Current Trends in Battery Development and CO_2 Emissions Reduction for Automobiles

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REFLECTING ON BATTERY DEVELOPMENT

In 2000, I established the BRFC Production Engineering Department within Toyota to focus on the development of fuel cells and lithium-ion secondary batteries. At the time, both technologies were far removed from automotive manufacturing, as they were primarily electrochemical in nature. The materials, components, and structures involved had never been handled by Toyota before, making it impossible to draft blueprints from the outset. Without blueprints, manufacturing was impossible, but without manufacturing, blueprints could not be created—we were trapped in a “chicken-or-egg” dilemma. However, we started by building whatever came to mind ourselves while studying the fundamental principles, repeating the process over and over.

Before long, fuel cells came to be recognized as a crucial component of next-generation vehicles. Within the company, the number of engineers involved exceeded 1,000, and development efforts expanded with annual investments reaching several tens of billions of yen. The development team also came to understand that they needed to fully commit to the challenge, persevering until they achieved success. Automobiles operate in harsh environments, with temperatures ranging from −30°C to 80°C, and they require a lifespan of several decades. Furthermore, each vehicle incorporates hundreds of individual cells, necessitating a level of reliability of tens of times higher than that of devices such as mobile phones. Additionally, the electrolyte membrane, a key component of fuel cells, is as thin as cellophane tape or plastic wrap, yet it needed to last for decades, just like an engine block. However, once the major challenges were clearly identified, the responsible departments as well as research institutes and universities in Japan and abroad provided strong support for development. Step by step, issues were resolved from multiple perspectives—mechanical, chemical, and physical—until all technical requirements were met, except for cost. Looking back, I am reminded of the saying, “Many minds are better than one.” A wealth of ideas emerged, and the progress achieved far exceeded anything I had imagined.

There were many times when I felt like giving up due to significant challenges, and I even came close to suggesting that halting development would be in the best interest of the company. However, in hindsight, I am very glad that I did not. If development is abandoned midway, everything comes to a halt—this was something I came to understand firsthand.

Fuel cell vehicles efficiently generate electricity by combining hydrogen and oxygen, which are abundantly available on Earth, producing only water as a byproduct. They are clean, with zero CO_2 emissions, making them an ideal form of transportation. This fundamental advantage was the main reason we were able to maintain our motivation for development from the outset.

In December 2002, we introduced a prototype fuel cell vehicle for lease, and by 2014, we successfully launched the first mass-produced fuel cell vehicle on the market. Similarly, lithium-ion battery development steadily progressed, with advances in materials, components, and manufacturing methods, eventually reaching a level where they could be installed in vehicles. This made electrification of vehicles a real option. However, lithium-ion batteries have been linked to fires across various fields, including personal computers, mobile phones, airplanes, and automobiles. When a malfunction within the battery leads to a short circuit, it causes the electrolyte inside to heat up and undergo thermal decomposition. This triggers exothermic reactions between the anode and cathode, which can then cascade into further reactions, ultimately resulting in combustion.

This led to the emergence of all-solid-state batteries as the next generation of battery technology. Research and development began with the idea that replacing the flammable liquid electrolyte with a solid electrolyte—which is much less prone to combustion—could create a safer battery. Believing in its non-flammability, we focused on achieving performance that would surpass that of conventional liquid-based batteries. When we tested small coin cells, they remained completely undamaged, even when exposed to extreme heat conditions. Their performance also reached levels comparable to liquid-based batteries, so we proceeded to develop medium-sized cell prototypes. However, in ignition tests, one out of three of these cells caught fire. Assuming the test had been flawed, we increased the number of samples, only to find that many of them also burst into flame. It was truly disheartening. We had assumed that using non-flammable materials would make the battery inherently non-flammable, but that was not the case. When a high-energy battery shorts, the localized temperature can quickly exceed several hundred degrees Celsius. At such extreme temperatures, even non-flammable materials can undergo exothermic reactions. Today, development is progressing toward batteries that are significantly more fire-resistant than current lithium-ion batteries, while also offering longer driving ranges and shorter charging times.

DIVERSE VEHICLE TECHNOLOGIES (MULTIPATH APPROACH)

In recent years, the automotive industry has been experiencing a once-in-a-century transformation, driven by the Sustainable Development Goals (SDGs) initiated by Europe. A variety of vehicles now coexist, including electric vehicles (EVs), hybrids, plug-in hybrids, fuel cell vehicles, and even e-fuel vehicles. At one point, the industry seemed fully committed to electrification, but that momentum has begun to slow. One major factor is the withdrawal of government subsidies. Another is that early adopters have already completed their initial wave of purchases. Countries such as the United States, Germany, China, and Norway have been offering subsidies of around one million yen per battery electric vehicle (BEV), but when these incentives are discontinued, demand drops sharply. In some countries such as Germany, where many company cars are purchased by businesses and distributed to employees, the situation is somewhat different, but for the vast majority of buyers, choosing a vehicle remains a personal decision, so it is only natural that the discontinuation of subsidies would affect sales significantly.

EVs still have several shortcomings from the user's perspective. These include not only limited driving range but also long charging times, no price advantage over gasoline vehicles, faster battery degradation than engines, and a higher risk of fire. From a life cycle assessment (LCA) perspective, EVs are not always the most environmentally friendly option, as their impact depends on how the electricity used to charge them is generated. In fact, an organization in Germany, the leader in EV adoption in Europe, examined how best to tackle CO_2 reduction. The FVV (Forschungsvereinigung Verbrennungskraftmaschinen e.V.), a consortium of 170 companies and 110 research institutions specializing in internal combustion engines, conducted an LCA to determine what types of vehicles should be introduced and when, in order to limit global temperature rise to 1.5°C and keep cumulative CO_2 emissions below 400 Gt by 2040[(1)]. Instead of evaluating only the CO_2 emissions from vehicle operation, the study considered the entire lifecycle, including emissions from fuel production, raw material extraction, processing, component and unit manufacturing, and end-of-life reuse and recycling. Their interim findings suggest that while EVs may have some advantages, these are generally minor and largely dependent on how electricity is produced. Moreover, even if EV adoption accelerates, the impact will not be large enough or soon enough to meet climate targets. Instead, the study concludes that in addition to existing gasoline vehicles, a mix of e-fuel-powered cars, fuel cell vehicles, and hydrogen vehicles must be deployed simultaneously to achieve meaningful CO_2 reductions. This conclusion is not surprising. More than 1.3 billion vehicles are already in operation worldwide, and even with aggressive EV adoption, replacing them would take at least a decade. A more immediate and practical solution is to introduce e-fuel blends into existing gasoline vehicles. However, e-fuels also face significant challenges. Large-scale production facilities are still scarce, and the cost of e-fuel remains more than twice that of gasoline. Addressing these issues is essential for broader adoption. At present, I cannot help but feel that both consumers and automakers are caught in a situation of uncertainty, largely due to governments taking too much of a lead and creating market confusion. Rapid shifts in consumer purchasing behavior have forced automakers to drastically revise their strategies, with several companies changing course in just the past few months. As a result, even short-term forecasting for vehicle sales and production has become extremely difficult.

Amidst this situation, I would like to briefly touch on the characteristics and positioning of the various types of vehicles that are currently proliferating.

First, hybrid vehicles not only offer excellent fuel efficiency but also have a driving range of around 1,500 km on a single fill. They can cruise quietly using only the electric motor, avoiding disturbances to neighbors late at night, and require fewer trips to refuel than regular vehicles. Apart from the fact that they primarily rely on gasoline, they have many advantages. Plug-in hybrid vehicles (PHVs) are also being reevaluated, as they have battery capacities 5 to 20 times larger than the ones in regular hybrids, allowing them to run solely on electricity for frequently traveled distances. However, the inconvenience of having to plug in the charging cable at home and unplug it before departure discourages many users from charging, leading them to rely solely on gasoline. Although these vehicles are purchased with government subsidies, if they are not used as intended, they do not contribute to CO_2 reductions. The early development of wireless charging systems is therefore highly desirable. Next, fuel cell vehicles (FCVs) offer a high level of user satisfaction in terms of performance and functionality. With a driving range of 800 km and a refueling time of just 3 min, they surpass EVs in convenience. Because they are motor-driven, they have all the advantages of EVs. However, their widespread adoption has been hindered by the high cost of hydrogen infrastructure and the slow spread of refueling stations. While the current price of fuel cell vehicles is still high, it is expected that, with mass production, their cost will become comparable to that of other vehicle types.

In this way, vehicles with various power sources will continue to be developed and improved, each progressing toward solving its particular challenges. Rather than rushing into an overly hasty decision and focusing solely on EVs, countries should maintain a multipath approach for the time being. In the end, I believe this is what will naturally happen.

Returning to the topic of batteries, lithium-ion batteries, all-solid-state batteries, and fuel cells all serve as tools for energy management, and their potential applications are extremely broad. It is clear that new fields such as battery reuse, recycling, vehicle-to-grid (V2G) technology, and charging stations will continue to expand in the future.

I sincerely hope that Yokogawa Electric Corporation will fully leverage its technological capabilities and establish itself in new business ventures related to batteries.

REFERENCE

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