Technology Report

# Development Trends and Technological Issues of Rechargeable Batteries for Vehicle Use

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## 1 History of the laws and regulations that have come into effect pertaining to electric vehicles and of the evolution of rechargeable batteries[1)]

The ZEV (Zero Emission Vehicle) mandate, which requires that electric vehicles (EV) be made available for purchase, enacted in September 1990 by the government of the state of California sent shocks throughout the world. The three major auto companies in the United States. at the time that this mandate, which originally contained a requirement that 2% of the vehicles on the road in California in 1998 be EVs, started being enforced were vehemently opposed to the mandate and lobbied to have it overridden.

On the other hand, rather than opposing the enforcement of this mandate, groups in Japan accepted it objectively and started work on setting up research and development systems and development programs. Research and development at Honda, at which the author was previously enrolled, was also started at the Fundamental Technology Research Center, and the author was engaged in the creation of organizations and the establishment of research systems as an individual responsible for the research of batteries.

At the first stage of the initial research and development system, the starting task was to analyze what type of battery from among a wide variety of batteries would be appropriate for use in the EVs to come. While constructing a research and development strategy, we examined lead, nickel metal hydride (Ni-MH), lithium, and sodium-sulfur (NaS) batteries and narrowed down our selection.

In 1991, the predominance of Ni-MH batteries was determined and we also pressed forward with research and development from that of the basic technology of the positive electrode material and negative electrode material. At that time, GM in the United States was developing an EV equipped with a lead-acid battery, but although this gave the EV an attractive low price, the lead-acid battery, with its small energy density of 40 Wh/kg, provided a poor driving range. In addition, the fitness of lithium batteries was at that point in time not yet clearly proven. What's more, there were questions pertaining to the reliability of NaS batteries. From these and a variety of other reasons, we narrowed down our selection to Ni-MH batteries.

From this process, although Ford of the United States and BMW of Germany proceeded with the development of NaS batteries, among the groups in Japan, Honda and Toyota continued development with their eyes set on Ni-MH batteries and Nissan focused on the development of an EV with a lithium-ion battery (LIB).

In 1991, I visited Battery manufacturer A in Germany, who develop and supply NaS batteries. Automotive company B was developing an EV by applying this battery, and I took this EV for a test drive. However, in 1994, this battery caused fires in the test vehicles of both Automotive company B and F at nearly the same time, which proved that NaS batteries were not applicable for use in EVs and led to the termination of development of NaS batteries. The major cause of the fire was the application of the vehicle's vibrations and shocks to the beta-alumina ceramic electrolyte, which was used to separate the melting sulfur of the positive electrode and the sodium of the negative electrode. This led to the ceramic's mechanical strength limit being exceeded, which caused the ceramic to rupture and catch fire.

On the other hand, Automotive company G's EV car, which was equipped with a lead-acid battery, was put on sale, but in 1995, this EV was also involved in fires due to hydrogen leaks from the lead battery. In the end, Automotive company G was also forced to stop selling the EV equipped with a lead-acid battery. Fires, accidents, and recalls attributable to rechargeable batteries for consumer, vehicular, and fixed uses are shown in **Figure 1.**

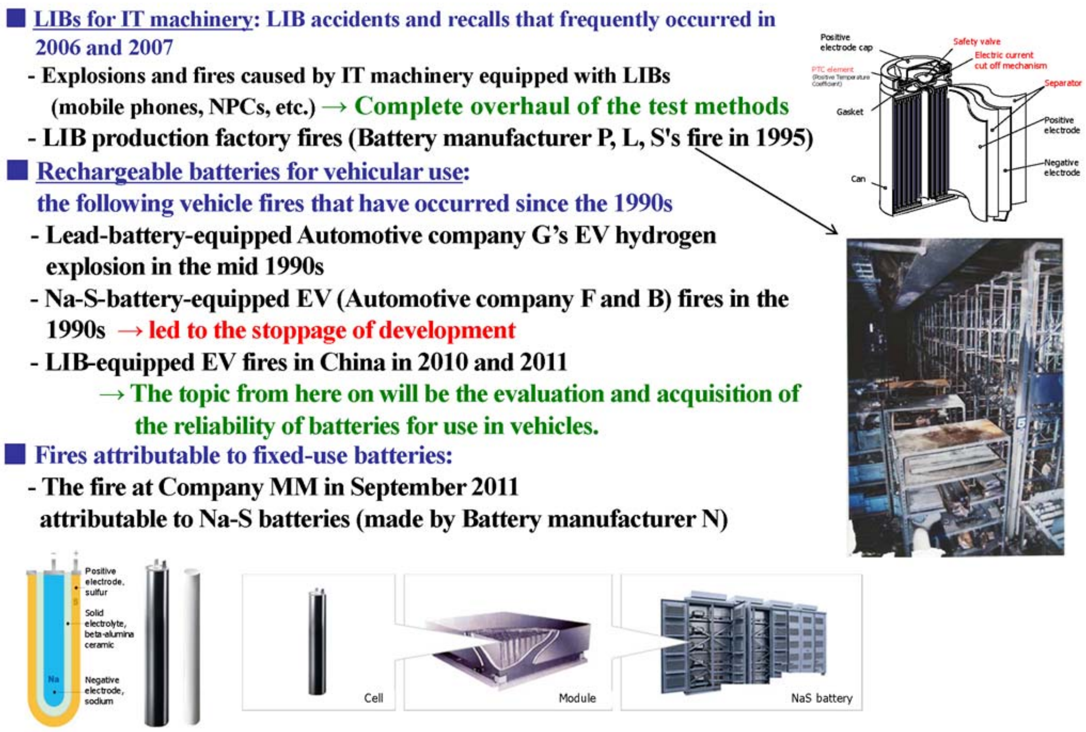


**Figure 1: History of accidents attributable to rechargeable batteries**

Among the situation described above, Honda and Toyota succeeded in making large Ni-MH batteries, built EVs equipped with Ni-MH batteries, and released these vehicles for sale in the United States and Japan in 1997. The Honda EV Plus had an energy retention of 27 kWh and a range of 215 km under various driving patterns.

While the EV Plus was being developed, Honda developed two types of hydrogen storage alloy (which is used for the Ni-MH battery negative electrode): the rare earth system AB5 type and the Laves system AB2 type. However, the hydrogen storage characteristics of the latter led to it being deemed unsuitable for use in EVs, and Honda decided on the rare earth system.

A variety of evaluations have been given to EVs in the United States, but overall, the distinct problems are the limiting cruising range, the long charge time of 8 hours, and the price of batteries. As such, it has been judged that there are limits on the degree to which these vehicles can penetrate the market. The future evolution of current hybrid vehicles (HEV) and plug-in hybrid vehicles (PHEV) is shown in **Figure 2**.

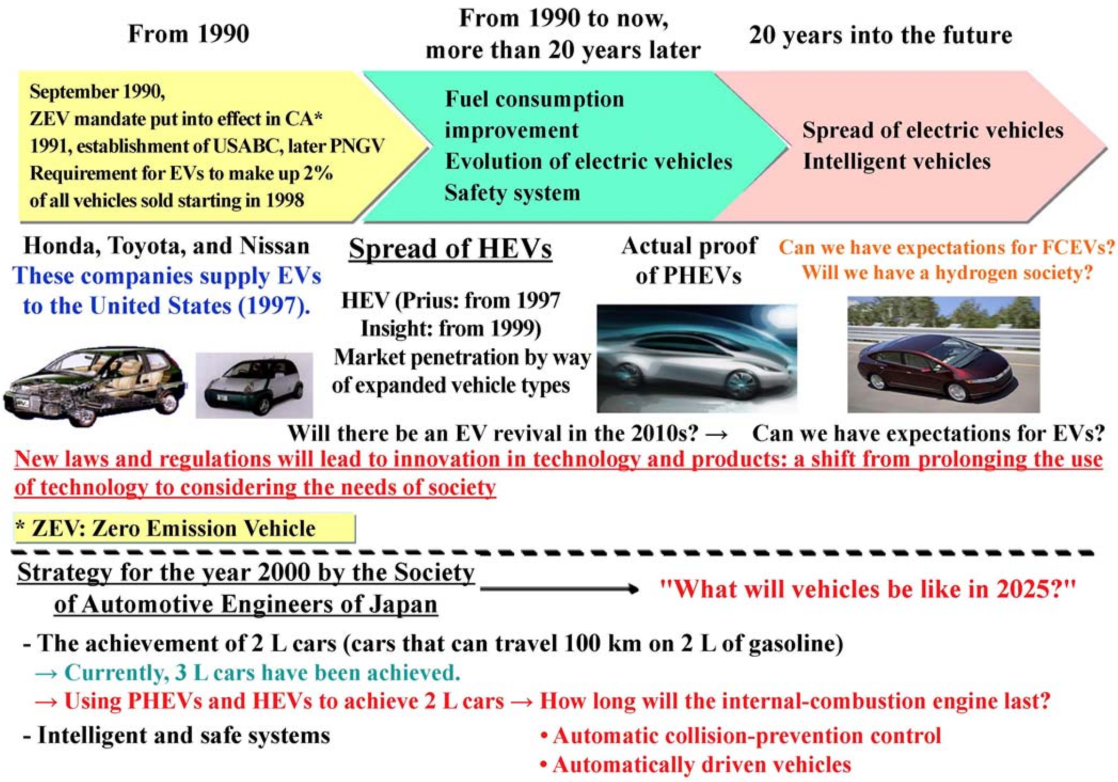


**Figure 2: Changes in the shift to electric vehicles starting from the enforcement of ZEV laws and regulations**

**2. The shift from EVs to HEVs and battery development**

At the time in question, a large number of issues still remained to be solved before EVs could spread in the market of the United States. What's more, the business model for limited-use commuter EVs was incomplete. Eventually, the interest in EVs waned and there was then a paradigm shift to HEVs.

As a result, history was made in 1997 when Toyota released the Prius, the first HEV, to market. Two years later, in 1999, history was made again when Honda released the Insight HEV to market. The technology cultivated in the development of EVs—vehicle technology and battery technology—was unmistakably put to use in these HEVs, and these two companies obtained overwhelming intellectual property rights to HEVs.

More than 15 years have passed since the first introduction of these vehicles, and we have now reached a point in time in which HEVs are completely spread throughout the market. On the basis of current trends, HEVs are forecast to be the mainstream vehicle as of 2020 (**Figure 3**).

On the other hand, interest in EVs has been revived, and it would appear that a new paradigm shift is occurring. The pioneers of this paradigm shift are the i-MiEV, corporate sales of which were started by Mitsubishi Motors Corporation in 2009, and the Leaf, sales of which were started by Nissan Motor Co., Ltd. in the United States in December 2010.

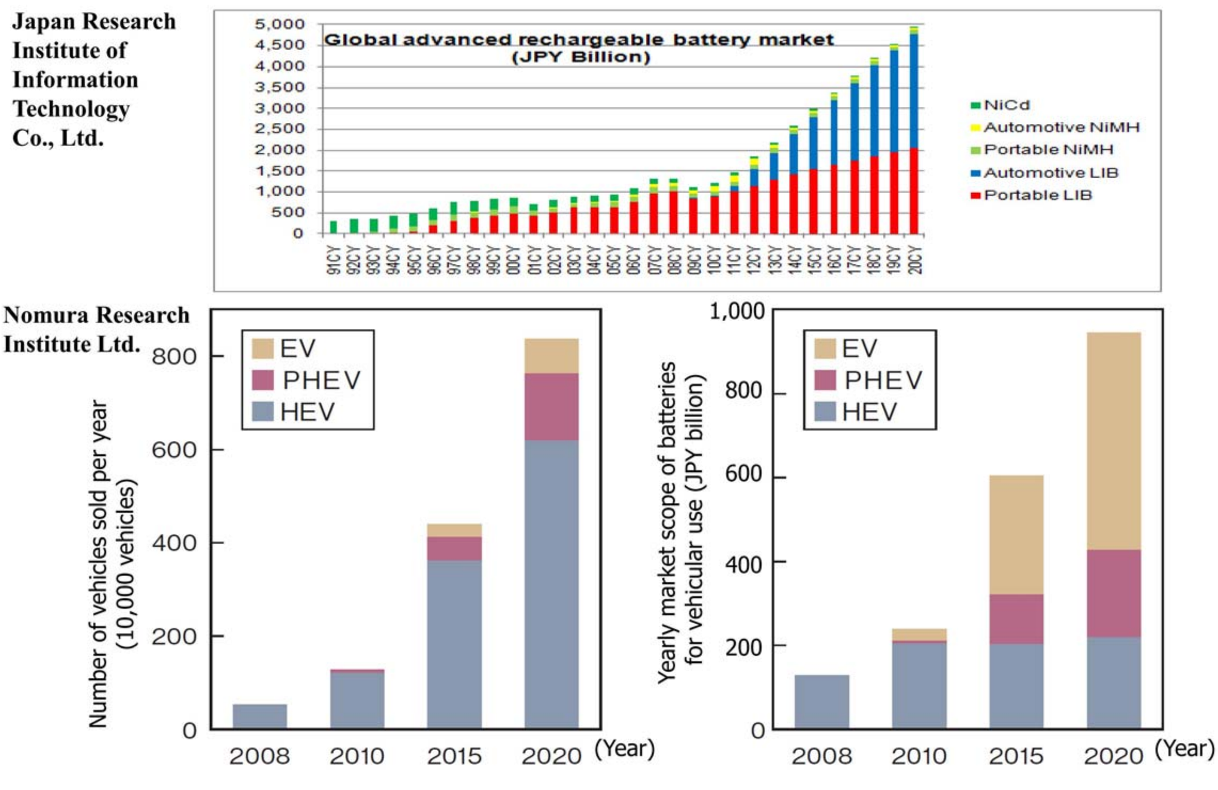


**Figure 3: Market forecasts pertaining to the switch to electrification**

Thereafter, it appeared as if due to the evaluations of these EVs dispatched to the world from Japan, EVs would once again be in the spotlight. However, the market response, both in and outside of Japan, was quite chilly. Toyota and Honda both planned once more to enter the market with EVs starting in 2012, however, this was a measure to clearly differentiate themselves from Mitsubishi and Nissan, who were the driving forces behind the proactive commercialization of EVs, in the support of the ZEV laws and regulations of the state of California.

As shown in **Figure 4**, the improvement of internal-combustion engines, the achievement of clean diesel vehicles, and the switch to powering HEVs and PHEVs with electricity have important roles in the development of low carbon vehicles. Linked with the development of low carbon vehicles is the steady improvement of rechargeable batteries, and progress has been made towards this goal.

Only EVs, fuel cell vehicles (FCEVs), and hydrogen engine vehicles will survive should the fossil fuel economy collapse. As batteries evolve, so too do EVs; rechargeable batteries have to be installed in FCEVs for use in energy regeneration; and there is a high need for hydrogen engine vehicles and hybridization, both of which use rechargeable batteries. All vehicles in the future will require rechargeable batteries, which has made the research and development of rechargeable batteries an important topic on a global scale. Consequently, the achievement of rechargeable battery reliability is a permanent issue.

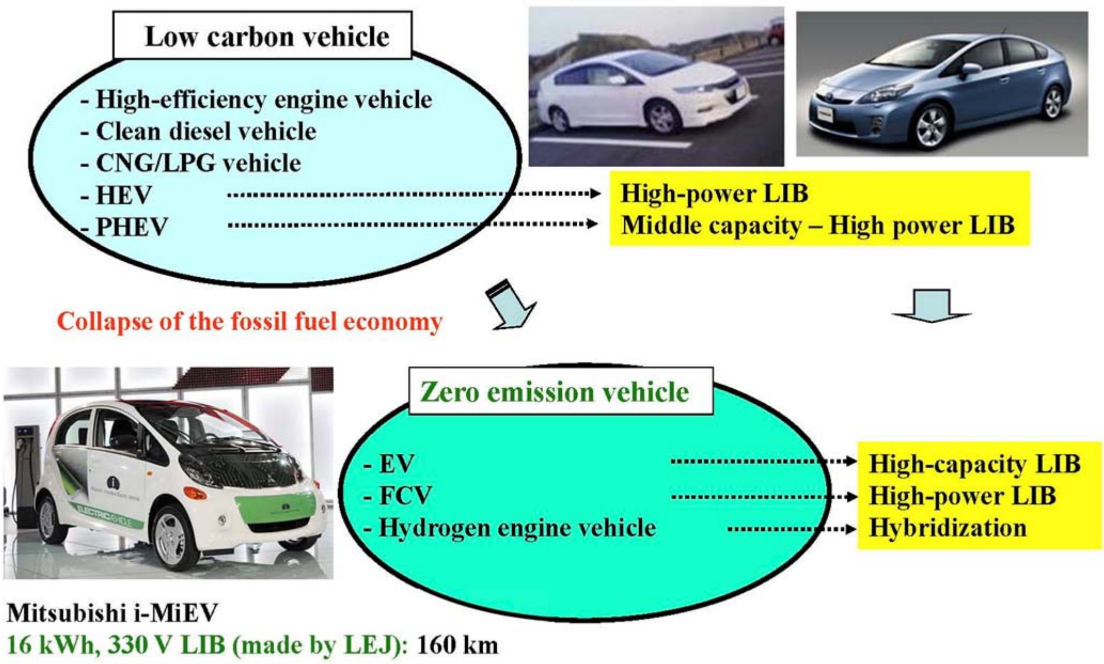


**Figure 4: Evolution of vehicles and the necessity of rechargeable batteries**

**Figure 5** shows the materialization of PHEVs and EVs in Toyota's strategy for switching to electric power, but Toyota is taking an omni directional stance by also bringing HEVs to the fore. Traditionally, Toyota equipped its HEVs with Ni-MH batteries, but the new model Prius $\alpha$ is equipped with an LIB. Toyota has kept the battery capacity low for the Prius Plug-in hybrid, so LIBs have been adopted from the start. What's more, the same LIBs that Toyota has been equipping PHEVs with have been adopted for use in EVs as well. This implies that the reliability and safety of LIBs has improved, but it took a long time to establish this level of reliability and safety.

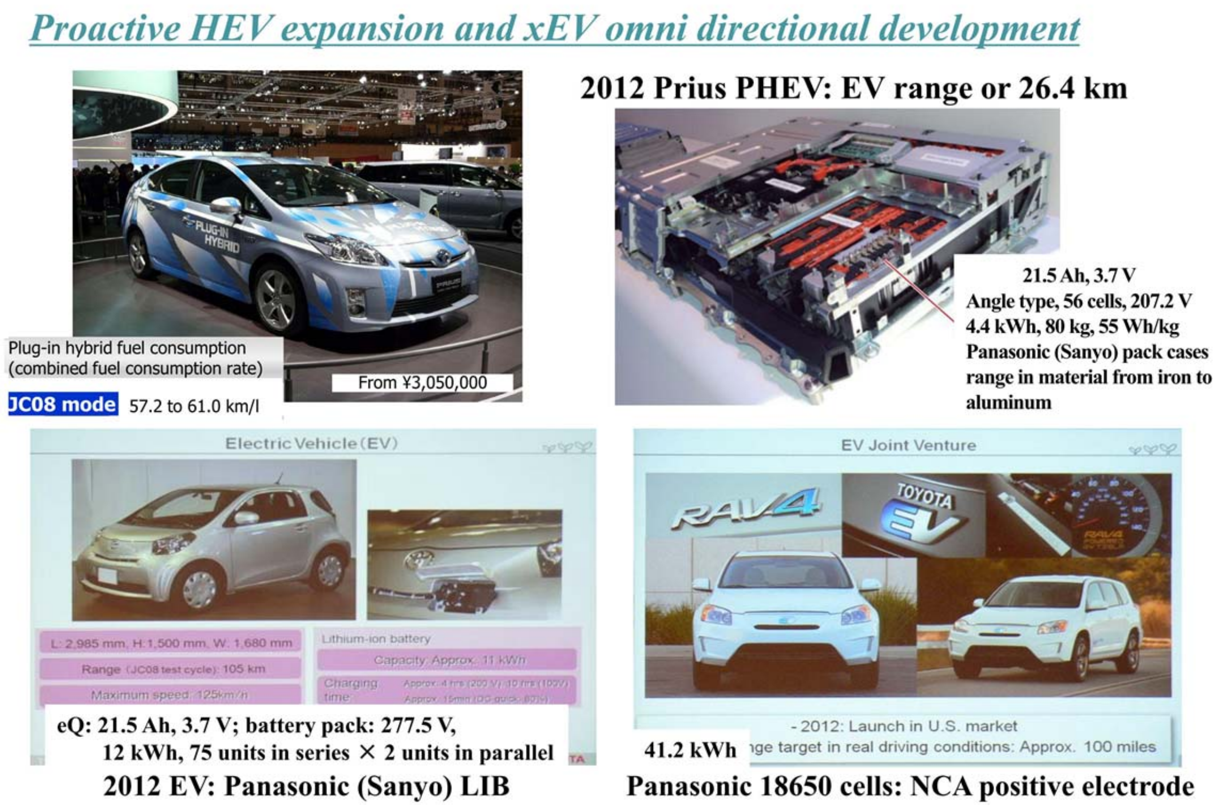


**Figure 5: Toyota's omni directional strategy for switching to electric power**

**Figures 6** and **7** show the strategies for switching to electric power of Honda and Nissan. Honda has an omni directional way of thinking. HEVs are at the core of their strategy, but they are also implementing PHEVs and EVs as one aspect of their support for the environmental laws and regulations. Nissan has settled on a strategy focused on being a pioneer in bringing EVs, of which there are future market expectations, to the world. However, they have also adopted a strategy of releasing to market later-developed HEVs and PHEVs.

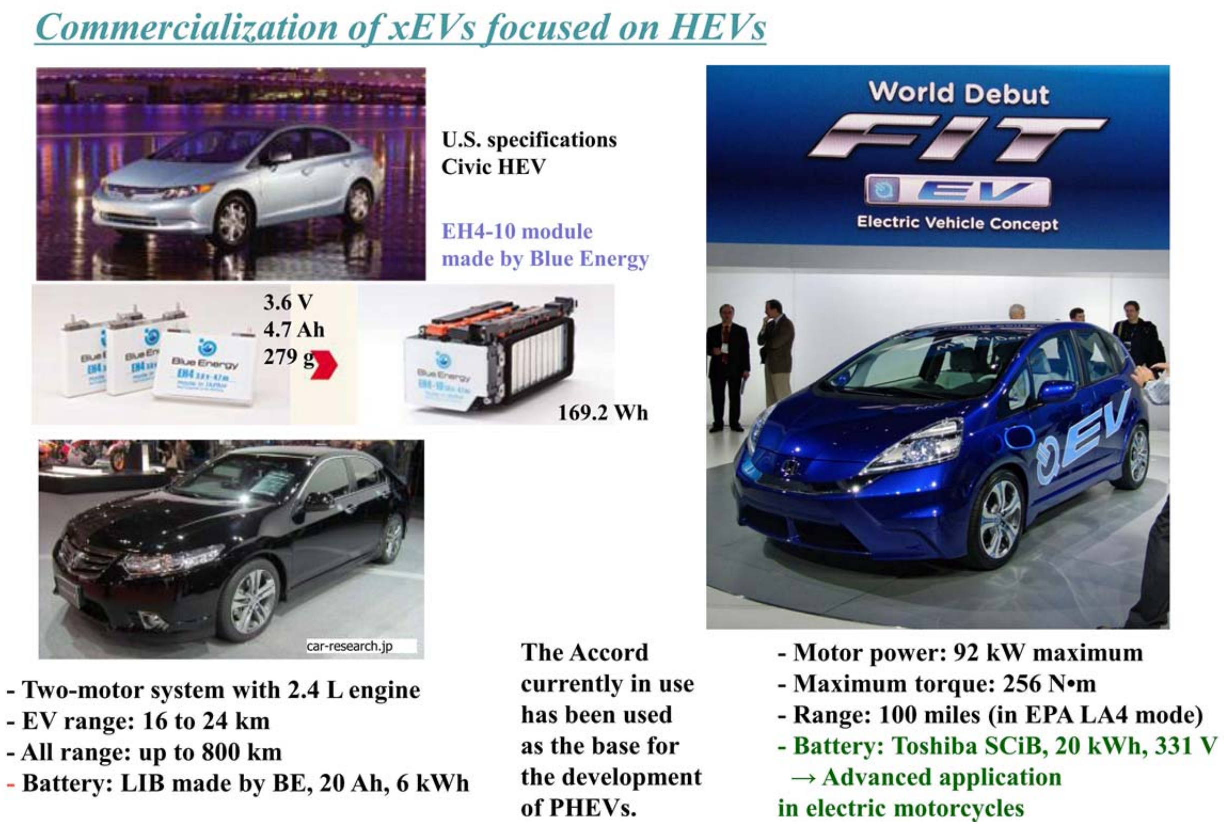


**Figure 6: Honda's strategy for switching to electric power**

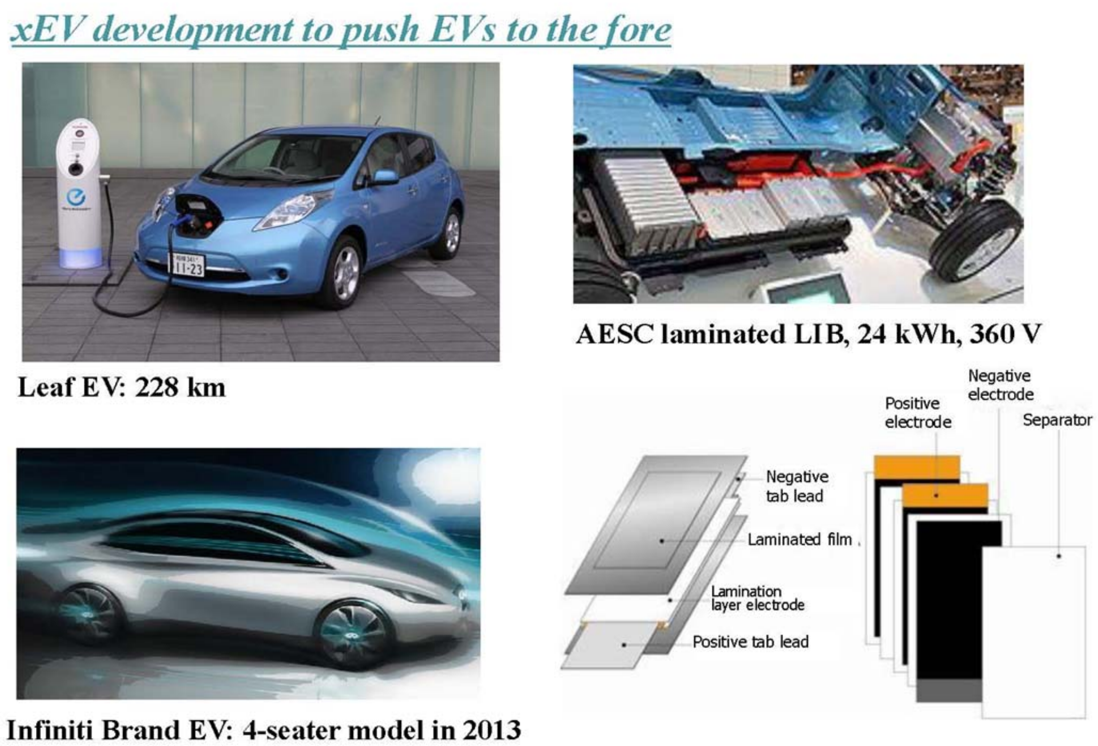


**Figure 7: Nissan's strategy for switching to electric power**

Led by the group of companies in Japan, the wave of companies newly switching to electric power is rising. In addition to the above examples, one other example is Mitsubishi Motors Corporation, who started introducing to the market their Outlander PHEV equipped with an LIB in 2013.

### 3 Establishment of reliability and safety of vehicular batteries

The indispensable aspects of technological development are battery durability and improvements to battery reliability and safety. In the long term, there are great expectations for the research and development of next-generation batteries that surpass the LIBs currently in use. The research and development issues related to battery development are grouped into different categories in **Figure 8**. Amongst these categories, a discussion of safety support is shown in **Figure 9**.

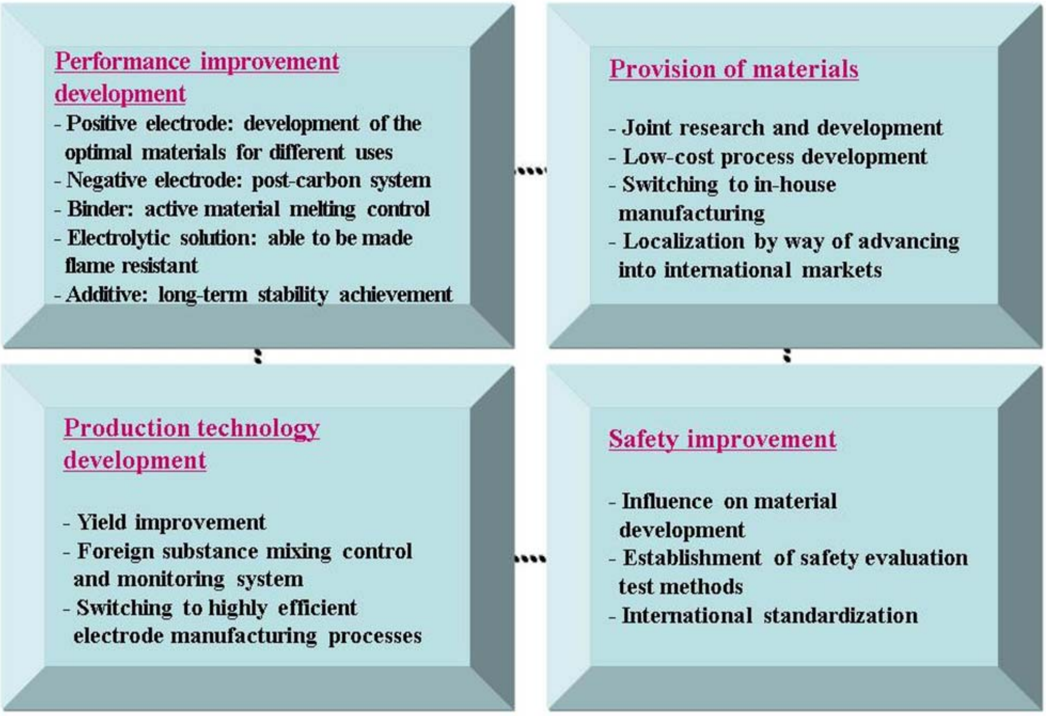


**Figure 8: Research and development issues related to battery development**

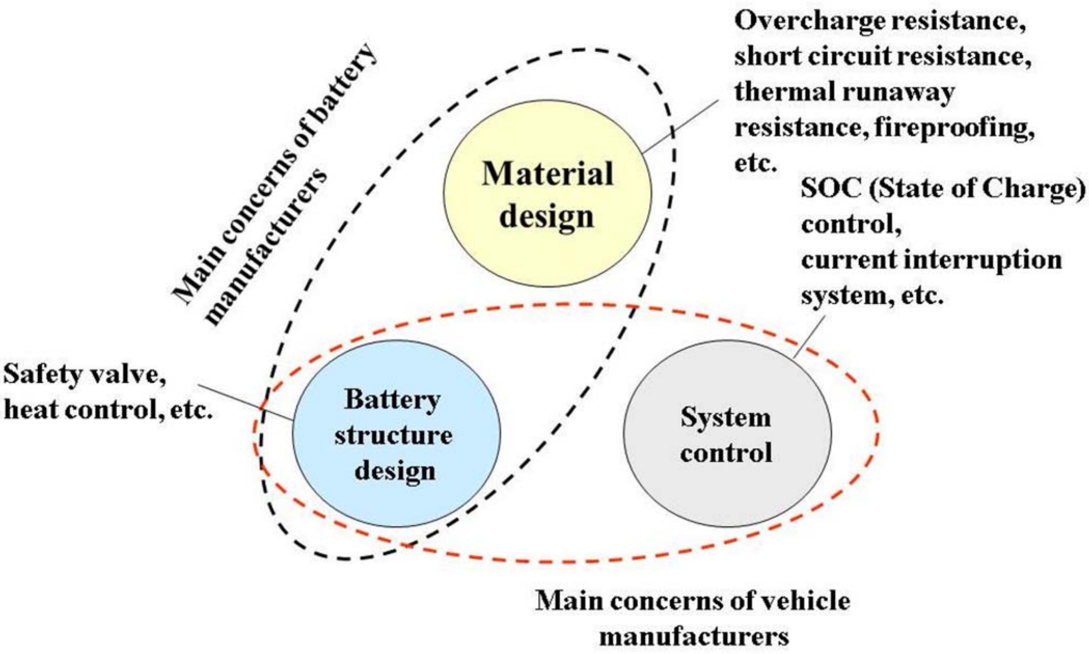


**Figure 9: Battery safety establishment process**

From the points of view of safety and reliability, the design and development of battery materials are also important themes.[2)] **Figure 10** shows the major classifications of positive electrode materials and negative electrode materials. However, the material used has an effect on a great many aspects of safety. As such, future material development will be focused on the achievement of safety.

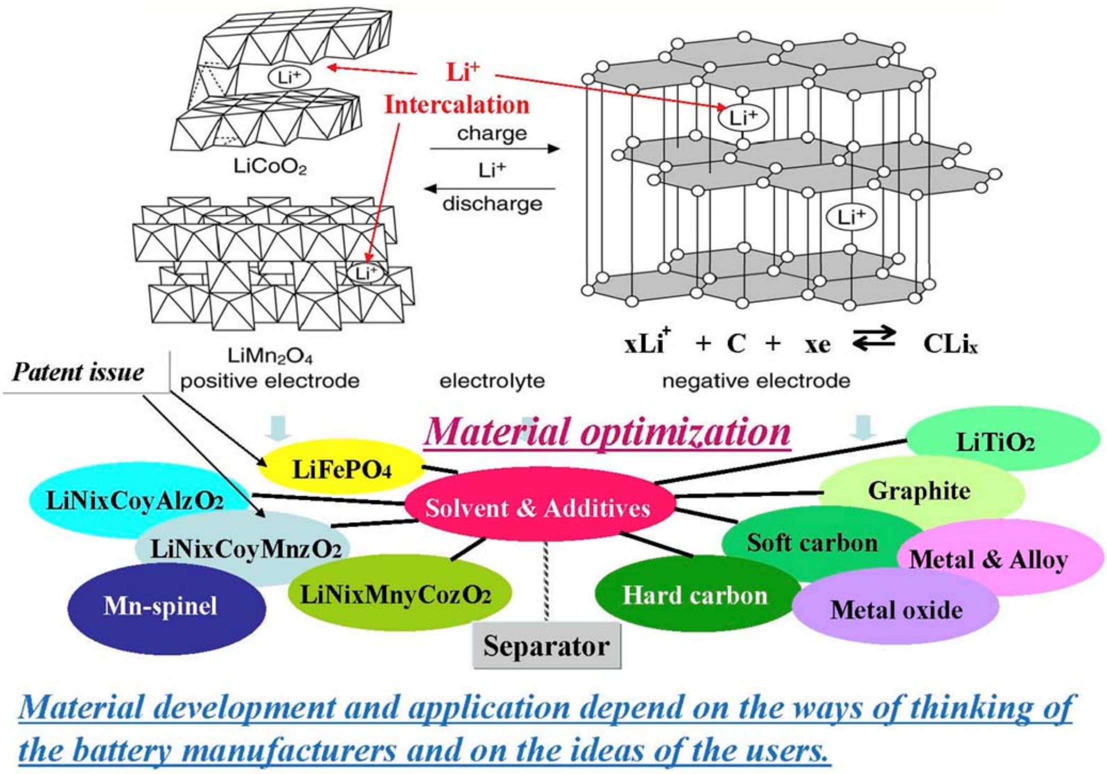


**Figure 10: The topic of LIB material composition and safety**

**Figure 11** shows an evolution prediction of the new LIB materials to be developed in the future. There are expectations for improvements in positive electrode capacity and output due to the switch to high-voltage active materials. However, an electrolytic solution component decomposition voltage problem equal to any such improvements will appear, which means that these batteries cannot be realized without the development, together with the material development stated above, of technology to improve the decomposition voltage of electrolytic solutions. Previously, putting effort into the achievement of safety put battery manufacturers at a disadvantage, so the switch to establishing reliability and safety is a major problem.

In the same way, while carbon materials, primarily graphite materials, have traditionally been used for negative electrodes, there is a steady change to the partial usage of metallic oxides such as silicon. This leads to an improvement in the battery capacity, but because of the electrode's volume swelling problem, a mixture of metallic oxides and graphite is being used. In the future, the problem is not only to increase the ratio of silicon metallic oxide to graphite but also to establish reliability and safety related to this change in technology.

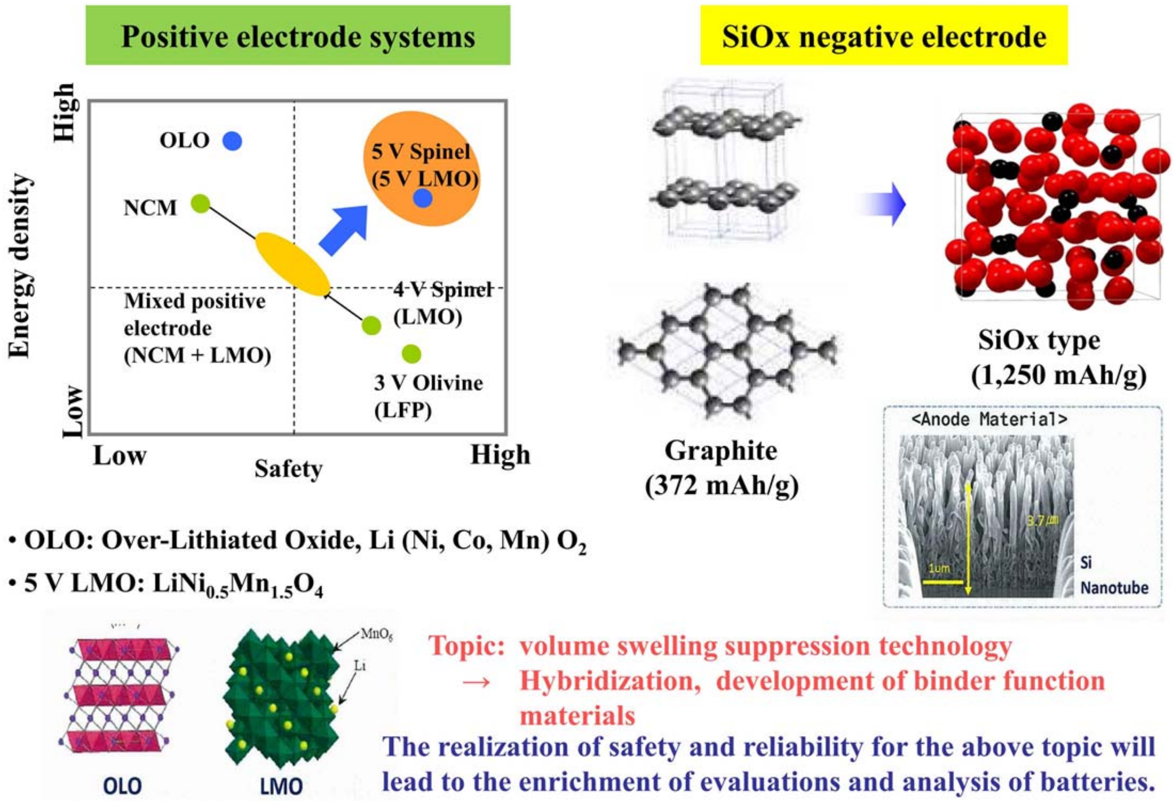


**Figure 11: The topic of expectations for and safety of new LIB materials**

**Figure 12** shows the alliances between vehicle manufacturers and battery manufacturers. However, just as venture businesses such as EnerDel and A123 in the United States failed in 2012, it will be difficult for some manufacturers to survive in the future. One cause of this difficulty is the overabundance of battery manufacturers in the world.

However, the key to a manufacturer's survival is their combined competitiveness in the areas of performance, price, reliability, and safety. Among other things, the reliability and safety of Japanese batteries have been highly evaluated by vehicle manufacturers. This is the result of proactively participating in battery development while receiving the strictest specifications in the world from a cooperative industry made up of the vehicle manufacturers that have been leading the switch to electric power.

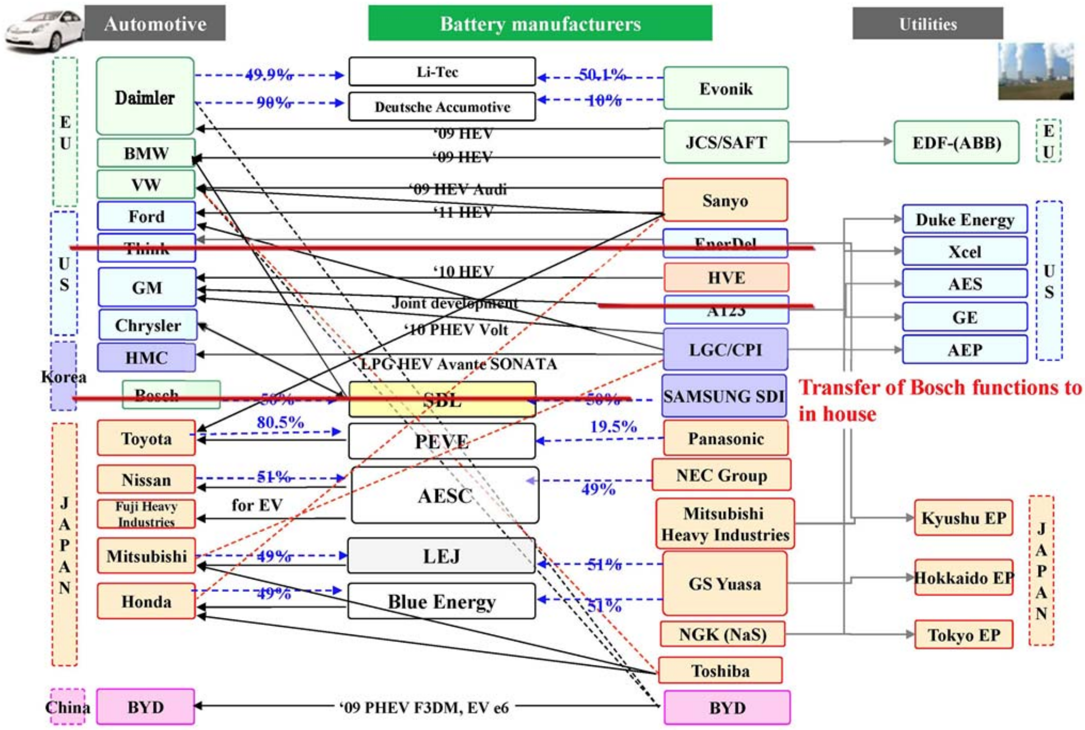


**Figure 12: Alliances between vehicle manufacturers and battery manufacturers**

**Figure 13** shows examples of Samsung vehicular LIBs, but Samsung also started a business model in 2012 to use some of these batteries as electricity storage for fixed usage in Japan. A characteristic requirement of these fixed usage batteries is that they must have reliability and safety to match the way that they are used. Reuse of these vehicular batteries in such a horizontal development is possible because vehicular batteries can cover the load modes and usage conditions that can be thought of with this fixed usage.

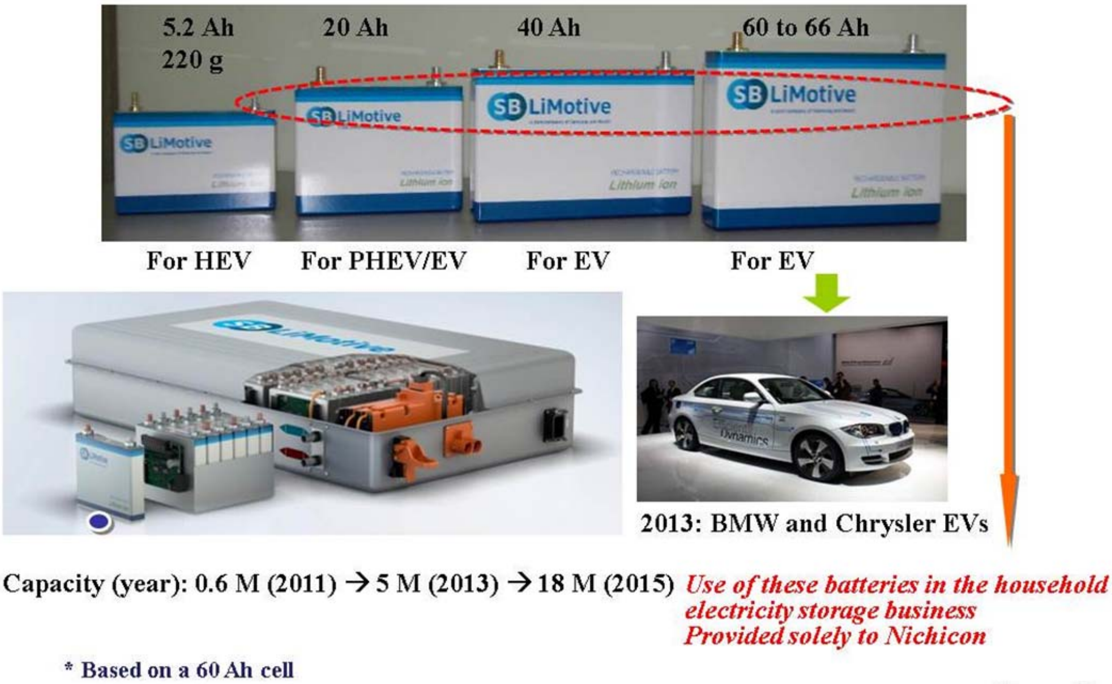


**Figure 13: Samsung's business model of using vehicular LIBs for fixed usage**

**Figure 14** shows the key items pertaining to batteries. One of the key items that is shared between the vehicle industry and the battery industry is the minimum guidelines and specifications related to reliability and safety that the vehicle companies provide to the battery manufacturers. However, the ways that the vehicle companies think about the specifications of the same HEV battery vary. As a result, the specifications are not uniform, which is a problem.

The exact same problem exists for PHEV and EV batteries. Battery manufacturers have to respond to the different needs of each vehicle company, which leads to an increase in the number of evaluation test items. However, battery manufacturers can cover the majority of specifications by collaborating with Japanese vehicle manufacturers, the strictest vehicle manufacturers in the world. The establishment of reliability and safety is one of the most important items for vehicular batteries, and the question of how to do this efficiently is a major issue to solve in the future.

Vehicle manufacturers must carefully evaluate battery providers before selecting which one to use. During this evaluation, vehicle manufacturers inquire as to whether the battery provider can give detailed support. On the other hand, because more than 10 battery manufacturing companies mix together around the world, the more the types of batteries under evaluation increase, the more time and manpower is required to evaluate them.

What's more, LIBs can be separated on the basis of their construction into two main groups: metal can types and laminated types. Even within the group of metal can types, there is a wide variety of sub classifications such as prismatic types and cylindrical types. The majority of the responsibility for this situation lies with the design philosophies of the different battery manufacturers. However, vehicle manufacturers are also involved in parts of battery construction, so it is often the case that a battery manufacturer cannot single-handedly decide on a battery design.

As a result, processes that reduce the burden associated with a vehicle manufacturer's evaluation and business models involved with such evaluations are highly effective. It is possible to imagine a wide variety of businesses such as the case in which a vehicle manufacturer purchases evaluation equipment and generates the results of the evaluations that they themselves perform directly, the vehicle maker reducing their load in terms of time and manpower by consigning a company such as ESPEC CORP. (a company that has consignee functionality) to perform the evaluation and provide the results, and the case of a consignee providing the lab functions of a specific vehicle or battery manufacturer to the consignor such that the consignor can always make use of these lab functions as if they were part of the consignor's own company.

Among the vehicle manufacturers that are expanding the models of vehicles under development to actively progress with the switch to electric power, the increasing number of different types of applicable batteries is making various business models, such as those outlined above, valid.

Conversely, even vehicle manufacturers for whom it is not easy to install the necessary amount of evaluation equipment can improve their development efficiency by actively consigning other companies to perform this evaluation work. It goes without saying that the above business models provide improvements in time efficiency, but they also provide other benefits such as evaluation result know-how and the selection and proposal of technological topics regarding evaluation results. New business models like those described above can provide solutions that have advanced further than the current ones available, so there are expectations for the future development of these business models.

In the future, the keys to competitiveness in the field of rechargeable batteries for vehicular use will be the construction of relationships between consignors and consignees and the cooperation between the involved industries. This is a common statement that can be made regarding the battery industry and that can be made on the basis of the fact that the specifications of various vehicle companies vary when considering the possibility of cooperating with a large number of vehicle manufacturers.

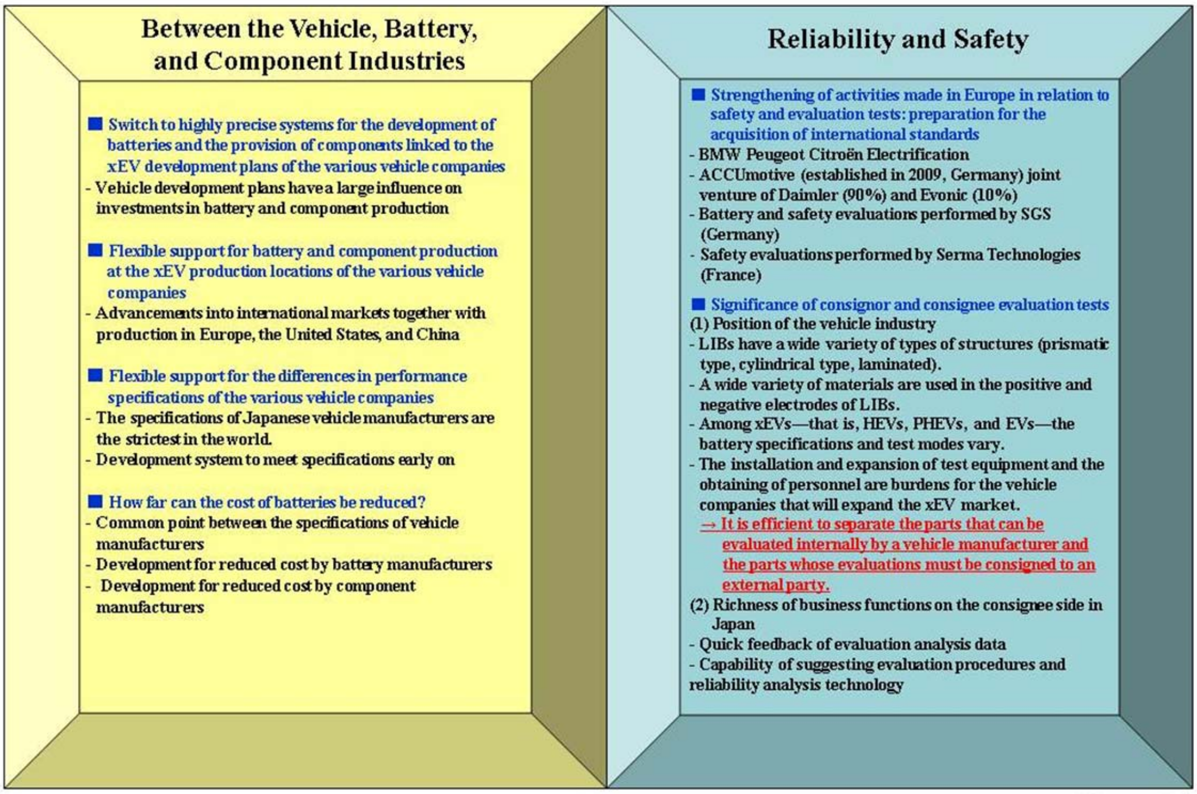


**Figure 14: Matter of interest for battery**

## References


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2. N. Sato and A. Yoshino, eds.: *Safety Technologies and Materials for Lithium-ion Batteries*, CMC Publishing CO., LTD., pp. 247 (2009) [in Japanese]