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# Inspira™ — an enabling battery technology for high voltage automotive electrical systems

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**Abstract**

Vehicle manufacturers worldwide are recognizing the need to elevate the electrical system voltage on their product from the present standard of 12 V to a significantly higher, yet safe, voltage. One of the major challenges emerging from the move to higher voltages is the size, weight, volume, cost and complexity of the battery required to support such a system. Inspira™, a valve-regulated, lead–acid, spiral-wound Thin Metal Foil™ battery, provides a small, lightweight, flexible solution to the challenge. 

*Keywords:* Inspira™; Electrical system voltage; Lead–acid batteries

## 1. Introduction

The last major change in vehicle electrical system voltage occurred more than 40 years ago when the universal standard was raised from 6 to 12 V. In the intervening period, the vehicle electrical system has developed from a simple series of electromechanical devices to an extremely complex array of electrical and electronic components, all of which require electrical energy to operate. The total electrical load demand in North American vehicles of varying feature content as a function of model year is shown in Fig. 1. When the vehicle's engine is running, the alternator is designed to supply the bulk of the electrical requirements, however, the role of the battery has gradually been expanded from the traditional starting, lighting, ignition (SLI) function to include load leveling and standby power functions.

Vehicle designers worldwide reacting to the constant demand for additional feature content as well as enhanced emission control, safety and fuel economy are concluding that the time is right for another step-function change in vehicle electrical system voltage. Rather than doubling the system voltage to 24 V, the consensus among vehicle developers is to elevate the voltage to the maximum safe level resulting in a system voltage of 42 V and a battery voltage of 36 V [1].

While the high voltage electrical system will present opportunities for reducing the size and weight of components, thereby enhancing fuel economy or CAFE rankings, it will also permit engineers to completely redesign the vehicle electrical and electronic system architecture. Power-sapping, belt-driven loads such as air conditioners, water pumps and power steering will become electrical appliances that will operated only on demand and advanced electronic technologies such as steer-by-wire, brake-by-wire and mobile office — only a dream with the 12 V electrical system, will become realities with the high voltage system. In addition, the promising emission-lowering, electrically-heated catalytic converter and automatic engine stop at idle for fuel economy and emission control become much more feasible with elevated system voltage. Not all components on a vehicle demonstrate enhanced efficiency at elevated voltages — light bulbs and computers, in particular, actually prefer lower voltages — and as a result, multiple voltages must be provided to optimize the performance of the entire system.

A systems approach is vital to the successful conversion to the high voltage vehicle. Existing as well as new components must be carefully optimized to gain the maximum advantage of the change. Many of the current components must be completely redesigned and optimized as a

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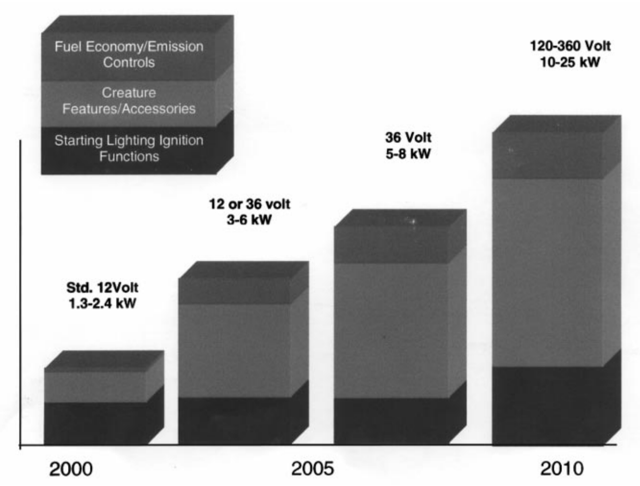


Fig. 1. Vehicle electrical power demand trend.

part of the new system. One such component is the venerable lead–acid 12 V storage battery.

The lead–acid battery has been in existence for over 100 years and the 12-V vehicle electrical system architecture has been a standard for more than 40 years. The performance and life of the battery have been significantly enhanced through innovation over time to its present state; however, a direct extrapolation of this technology would result in an unacceptably bulky, heavy and expensive compromised device with limited capability in such important characteristics as rapid rechargeability (charge acceptance) and packaging flexibility.

## 2. The architecture

Options for battery and electrical system architecture for high or multi-voltage vehicles have been proposed by several authors [2,3]. The two most prominently mentioned battery strategies are: (a) a single, universal 36-V battery that meets all of the vehicle's electrical demands, and (b) a dual battery system that combines a specially designed 36-V low impedance battery for high power applications including starting and a 12-V capacity battery optimized for capacity and cycling.

While opportunities exist to enhance the performance per unit weight or volume in designing a universal 36-V lead–acid battery (ultra thin plates, etc.), the resulting product would still likely be a heavy, bulky, expensive compromise possessing less-than-optimum performance characteristics.

The dual battery option gives the battery designer multiple degrees of freedom in optimizing each of the two batteries for its specific assignment. The 12-V high capacity battery can be a reasonable extension of today's automotive battery but designed for capacity and cycling rather than engine cranking. The 36-V power source, however, must embody significant technological innovation to meet the stringent size, weight performance and cost objectives.

## 3. Electrochemical system

Several technologies, which are newer and more exotic than lead–acid, i.e. lithium ion, nickel metal hydride, super capacitors, etc., have been advanced as the electrochemical system of choice for future high/multi-voltage vehicle power sources. However, in addition to being maturing technologies, each has one or more drawbacks, i.e. cost, operating temperature constraints, standloss, safety, etc., which must be overcome to make them viable candidates.

Traditional lead–acid battery technology likewise suffers some significant shortcomings. However, recent advances — particularly those in valve-regulated, lead–acid (VRLA) designs [2,4] — have made this well-established technology the leading short-term candidate for both halves of the vehicle's dual battery system.

In addition to being a mature yet optimizable technology, the infrastructure for manufacturing and recycling lead–acid batteries is in place. The cost, performance, dependability and life of the product have been clearly documented. The 12-V high capacity support battery can either be of the conventional flooded or the generally more expensive VRLA flat plate design, depending on cost/benefit analysis and location on the vehicle. The product should be designed for maximum capacity and deep cycling capabilities.

## 4. High voltage power source

The biggest challenge presented to battery designers by the high/multi-voltage system is the design and manufacture of a 36-V power supply optimized for cranking power with little or no weight or volume penalty when compared with today's 12-V automotive battery. One promising technology that lends itself to this demanding application is the Inspira™ battery system under development at Johnson Controls (JCI) [4,5]. A 12-V Inspira™ battery is shown in Fig. 2.


Fig. 2. 12 V, 6.5 A h Inspira™ Load 'n Lock tray assembly.

The Inspira™ technology combines the positive attributes of lead–acid (specifically VRLA) electrochemistry with spiral-wound Thin Metal Foil™ construction to yield a lightweight, low volume, 36-V battery with excellent cranking power capability combined with packaging flexibility and the potential of snap-on/snap-out termination.

## 5. Inside the Inspira™ technology system

The Inspira™ battery utilizes proven lead–acid chemistry, drawing on construction techniques that would be found in other energy storage devices ranging from capacitors to nickel–cadmium or nickel metal hydride cells. It is in this reference that Inspira™ technology is dramatically set apart from other lead–acid batteries. Looking beneath the outside shell will help illustrate the construction differences.

A sectional view of the Inspira™ battery is shown in Fig. 3. Similar to traditional automotive lead–acid batteries, the Inspira™ battery uses a series connection of six 2-V cells. However, this is where the similarity ends. The design utilizes patented spirally-wound Thin Metal Film™ electrodes, which provides extremely high power capability. This power advantage is developed from a highly compressed cell design and very short current paths to minimize IR drop at high rates of discharge.

Each cell uses one long strip of thin lead foil, on the order of 0.003–0.005 in. thick. A thin coating of lead oxide is applied to form both the positive and negative electrodes. A strip of absorptive glass mat separator is added in between, and the materials are wound at a high speed to form a structure similar to that of a jellyroll as shown in Fig. 4. The distance formed between the electrodes is about 25% of a separator found in a conventional flooded SLI battery.

The edge of the electrode strip is offset, producing a continuous contact point for the dual top/bottom intercell connectors as shown in Fig. 5. The path for current collection, therefore, becomes much shorter than what is found in discrete plate/tab traditional designs (20–100 × less), and is critical to harnessing the power developed over the large electrode to electrode surface area, which is up to 20 × that of a conventional SLI battery.

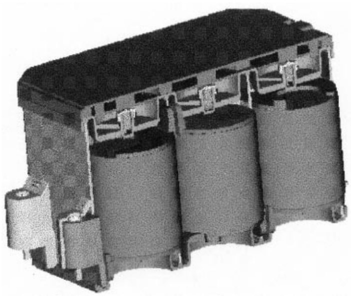

Fig. 3. Sectional view of 12-V Inspira™ battery.

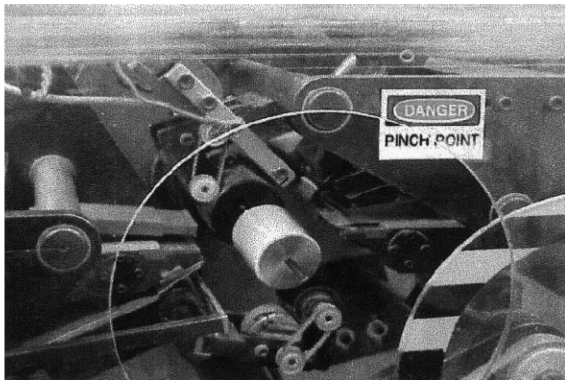


Fig. 4. View of components wound to form a jellyroll assembly.

Each cell is isolated and the venting/vent pressure is controlled through an individual vent seal. Common to most VRLA designs, the venting system allows for one way release of excess gas in the event of an abusive overcharge condition. The design also permits the addition of a secondary cover that collects and channels the off-gas to a single port, making possible the connection of a tube to further isolate the battery.

In short, a VRLA design eliminates much of the off-gassing of hydrogen and oxygen under normal operating conditions as compared to the conventional lead–acid batteries found in today's vehicles. Through the recombination of gases, a closed loop system is formed, which permits the placement of an AGM battery in areas of the vehicle where the build-up of hydrogen would pose a danger.

The overall construction of the Inspira™ is very well suited for future automotive applications. The spiral, compressed cell design provides rugged, vibration resistance for internal components which contain the active material. The battery design also incorporates the integral RADSOK® quick connect terminations as shown in Fig. 6, that allow for easy installation into a specially designed Load 'n Lock snap-in battery tray. The terminals are

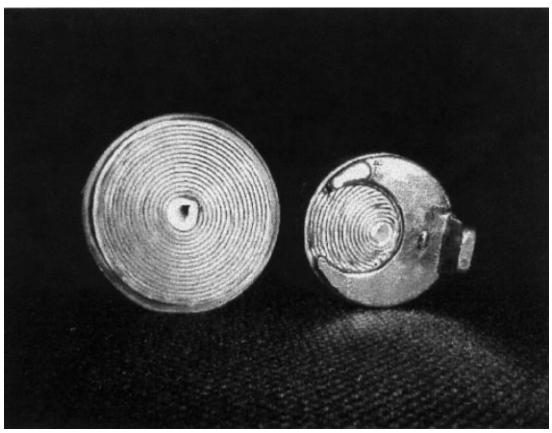

Fig. 5. Wound cell before/after attachment of intercell connector.

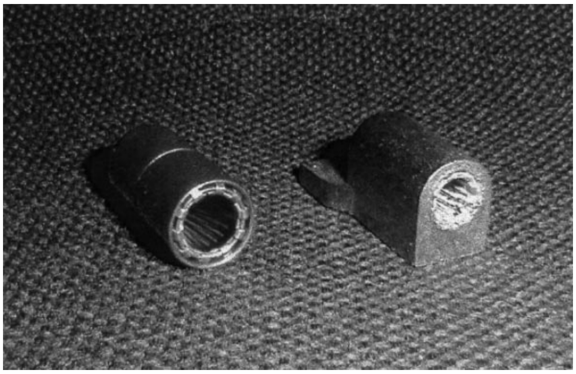

Fig. 6. RADSOK® connector and JCI Load ’n Lock terminal design.

specifically designed for the high-current-carrying capability that would be demanded in a 42 V system.

This new terminal design has been tested and used in other automotive components and has proven to be highly reliable in service, as well as reducing installation complexity for the vehicle assembly plant.

The individual 12-V module can be packaged in a number of ways to meet the needs of the vehicle electrical system. Fig. 7 shows the Inspira™ battery used in a 12-V dual battery system. The advantage of this configuration is the ability to optimize each 12-V battery, enhancing the performance and life of the batteries, and the overall system performance.

Today’s vehicles use a single battery in which the design is compromised to provide both the power for starting and energy for accessories. In dividing the power and energy requirements into separate batteries in a dual system, the Inspira™ battery becomes a smaller, lightweight, high power source, whereas the energy battery can be optimized for low current back-up. The combined system improves upon vehicle weight, system packaging volume, and provides further advantages for the electrical system design. For instance, critical loads such as engine controllers, ignition components, and fuel pumps would see a relatively constant, higher voltage during starting. Engine start performance can be enhanced and components would require less oversizing, taking advantage of the tighter operating voltage range. The Inspira™ battery provides the high power burst, improving engine cranking speed.

Independent lab testing, comparing a conventional starting battery vs. the Inspira™ dual battery system, confirms that in addition to the benefits mentioned above, lowered emissions are also realized as a result of quicker light-off of the catalytic converter. A carbon monoxide emissions reduction of 10–16% was demonstrated over a temperature range of 75–10°F. Southwest Research Institute, an independent testing facility for automotive OEMs, conducted this study. The emissions reduction is made possible as a result of the improvement in performance of the fuel handling and starting components when starting and reserve battery functions are separated.

As we shift to 14/42 V systems, Inspira™ can provide options that are virtually endless because of its small size and configuration versatility [5]. With current sizes that range from 2.4 to 6.5 A h, a system can be matched for a wide range of power requirements. An example of a 36-V battery system for use in a 42-V charging system is shown in Fig. 8.

This represents one simple concept as to how the batteries might be configured, yet many other options need to be considered. For example, the system designer can take advantage of the VRLA attributes and place the batteries on their side or on end since no free electrolyte is present to potentially leak out. The batteries do not need to be placed in one single area and are quite suitable for placement within the passenger compartment, increasing the available space for other under hood components.

The complete 36-V system provides up to nine times more power/mass and five times more power/volume than a traditional 12-V lead–acid battery. In addition to the Inspira™ batteries, JCI has developed state diagrams and a

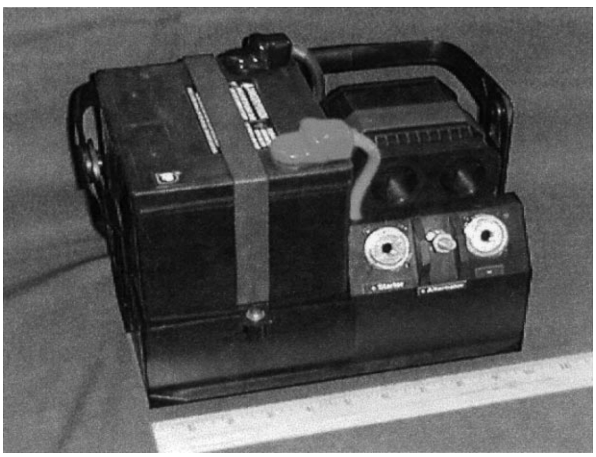

Fig. 7. 12-V dual-battery system.

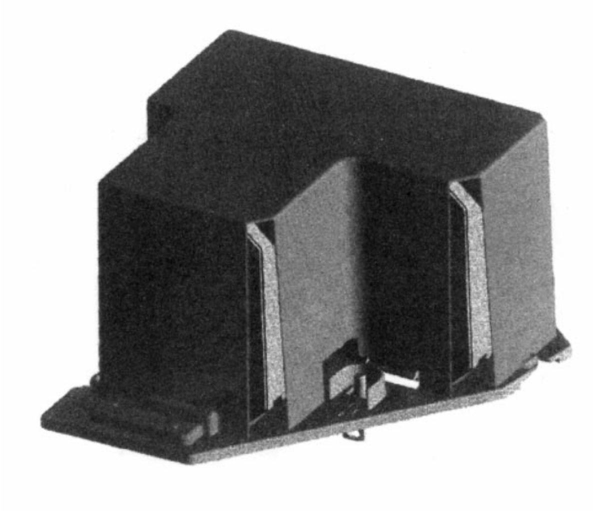

Fig. 8. Inspira™ 36-V “T” design.

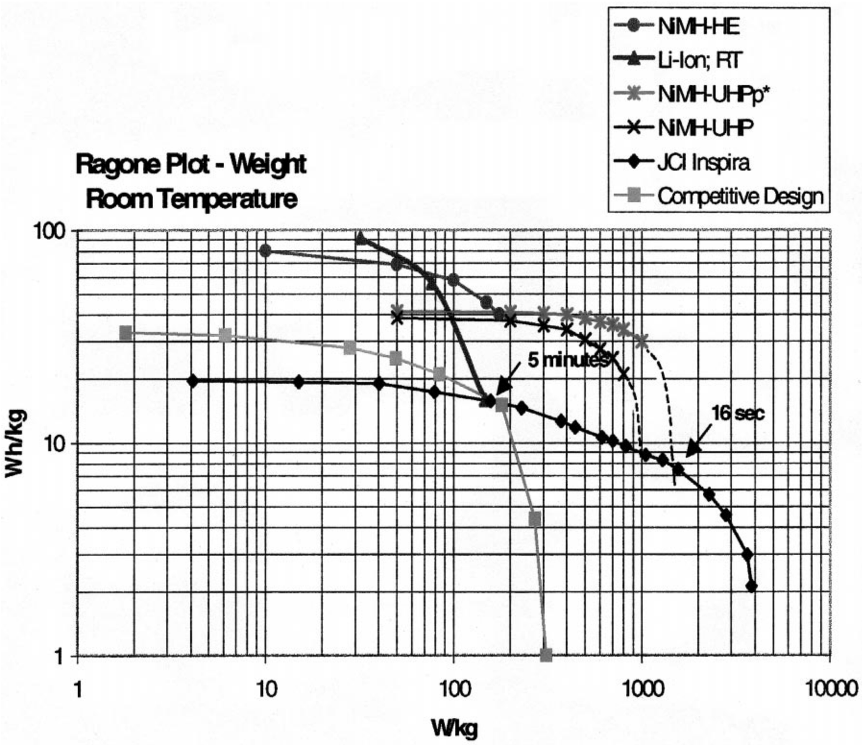


Fig. 9. Ragone plot — weight, room temperature.

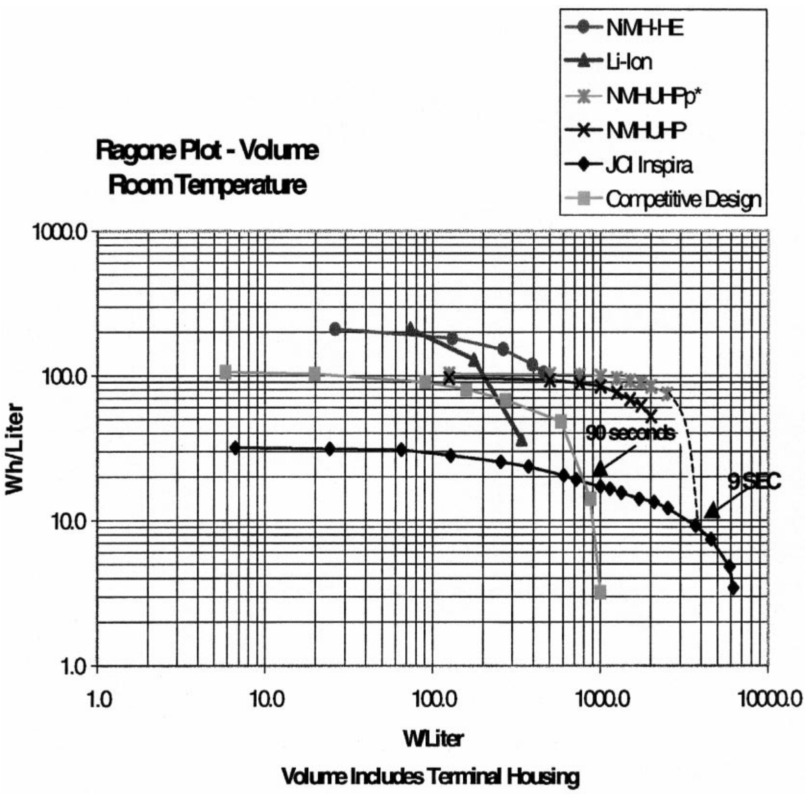


Fig. 10. Ragone plot — volume, room temperature.

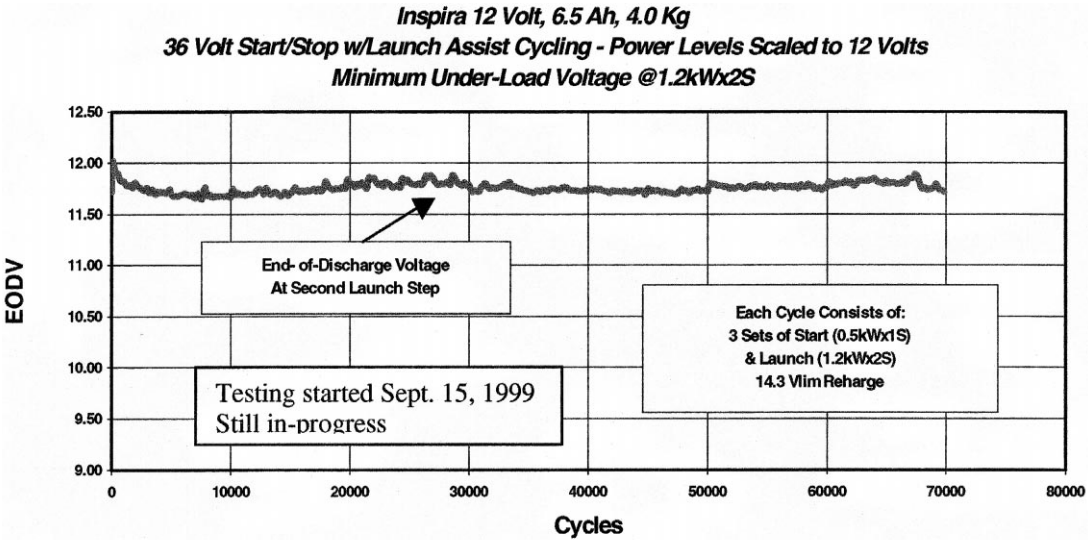


Fig. 11. 36-V start–stop test.

software program for the 14/42 V system that is embedded into the motor controller processor. The processor can include charge control and state of health information for both starting and reserve batteries.

## 6. Performance

To emphasize the advantage of Inspira™ in applications of increasing power requirements, a comparison was made between traditional lead–acid and several other more exotic technologies for power requirements ranging from 2 to 90 s. Shown in Figs. 9 and 10, Inspira™ is three to ten times more powerful compared to conventional lead–acid technology.

In addition to boasting exceptional performance of up to 7.8 kW peak power in the 6.5 A h size, both field trials and laboratory tests have yielded impressive cycle life results.

Fleet testing of Inspira™ system technology has been extensive. Over 3,200,000 cumulative test-vehicle miles to date have been logged on vehicles ranging from continuous-use limousines in the northern United States, to the extreme heat of taxis found in Las Vegas. With no available fleets of 14/42 V vehicles, the testing has been limited to the conventional 14-V charging system with Inspira™ dual battery systems installed.

Several fleet vehicles have exceeded 70,000 miles. With three separate taxi-cab fleets active in the southwest using JCI's fourth-generation electronic control module, one is exhibiting over 60,000 miles to date. The electronic module monitors the state-of-charge of the Inspira™ battery and precisely controls the amount of recharge energy in order to maximize battery life.

Emerging advanced power trains, including stop/start profiles, will require hundreds of thousands of cycles from the battery. Bench test data from Inspira™ testing at JCI show encouraging results. Referring to Fig. 11, a total of 70,000 cycles have been accumulated to date on a simulated start–stop launch assist profile. It is estimated that 300,000 cycles would be equivalent to 10 years of driving an average vehicle.

## 7. Conclusion

Among the significant challenges facing vehicle electrical system designers with the advent of high voltage systems is the definition of the on-board power sources (batteries). The combination of traditional lead–acid chemistry with innovative thin film, spiral-wound construction yields a small, lightweight, high power "Inspira™" packaging capable of performing the demanding 36-V starting and support function. When the Inspira™ package is combined with a more conventional 12-V battery optimized for capacity and cycling, the result is a reliable, high-performance, manufacturable, recyclable power source for vehicles of the future.

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