

# High-power and High-energy Lithium Secondary Batteries for Electric Vehicles

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*OVERVIEW: Hitachi Group has long promoted the development of total technical solutions, in addition to individual products, such as motors, inverters, and batteries, with the objective of being a total solution partner in electric powertrain systems. Based on our extensive experience and achievements in battery systems for vehicles and industrial instruments, Hitachi Group is now active in the development of lithium secondary batteries, including their power source systems which are favorites for electric powertrains. To date, we have commercialized lithium secondary batteries; 1) for HEV (hybrid electric vehicles) with high I/O (input/output) properties; 2) for EV (electric vehicles) with capacities as high as 90 Ah; and, 3) for light vehicles that can accommodate both high output performances and high energy densities.*

## INTRODUCTION

DUE to worldwide concerns about environmental issues and the depletion of our natural resources, there has been an increased demand for automobiles with lower emissions and lower fuel consumption. This has resulted in a race to develop more sustainably, EVs (electric vehicles) and FCEVs (fuel-cell electric vehicles). HEVs (hybrid electric vehicles) that have both an engine and motor as power sources are already on the consumer market, and have obtained excellent fuel efficiency ratings that cannot be realized in vehicles with only an engine powertrain. Motor scooters with rechargeable batteries that can tap into home power supplies have also become popular.

These electric powertrains need secondary batteries that can be charged and discharged frequently. Hitachi

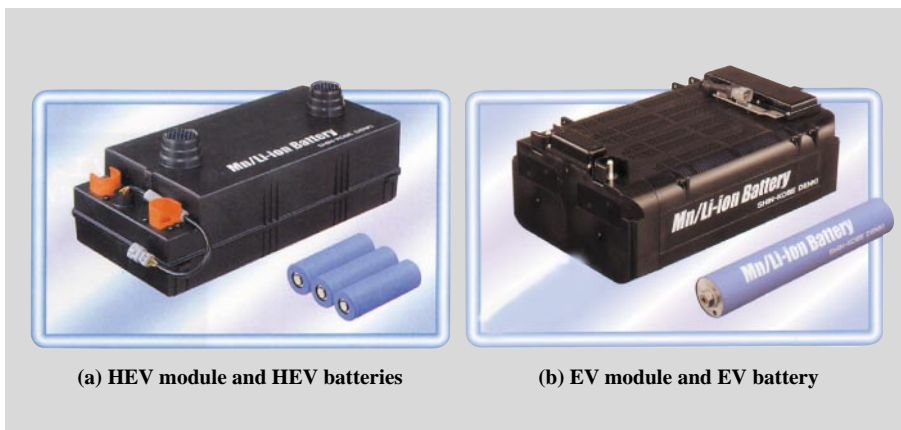
Group chose a lithium secondary battery as the most practical battery for these applications. We have developed and commercialized lithium secondary batteries for EVs, HEVs (see Fig.1), and light vehicles.

This paper describes the properties, characteristics, and applications for Hitachi Group's lithium secondary batteries.

## PRINCIPLES AND CHARACTERISTICS OF LITHIUM SECONDARY BATTERIES

### Cell Structure and Principles

Lithium secondary batteries consist of positive electrodes, made with lithium metal oxides, negative electrodes, made with carbon materials, electrolytes, composed of organic solvents and lithium salts, and separators (see Fig. 2). Lithium secondary batteries



*Fig. 1—Lithium Secondary Batteries for HEVs and Battery Modules Developed by Hitachi Group. Lithium secondary batteries for HEVs feature high I/O (input/output) and those for EVs feature high energy. Both have practical driving applications and are mounted in a vehicle.*

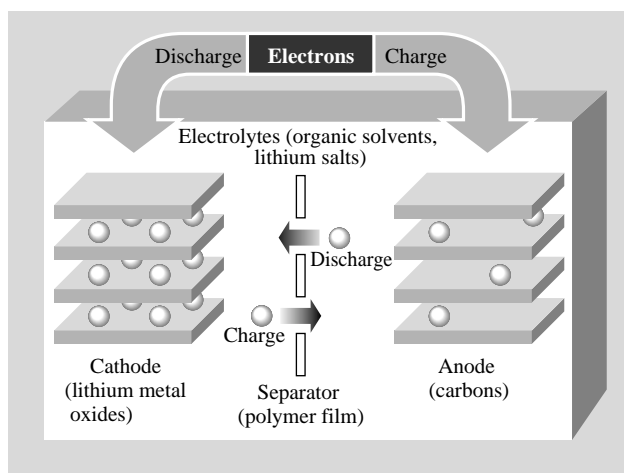


Fig. 2—Cell Structure and Principles of Lithium Secondary Battery.

The charge and discharge cycles are achieved through the exchange of lithium ions between the positive and negative electrodes.

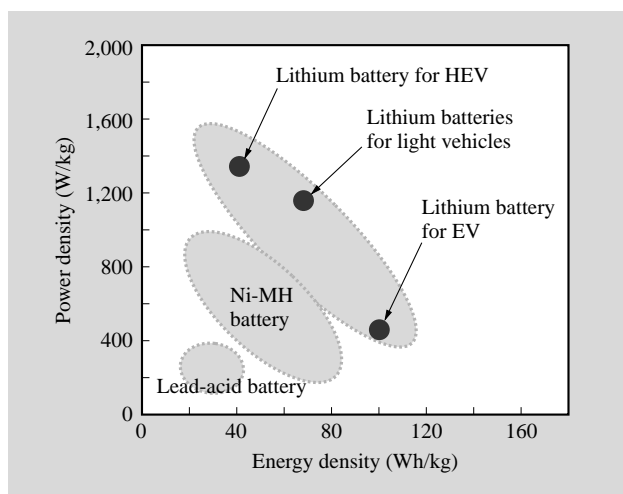


Fig. 3—Characteristics of Lithium Secondary Batteries. Comparison to other batteries and characteristics of Hitachi's lithium secondary batteries for vehicle applications are shown.

are charged and discharged by releasing and adopting lithium ions, a process that does not involve any harmful chemical reactions. Therefore lithium secondary batteries are highly reliable, have long life cycles, and are highly efficient. Furthermore, we can expect more improvements in their performance by developing new electrodes and electrolyte materials<sup>1)</sup>.

### Types and Characteristics of Lithium Secondary Batteries for Vehicles

Lithium has the lowest electric potential of all other elements. This allows lithium secondary batteries to have the highest operating voltages among existing

TABLE 1. Specifications and Performance of Lithium Secondary Battery Module for HEVs and EVs

High power and high voltage battery modules are preferred for HEV applications, and EV applications require large capacity modules with high energy density.

Item		HEV	EV
Dimension	mm	260 × 541 × 160	290 × 440 × 186
Weight	kg	20.2	29.3
Rated voltage	V	173	30
Capacity	Ah	3.6	90
Energy	Wh/kg	—	93
Power	W/kg	1,350 <sup>a</sup>	350 <sup>b</sup>

a: DOD 50%

b: DOD 85%

DOD: depth of discharge; shows the battery's state of discharge, 0% indicates a fully-charged state.

batteries and higher specific energy and power than lead acid batteries and Ni-MH (nickel-metal hydride) batteries (see Fig. 3).

Hitachi Group has commercialized lithium secondary batteries for various applications by selecting relatively safe materials and adapting the cell design (see Fig. 3). The HEV system requires high-power properties for regeneration and engine assist to improve fuel efficiency and reduce exhaust gases. The EV system needs high energy to improve the driving distances on one charge. The electric motor scooter system needs high energy and high power to get longer driving distances and good acceleration.

### LITHIUM SECONDARY BATTERIES FOR VEHICLES

#### Lithium Secondary Batteries for HEV

Because HEV modules require high voltage, 48 units of 3.6 volt-per-cell lithium secondary batteries are connected in a series and compactly packaged to generate a total of 173 volts per module (see Table 1). This module is 541 mm (W), 260 mm (L), and 160 mm (H). Its volume is about 22 liters and it weighs about 20 kg, including the control circuit and wiring system. This module generates 1,350 W/kg output power.

The HEV module has six CCs (cell-controllers) that control eight individual series-connected cells as one unit. These CCs monitor the voltage, temperature, etc., for each battery, and send signals to the master battery control system (see Fig. 4). The control algorithm, which is based on our accumulated technology and experience in lead-acid batteries for vehicles, and on

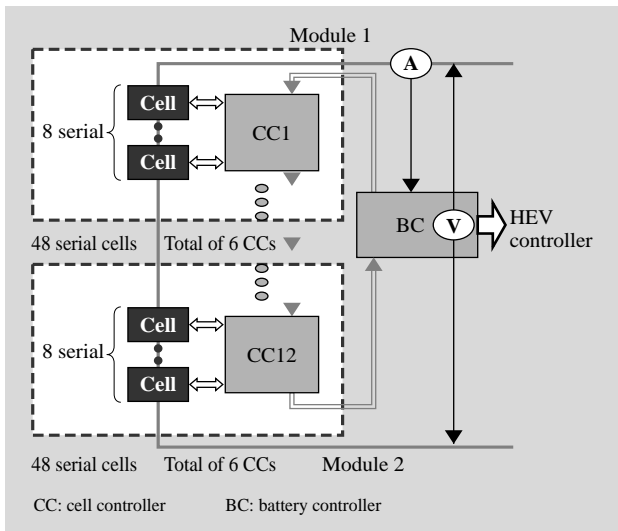


Fig. 4—Characteristics of Lithium Batteries and Product Positioning.

It shows the characteristics and product positioning of lithium secondary batteries, developed by Hitachi Group for vehicles.

our research into materials for lithium secondary batteries, is highly reliable.

### Lithium Secondary Batteries for EV

As the EV module requires high capacity, batteries with capacities as high as 90 Ah are employed. This module consists of eight individual series-connected EV batteries and a control circuit, designed to generate about 30 V (see Table 1). This module is 440 mm (W), 290 mm (L), and 186 mm (H). Its volume is about 23 liters and it weighs about 29 kg including the control circuit and wiring system. This module also has more than four years of practical driving experience mounted on the EV.

The EV module has been examined for use in other applications, such as industrial machines and two-person golf carts, and some of these are already commercially available.

### Lithium Secondary Batteries for Light Vehicles

The lithium secondary batteries for light vehicles that were developed for electric motor scooters, have a capacity of 7 Ah and a specific energy of 74 Wh/kg, higher than those of HEV batteries. Furthermore, their output density is 1,200 W/kg, higher than that of EV batteries. These batteries were adapted for Yamaha Motor Co., Ltd.'s electric motor scooter, and feature a detachable module with a weight of 5.9 kg<sup>2</sup>) (see Fig. 5).

This module consists of seven series-connected



Fig. 5—Lithium Battery Module for Light Vehicles (a) and Yamaha Motor Co., Ltd.'s Electric Motor Scooter (b). This compact sized module with 26 V and 14 Ah can power this light vehicle run at around 30 km. The module can be charged to 80% in one hour with a specially developed battery charger operated by 100-V AC supply.



Fig. 6—New Lithium Battery Module for HEV. Newly-developed high-performance lithium secondary batteries have been adapted to the battery module and have obtained a 30% volume reduction (Exhibited as display sample in 2003 37th Tokyo Motor show).

units of lithium secondary batteries for light vehicles, arranged in parallel, and designed to generate 26 V. It is 95 mm (W), 147 mm (L), and 370 mm (H). Its volume is about 5 liters. This module also can be charged using a 100-V home power source, by using a special battery charger. Mounting this module allows the scooter to drive about 30-km per charge.

### New Lithium Secondary Batteries Module for HEV

In response to the strong demand for a smaller, lighter, and higher output battery module, Hitachi Group has been working on higher-performance lithium secondary batteries. For HEVs, new lithium secondary batteries have been developed, that increased the I/O density and capacity density by 1.5 times, compared to conventional batteries. The low-temperature performance of these batteries is double

that of conventional batteries, due to the improved electrolytes<sup>3)</sup>. These performance improvements enable a smaller and lighter battery module. We are now developing a new HEV module, using these batteries (see Fig. 6).

## CONCLUSIONS

We discussed high-power and high-energy lithium secondary batteries for electric powertrain sources. Hitachi Group continues to promote high-performance batteries and provide total solutions for electric powertrains, thus contributing to the protection of the environment by preventing global warming.

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