Lithium-ion Battery for HEVs, PHEVs, and EVs

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OVERVIEW: Hitachi Vehicle Energy, Ltd. commenced the full-scale production of lithium-ion batteries for hybrid vehicles in 2005. As of the end of 2012, its cumulative sales of battery packs was sufficient to supply approximately 80,000 vehicles. In addition to commencing the production of generation-3.5 battery packs in July 2013, the company is also working on the development of new generations of technology in anticipation of significant growth in the market for xEVs. By meeting customer needs with technologies for high reliability as well as other advanced technologies that it has built up through involvement in the market, Hitachi is working to reduce exhaust emissions by encouraging the wider use of xEVs.

INTRODUCTION

ACCORDING to the United Nations, global warming has been occurring faster than ever since 2001. Sea levels are rising at roughly twice their previous rate, and the number of deaths associated with heat waves has increased approximately 20-fold. There are also parts of the world where atmospheric pollution, as measured in terms of the particulate matter 2.5[*1] (PM2.5) concentration, is becoming more severe. Vehicle exhaust gas is one of the major causes of these environmental problems. The number of vehicles is set to continue increasing in future, particularly in emerging economies. For these reasons, it is no exaggeration to say that reducing the load that vehicles place on the environment is a major global challenge.

MARKET ENVIRONMENT AND PAST INVOLVEMENT

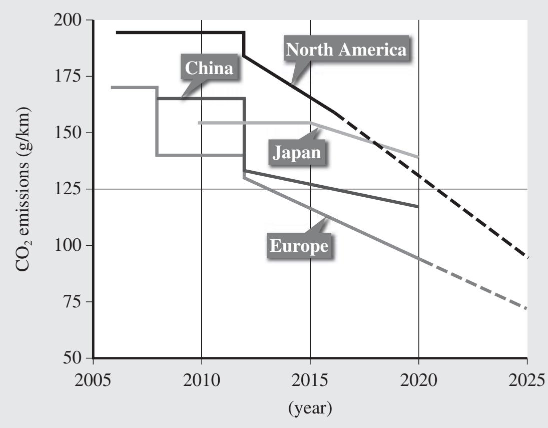
Market Forecasts for xEVs

As environmental awareness grows, countries are tightening their regulations pertaining exhaust emissions (see Fig. 1). Europe has set a target of reducing the amount of carbon dioxide (CO_2) emitted per kilometer driven from 130 g at present to 95 g in 2020. This is not a target that can be achieved solely by improving the fuel efficiency of gasoline engines, and will require the full-scale introduction of electrically powered vehicles such as hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and electric vehicles (EVs). Meanwhile, market forecasts for the sales of electrically powered vehicles continue to be revised downward.

Having forecast in 2012 that the market for electrically powered vehicles would reach 13 million in 2020, Fuji Keizai Co., Ltd. has now reduced this figure to 9.6 million. The main reasons for the change include a poorer outlook for sales of EVs and PHEVs, and concerns such as the short range of EVs and lack of charging facilities. Despite this, strong growth is still forecast for HEVs, with the market expected to grow four-fold between 2012 and 2020 to 7 million vehicles.

Past Involvement by Hitachi Vehicle Energy, Ltd.

Hitachi Vehicle Energy, Ltd. led the world by commercializing a lithium-ion battery for vehicles in 1999. Its total sales to date are approximately 4.2 million cells, enough for about 80,000 vehicles.



Source: Prepared from government regulations.

CO_2: carbon dioxide

Fig. 1—Trends in Regulations Exhaust Gas.
The graph shows the expected levels of permitted emissions in different markets up to 2025.

*1 Particles with a size of 2.5 µm or less (1 µm = one-thousandth of a millimeter) suspended in the atmosphere.

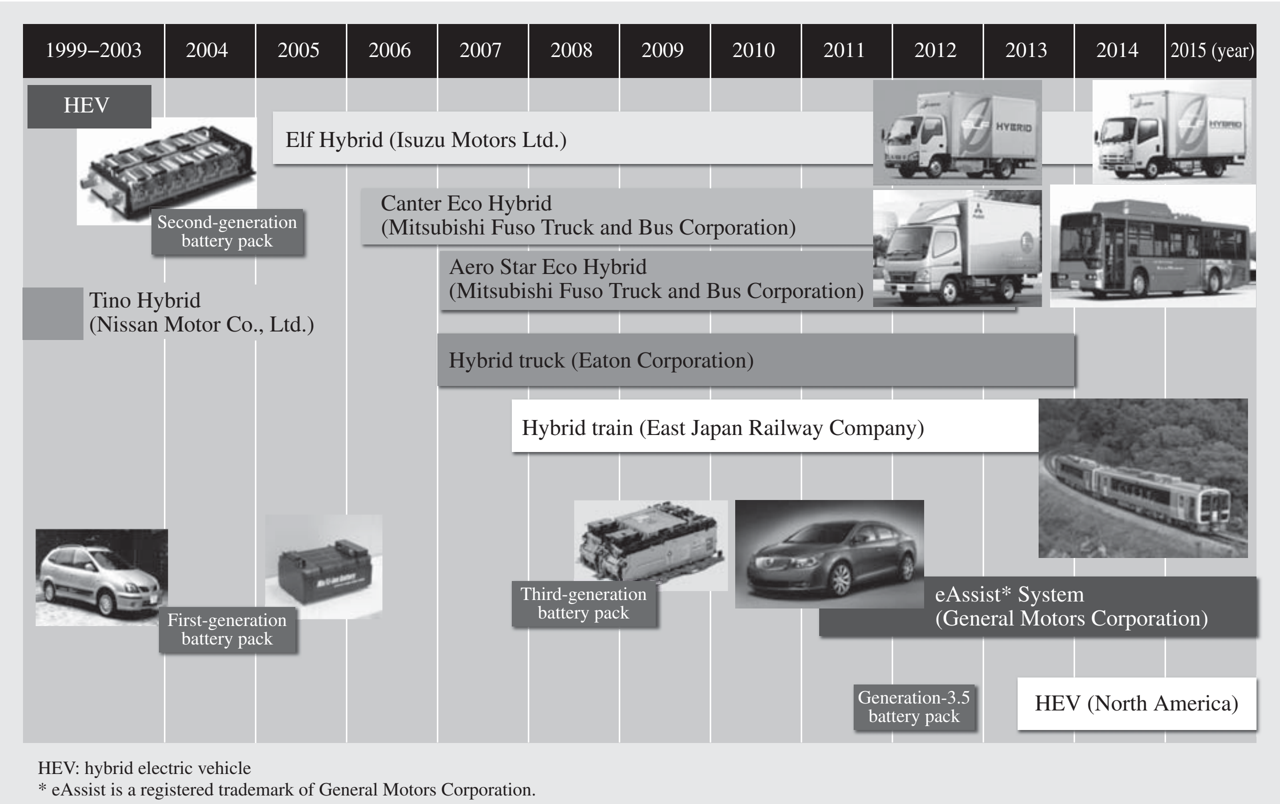


Fig. 2—Use of Hitachi Lithium-ion Batteries in Electric Vehicles.
These are the main examples of vehicles that have used products from Hitachi Vehicle Energy, Ltd. between 1999 and the present day.

Its second-generation battery packs are widely used in applications such as commercial vehicles and hybrid trains operated by the East Japan Railway Company. Its third-generation battery packs are used in HEVs made by the General Motors Corporation, with a total of more than 65,000 units shipped to date. Based on the quality and safety that are underpinned by these many years in the market, Hitachi commenced production of generation-3.5 battery packs in July 2013 (see Fig. 2).

DEVELOPMENT OF GENERATION-3.5 BATTERY PACKS

Hitachi has developed a generation-3.5 battery pack for use in cars supplied to the North American market in 2013. The functions of the battery packs include providing power assist during acceleration and when starting the engine, and regeneration during deceleration and braking.

The batteries are produced at the Kentucky plant of Hitachi Automotive Systems Americas, Inc.

Battery Pack Design

The generation-3.5 battery pack is supplied in a box housing that includes battery modules made up of cylindrical cells, a battery management system (BMS), a junction box used for electrical switching of the heavy current circuits, and a manually operated service disconnection switch for physically isolating the heavy current circuits. Fig. 3 shows the design of the battery pack.

The three battery modules are connected together by a wire harness. Table 1 lists the main battery pack specifications.

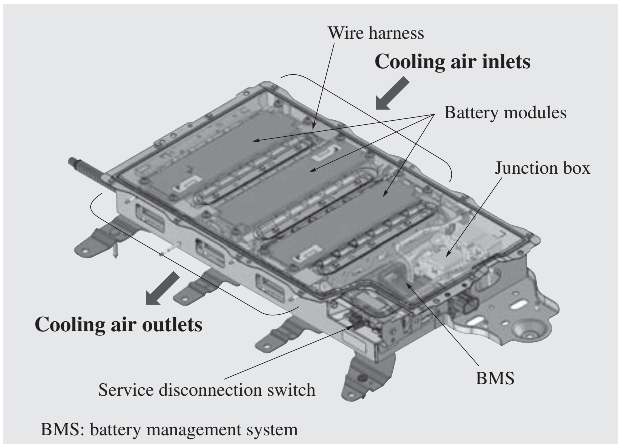


Fig. 3—Battery Pack Components.
The new battery pack includes battery modules and a BMS, junction box, and service disconnection switch.

Table 1. Main Battery Pack Specifications
These are the specifications of the generation-3.5 battery pack.

Parameter	Specification	Remarks
Energy capacity	634 Wh	
Capacity	4.4 Ah	
Voltage	144 V	50% SOC
Input power	19 kW	25°C, 50% SOC, after 10 s
Output power	17 kW	25°C, 50% SOC, after 10 s
Operating temperature	–30°C to +60°C	
Mass	29 kg or less	
Dimensions	744 (W) × 427 (D) × 93 (H) mm	

SOC: state of charge

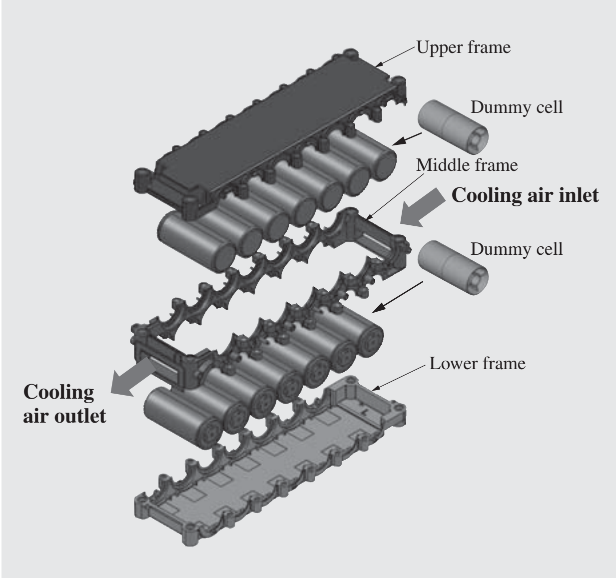


Fig. 4—Module Components.
Based on cooling considerations, the module consists of three frames (upper, middle and lower) and the battery cells.

Battery Module

The battery modules are housed in metal boxes, with 12 to 14 battery cells per module. Fig. 4 shows how the battery module components fit together. The low-profile design sandwiches the battery cells between three plastic frames (upper, middle, and lower), with the upper and lower rows of batteries arranged in a staggered formation to keep the total height down to only about 93 mm. To ensure sufficient cooling, air channels are provided between the battery cells. A battery pack consists of a row of three modules with air channels branching off from the cooling air inlets (see Fig. 3). Also, copper plates are fitted between the battery cells with welded joints connecting the cells together in series.

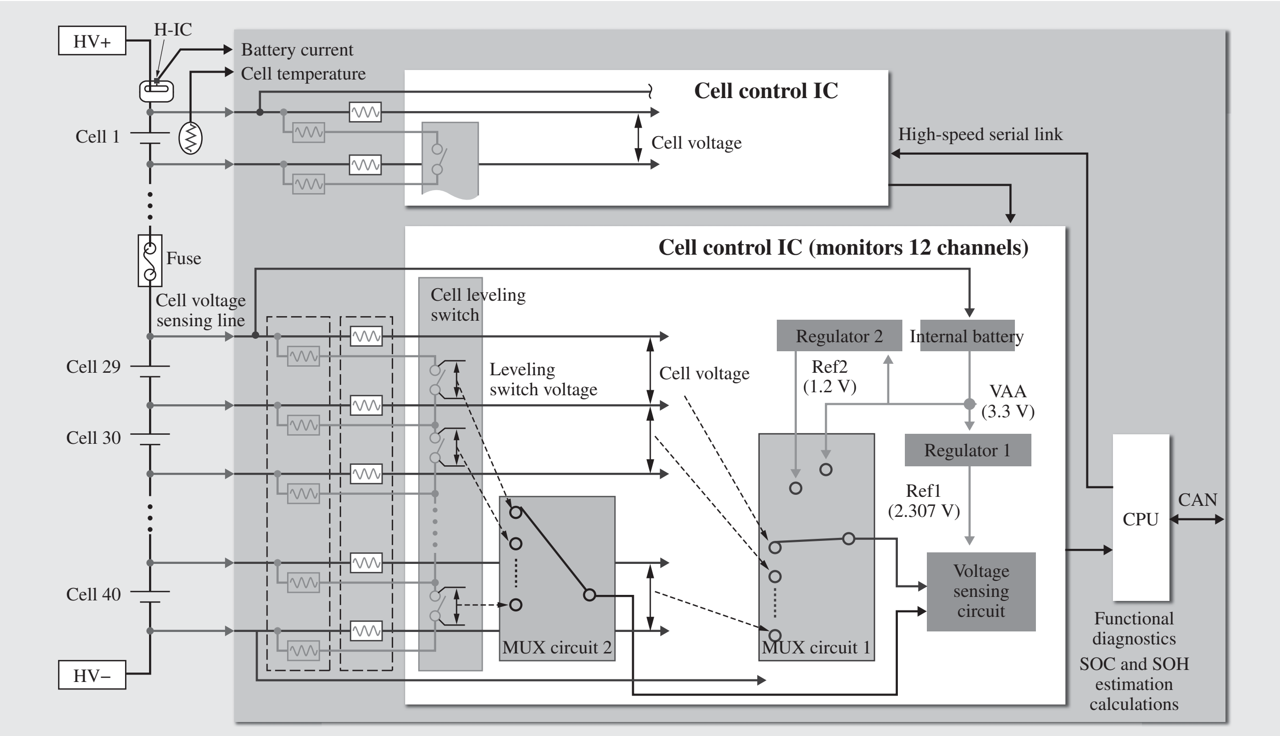


Fig. 5—BMS Block Diagram.
The functions of the BMS consist of monitoring the status of the battery cells, estimating the states of the battery cells, leveling cell voltage, performing diagnostics, and communicating with diagnostic tools.

BMS

The BMS sends information from the battery pack and battery cells to controller in the vehicle via a controller area network (CAN), and controls the battery pack and battery cells based on the commands it receives in response. Fig. 5 shows a block diagram of the BMS. The functions of the BMS consist of monitoring the status of the battery cells (voltage, current, and temperature), monitoring state of charge (SOC) and state of health (SOH) to estimate the states of the battery cells, leveling cell voltage, performing diagnostics, and communicating with diagnostic tools. To comply with Onboard Diagnosis II (OBD-II), a North American standard for self-diagnosis, Hitachi has also developed additional functional diagnostics, including for circuit faults and the rationality diagnosis of measured and estimated signals. Furthermore, Hitachi has developed functions for supporting diagnostic tools. These provide compatibility both with the diagnostic tools used by specific vehicle manufacturers and also the generic scan tool (GST) specified in OBD-II.

Lithium-ion Battery Cells for HEVs

The cylindrical cells used in the generation-3.5 battery packs were designed specifically to deliver both high performance and safety in HEVs, and commenced production in 2011[1]. As a result of this development, the battery packs have also been adopted by new customers who recognized their commercial success in cars.

Cell Assembly Line

With the aim of optimizing its electrode supply chain, Hitachi has constructed a new production facility for cylindrical cells in Oyamazaki Town, Otokuni District, Kyoto Prefecture (see Fig. 6). The achievements of this new battery production line include roughly twice the investment efficiency and half the operating costs of existing lines. The construction of this new production line lifts Hitachi's total capacity for cylindrical cells to more than one million per month and provides competitive and efficient production infrastructure. Drawing on this experience of setting up a manufacturing plant that is geographically separated from the design and development facility, Hitachi intends to expand its operations globally.

Battery Pack Assembly Line

In December 2012, Hitachi built a battery pack assembly line at the Kentucky plant of Hitachi Automotive Systems Americas, Inc. (see Fig. 7). Introduction of the battery packs proceeded on the basis of mutual cooperation between the USA and Japan and involved the initial prototypes being produced in Japan before shifting to North America to start full-scale production with subsequent gradual introduction of locally sourced parts. Following production trials that commenced in January 2013, commercial production started in July. This approach in which a production line was established with a short lead time through mutual cooperation between the USA and Japan will serve as the foundation for the future launch of new products, and also for the site selection of production facilities around the world to fulfill "local production for local consumption" requirements.

BATTERY CELL TECHNOLOGY

This section describes a prismatic cell currently under development for use in the next generation of lithium-ion battery cells.

Fig. 6—New Cell Assembly Line Building.
Artist's impression of cell assembly line building in Oyamazaki Town, Otokuni District, Kyoto Prefecture.

Fig. 7—Battery Pack Assembly Line.
The battery pack assembly line at the Kentucky plant of Hitachi Automotive Systems Americas, Inc.

Parameter	Specification
Size (mm)	120 × 85 × 12.5
Mass (kg)	0.25
Rated capacity (Ah)	5.3
Specific power (W/kg)	3,400
Specific energy (Wh/kg)	76
Positive electrode material	Newly developed manganese-based material
Negative electrode material	Amorphous carbon

Fig. 8—Prismatic Lithium-ion Battery for HEVs.
This prismatic battery for HEVs is designed for higher output.

Development of Lithium-ion Battery Cells for HEVs

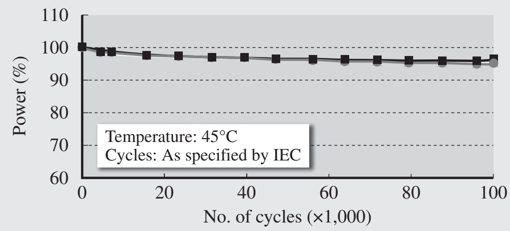
In addition to the cylindrical cells described above, Hitachi has also developed prismatic cells in response to the growing diversity of vehicle types. Hitachi has taken the technologies it has built up through its work on cylindrical cells and applied them to prismatic cells, including the adoption of new materials produced using techniques such as the control of crystal growth for optimized grain design to improve power characteristics in colder climates. Hitachi is also seeking to improve power by using thinner electrodes and other means to reduce reactive resistance. Fig. 8 shows the battery and lists its main specifications. Fig. 9 shows the results of performance testing which indicate that the new prismatic cell has long life and high reliability similar to those of the cylindrical cells, with power still at 95% after 100,000 cycles.

Fig. 10 shows the power at an ambient temperature of –30°C. The low-temperature power is 1.3-fold that of the previous battery used for comparison.

Lithium-ion Battery Cells for PHEVs and EVs

Hitachi is also developing a high-energy prismatic cell for use in PHEVs and EVs. Able to operate in both EV and HEV modes, PHEVs are recognized for their potential to achieve significant improvements in fuel economy and exhaust gas emissions. To power PHEVs, Hitachi is developing a battery cell that combines high energy (for EV mode) and high power (for HEV mode). Although these objectives conflict, a battery design that combines the two can be achieved by adopting a low-resistance structure and optimizing the composition of the active electrode material and the electrode thickness. Fig. 11 shows the battery and lists its specifications. Other measures adopted by Hitachi to ensure that the battery remains safe despite its higher energy capacity include the use of ceramic separators and the development of new electrolyte additives.

Note that, Hitachi Vehicle Energy, Ltd. and Hitachi, Ltd. are participating in the “Advanced Technology Research Project for the Application and Commercial Use of Lithium-ion Batteries” run by the New Energy and Industrial Technology Development Organization (NEDO), and are jointly undertaking some of the development of the next generation of high-energy batteries.



IEC: International Electrotechnical Commission

Fig. 9—Battery Life.
Power remains at 95% after 100,000 cycles.

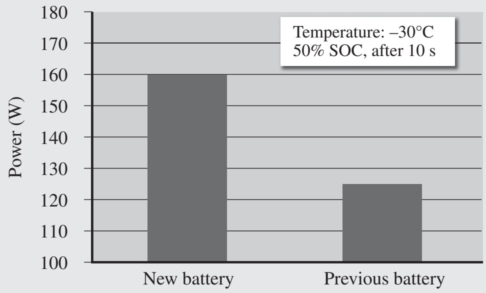


Fig. 10—Power at Low Temperature.
Low-temperature power is 1.3-fold that of the previous battery.

Parameter	Specification
Size (mm)	148 × 91 × 26.5
Mass (kg)	0.72
Specific power (Ah)	28
Specific energy (W/kg)	2,300
Energy density (Wh/kg)	140

Fig. 11—Lithium-ion Battery for PHEVs and EVs.
This prismatic battery for PHEVs and EVs features a high level of safety as well as combining both high energy (for EV mode) and high power (for HEV mode).

CONCLUSIONS

This article has described Hitachi's generation-3.5 battery packs and the newly developed battery control system technologies they incorporate, and also the new generation of high-power cells and high-energy cells currently under development.

Through these next-generation battery cells and battery control system technologies, and also the establishment of production systems designed for global deployment, Hitachi is seeking to pave the way for the wider adoption of electrically powered vehicles and deliver automotive lithium-ion batteries with higher levels of cost-performance.

REFERENCES

(1) "Latest Technologies for Battery and Electric Drive Components," Hitachi Review **60**, pp. 17–21 (Feb. 2011).
(2) S. Takahashi et al., "Lithium Ion Battery and Materials Technology for Low-carbon Society," Hitachi Hyoron **95**, pp. 358–363 (May 2013) in Japanese.

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