside the battery casing that could cause damage to the unit. By not removing the battery, a replacement may be needed a little sooner but the battery manufacturers and dealers are happy to provide a new pack.

A large number of Lithium-ion batteries for cell phones are being discarded under the warranty return policy. Some failed batteries are sent to service centers or the manufacturer, where they are refurbished.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>40% charge level</th>
<th>100% charge level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(recommended storage charge level)</td>
<td>(typical user charge level)</td>
</tr>
<tr>
<td>0°C</td>
<td>98% after 1 year</td>
<td>94% after 1 year</td>
</tr>
<tr>
<td>25°C</td>
<td>96% after 1 year</td>
<td>80% after 1 year</td>
</tr>
<tr>
<td>40°C</td>
<td>85% after 1 year</td>
<td>65% after 1 year</td>
</tr>
<tr>
<td>60°C</td>
<td>75% after 1 year</td>
<td>60% after 3 months</td>
</tr>
</tbody>
</table>

**Figure 1:** Permanent capacity loss of Lithium-ion as a function of temperature and charge level. High charge levels and elevated temperatures hasten permanent capacity loss. Improvements in chemistry have increased the storage performance of Lithium-ion batteries. +
Studies show that 80-90% of the returned batteries can be repaired and returned to service.

Some Lithium-ion batteries fail due to excessive low discharge. If discharged below 2.5 Volts per cell, the internal safety circuit opens and the battery appears dead. A charge with the original charger is no longer possible. The Cadex battery analyzers feature a boost function that reactivates the protection circuit of a failed battery and enables a recharge. However, if the cell Voltage has fallen below 1.5V/cell and has remained in that state for a few days, a recharge should be avoided because of safety concerns. To prevent failure, never store the battery fully discharged. Apply some charge before storage, and then charge fully before use.

Simple Guidelines
- Avoid frequent full discharges; recharge lithium-ion more often. Repetitive random charge does not harm the battery.
- There is no memory.
- Although memory-free, apply a deliberate full discharge once every 30 charges to calibrate batteries with fuel gauge. Running down the battery in the equipment does this. If ignored, the fuel gauge will become increasingly less accurate.
- Keep the Lithium-ion battery cool but do not freeze. Avoid a hot car. For prolonged storage, keep the battery at a 40% charge level.
- Do not remove the battery from a laptop even though fixed power is used. Operating without a battery can inflict harm to the laptop.

Avoid purchasing spare Lithium-ion batteries for later use. Observe manufacturing date. Do not buy old stock, even if sold at clearance prices.

BD

MEETINGS

See the Meetings page of www.BatteriesDigest for more information

April
- **Environmental & Energy Symposium**
  April 5-7, 2004
  San Diego Convention Center Sails Pavilion
  Sponsored by the National Defense Industrial Association
  [www.ndia.org](http://www.ndia.org)
  *NESEA Tour De sol*
  For details contact Nancy Hazard at nhazard@nesea.org

May
- **Battery Council International**
  116th Convention
  May 2-5, 2003
  Renaissance Esmeralda Hotel
  Palm Springs, California
  Tel: 1-312-644-6610
  Fax: 1-312-321-6869

Battery Council International sponsors an annual meeting to promote higher standards of quality, technical and environmental awareness in the Lead acid battery industry worldwide. BCI’s 116 Convention is designed to provide a forum for discussion on the latest advances and concerns for the battery industry.

Phone: 312-644-6610  Fax: 312-527-6640
E-Mail: ann_noll@sba.com
[www.batterycouncil.org](http://www.batterycouncil.org)

June
- **41st Power Sources Conference**
  June 14-17, 2004

July
- **SOLAR 2004**
  July 10-14, 2004
  Portland OR
  web site. [www.ases.org](http://www.ases.org)
  Tel: 1-303-443-3130, E-Mail: ASES@ases.org

September
- **Electric Drive Transportation Assn. Conference & Expo.**
  ‘Mobilizing the Market’ will provide a comprehensive and hands-on forum for information exchange, business venture development, and market forecasting and sales for new and emerging battery, hybrid and fuel cell products.
  September 21-23, 2004
  Orlando, FL
  [www.edtaconference.com](http://www.edtaconference.com)

November
- **2004 Fuel Cell Seminar**
  November 1-5, 2004
  San Antonio, TX
  Call for Abstracts due March 8, 2004
  [www.fuelcellseminar.com](http://www.fuelcellseminar.com)
  *
- **NASA Aerospace Battery Workshop**
  Huntsville, AL
  Tel: 1-256-544-3345
  [http://ntf-2.msfc.nasa.gov/battery/nsf](http://ntf-2.msfc.nasa.gov/battery/nsf)
**Ask George about Separators**

**Question:**

I am adding sodium sulfate to my AGM VRLA battery to prevent dendrites. What influence may the addition of sodium sulfate to the sulfuric acid in a VRLA battery have on electrical performance?

**ANSWER:**

The above graph shows laboratory data showing the influence of the addition of sodium sulfate when a microglass separator was tested using a Palico Test Method as outline in the Battery Council Test Methods for Flooded separators. The test determines the electrical resistance of the RBSM separator while in a flooded condition. The above graph is an average change of four different separators, two were 100% glass and two were hybrid-glass separators that are being used in greater percentage for their improved wet strength/durability. As the graph suggests, sodium sulfate will increase electrical resistance of the acid/separator interface.

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