8 KYOTO CARS

> In the annals of car history, there are many examples of companies falling victim to rivals after missing a narrow window of opportunity, even while in a hurry. The environment was a critically important theme to carmakers and we couldn't afford to take second place.
>
> —Satoshi Ogiso, Toyota managing officer, 2017

As interest in hydrogen and fuel cell electric propulsion grew, competition in clean car technology between General Motors (GM) and Toyota was reaching a climax. In March 1997, Toyota publicly announced that at the end of the year, it would introduce a commercial hybrid electric automobile equipped with a nickel-metal hydride rechargeable that would have double the fuel efficiency of conventional cars and produce 90 percent less effluent. The automaker did not specify the price or name of the vehicle, but suggested that it would be in the class of the Corolla subcompact and indicated that it had not yet decided whether to offer it for sale in the US.[1] At GM, the Ovonic Battery Company (OBC), and its parent Energy Conversion Devices (ECD), attention at the time was still focused on Toyota's RAV4 EV, the compliance car that the US camp believed it was competing against in the all-battery electric space and that Stanford Ovshinsky and Robert Stempel were confident would be no match for the Ovonic EV1. But OBC was growing anxious. Since early 1996, the company had been engaged in costly legal action with Matsushita and Toyota over Toyota's right to introduce electric cars equipped with advanced Matsushita nickel-metal

hydride batteries into the US market, events discussed in chapter 6. Even more worrying for OBC was that GM was developing the Ovonic EV1 at an inexplicably leisurely pace. So concerned were Ovshinsky and Stempel that they began to more openly discuss the scenario of working with the Japanese alliance, probably with the intention of goading GM into taking bolder action.[2]

The spring of 1997 did bring some good news for OBC. The US District Court for the District of Delaware moved to dismiss Matsushita's lawsuit and validate the 822 patent. The ruling restricted the industrial giant's nickel-metal hydride technology to an earlier chemistry yielding 63 watt-hours per kilogram of capacity, meaning that the RAV4 EV would have less range than the OBC EV1, whose battery pack was then rated at about 70 watt-hours per kilogram.[3] For Stempel, the legal process was doubly heartening because it caused GM to announce that the first module of production-intent equipment was operational, contradicting Matsushita's claim that GM-Ovonic was a joint venture in name only. OBC used this information in its countersuit to argue that a US manufacturing base for electric vehicle batteries existed and was vital to the "overall EV strategy."[4]

Stempel hoped that competitive pressures accentuated by the court ruling would concentrate GM's mind on the OBC EV1. Harry Pearce had advised OBC and ECD in the case against Matsushita, and with legal victory all but certain, Stempel wrote to thank the vice chair for his help: "Now that the Matsushita EV battery market position has been defined (and limited), it is clear that GM can be in a dominant, controlling position with nickel-metal hydride electric vehicle batteries."[5]

What GM intended to do with this dominance was another question. The automaker was poised to trump the RAV4 EV with the OBC EV1 in the dramaturgy of high-technology supremacy, its chosen field of battle, and its leaders were satisfied that Toyota's limited-production compliance car posed no threat. But Toyota was poised to pioneer and monopolize an entirely new market niche with its commercial hybrid electric car. If GM leaders were unconcerned with the immediate economic ramifications of that project, they began to be aware that it could at least cause them some public relations problems, with the signing of the Kyoto climate treaty only months away.

Managers of GM's hybrid electric programs felt a more urgent need to demonstrate progress, but their room for maneuver was limited. The

Partnership for a New Generation of Vehicles (PNGV) administered the research and development of batteries for Detroit's experimental hybrid electric cars, and the consortium internalized the US auto industry's philosophy of mobilizing the best as the enemy of the good in order to delay action on mandated technological change. Where Toyota and Honda used first-generation nickel-metal hydride rechargeables in their first-generation commercial hybrid electrics, the PNGV interpreted the hybrid as another type of electric supercar. Moreover, consortium planners insisted on developing not one, but two systems: a power assist hybrid and a dual-mode hybrid. The former required only a battery of high power and modest energy, since the average depth of discharge would be comparatively shallow depending on whether the battery was coupled to a prime mover that responded relatively quickly (the internal combustion engine) or slowly (the fuel cell) to demands for power. Dual-mode hybrid electric drive, on the other hand, required a larger battery that was energetic as well as powerful and also was robust enough to repeatedly deeply discharge when providing periods of electric-only transport.[6]

The dual-mode hybrid electric car was similar to the all-battery electric car, requiring precisely the sort of superbattery that US automakers insisted was necessary for all-electric cars to be competitive but that they could not quickly develop. OBC was caught in a game of technological leapfrog, wedged in the uncomfortable space between GM and Toyota's tacit cooperation in suppressing the all-battery electric format and their nominal competition in commercial advanced propulsion technology, an arena that Detroit had effectively ceded. OBC bore the burden of cutting the costs of the nickel-metal hydride battery for the EV1 by means of materials science before GM would consider moving the car into production. On the other hand, GM's sudden interest in hybrid electric propulsion, following Toyota's revelation of its commercial hybrid electric, offered the possibility of another application of OBC technology.

But the PNGV was becoming skeptical about the nickel-metal hydride rechargeable in the hybrid electric application, an ill omen for OBC's future in the automobile industry. As the countdown to Kyoto progressed and the media limelight shifted to the hybrid electric car, the tensions and contradictions between GM and OBC were cast ever more starkly into relief.

CONSORTIA CONUNDRUMS

The quandary of OBC was that it had partnered with a corporation that believed its status as the world's largest automaker gave it the role of arbiter of the technological progress of the global industry. GM and its domestic peers agreed that rapid technological change was undesirable, and the doctrine, structure, and governance of the US automaking industry's research and development consortia reflected this view. These organizations investigated almost every conceivable form of automobile propulsion technology and judged it to very high standards of performance. With the assistance of the national developmental state, Detroit created three distinct entities for these purposes. The United States Advanced Battery Consortium (USABC) was responsible for batteries for all-electric cars, and the PNGV was responsible for all other kinds of alternative propulsion systems, including batteries for hybrid electric configurations. Both groups were formally part of the United States Council for Automotive Research (USCAR), the umbrella organization for collaborative research in the US auto industry, but the PNGV's hybrid battery programs were collectively managed by the USABC. While the agendas of the two consortiums in galvanic batteries substantially overlapped, the car companies effectively treated these organizations as separate entities. Moreover, the Big Three automakers did not decide their priorities in advanced propulsion technologies collectively; rather, they apportioned responsibilities among its members in specific fields.

In short, the architecture of the US auto industry's collaborative research and development complex inhibited coordinated rapid action on specific technologies. OBC's experience with its hybrid battery illustrated these dynamics. While the USABC had helped fund OBC battery technology for all-electric vehicles, the PNGV excluded the company from its hybrid electric battery program, a notable omission because the partnership did fund research in nickel-metal hydride rechargeables but chose to contract with Varta and Yardney, companies with less experience in the technology. Both of these programs failed to meet initial PNGV milestones.[7]

Nevertheless, OBC used its own resources to develop its own battery for hybrid electrics, which it demonstrated to leaders of GM's hybrid electric program in a March 1997 meeting. The GM team was impressed. It had been working with an Optima spiral-wound lead-acid rechargeable, a device that fell well short of the PNGV's performance standards, which had been

devised by Ford. Ford called for 50 kilowatts of power from a 0.5 kilowatt-hour pack, a goal that the GM team felt was unrealistic.[8] The team agreed to have the GM contractor AeroVironment test the OBC technology and intimated tantalizing prospects. Larry Oswald, a senior member of the GM hybrid group, indicated that the automaker expected to sell over 50,000 hybrid electrics per year. But the GM team did not offer OBC any funding. Oswald suggested that OBC inquire at the USABC because he believed the consortium had surplus cash, $24 million out of a fund of $32 million for research on hybrid batteries left over as a result of the conclusion of Varta and Yardney's programs.[9] Oswald also recommended that OBC make funding inquiries with Harold Haskins, a Ford engineer who served as a PNGV team leader responsible for technical targets and who had designed the consortium's analytical tools for testing hybrid batteries.[10]

OBC was not optimistic that the USABC would cooperate, but it was heartened by the AeroVironment report on its hybrid electric battery. The device's energy density of 70 watt-hours per kilogram was around two and a half times that of the Optima lead-acid rechargeable, the best result, claimed OBC, of any battery that AeroVironment had tested for the PNGV.[11] Oswald was pleased, but he wanted OBC to manufacture a slightly smaller module at its own expense. If OBC could do the job, said Oswald, GM might purchase one or more complete hybrid electric battery packs for evaluation.[12] Haskins offered similar praise, noting that OBC's accomplishment was all the more impressive given that the company had funded all the work. But the Ford executive also echoed Oswald's criticism, holding that OBC's basic hybrid electric battery cell was too heavy for PNGV requirements. He wanted to increase the cell's power-to-energy ratio. If OBC continued to improve the battery, Haskins indicated that there was a chance the technology might be evaluated by the Idaho National Engineering and Environmental Laboratory as part of the cooperative agreement between the US Department of Energy (DOE), the PNGV, and the USABC. It was possible that the DOE might lend OBC some direct support.[13] In the meantime, Haskins recommended that OBC try to access PNGV resources through GM's Oswald.[14]

OBC had been given the runaround, and not only as a result of the consortia's circuitous chains of command. Auto industry planners were taking an increasingly dim view of the nickel-metal hydride battery in the hybrid electric role. The National Research Council (NRC)'s 1997 review held that without a materials breakthrough, the PNGV cost goal of $150 per kilowatt-hour

could not be met with nickel-metal hydride chemistry. The NRC agreed with the PNGV that the lithium ion rechargeable was a more promising power source in the hybrid electric application. The PNGV had already awarded contracts for lithium rechargeables to the French battery maker Saft and the US nonprofit SRI International as part of its Phase I program.[15] The new enthusiasm for lithium power was a harbinger of an effort by GM and the US auto industry to wind down their investment in nickel-metal hydride battery technology and reduce OBC's influence in their affairs.

COUNTDOWN TO PHASEOUT

OBC's prospects in the EV1 were hardly better than in GM's hybrid electric car. The battery company had the USABC's support in developing the EV1 battery only until the end of 1997, and much work remained to be done. GM-Ovonic chief John Adams was seeking to cut the cost per pack from $60,000 to less than $9,000, which was still twice the consortium's original target, and had only months to accomplish this goal. GM had promised to build a new dedicated battery manufacturing plant in Dayton, Ohio, only if quick progress was made at GM-Ovonic's Maplelawn preproduction plant.[16]

With limited resources, Adams worked to mechanize a facility that was one-tenth the size of a commercial production plant. By mid-1997, the negative electrode assembly equipment was operational, as was some of the equipment for *formation*, the process of curing new cells by repeated charging and discharging so that microstructures of electrode surfaces are prepared for optimum operation. Formation is sensitive, time-consuming, and vital for reliable and durable cells. GM-Ovonic's formation process then took fourteen days, and Adams wanted to cut that to three.[17] Additional formation equipment had been ordered, but it would not arrive for six to eight weeks. Also, the positive electrode coating machine had to be debugged and started. Until this was done, workers had to assemble cells by hand. By August, capacity was two packs per week, and Stempel hoped that this could be increased to one a day and five per week by December.[18]

OBC's future hung in the balance. There was just enough good news to give hope. In April, Adams informed OBC president Subhash Dhar that road tests of vehicles using OBC batteries gave good results. Personnel at GM Advanced Technology Vehicles (GMATV) used Ovonic EV1s on the Lansing-Detroit commute, a round-trip journey of around 180 miles that Dhar argued was

not possible in an electric car equipped with lead-acid batteries. One vehicle shown to GM's board of directors accumulated 18,000 miles.[19] OBC batteries were also being tested in Chevrolet's converted S-10 light truck, which competed with Ford's converted Ranger in the market for compliance cars.[20]

But Stempel wanted GM to take full advantage of OBC's "battery family," a lineup of four progressively more advanced power sources derived from the baseline 70–75 watt-hour per kilogram cell for the EV1. OBC also had a plan to develop a nickel-metal hydride auxiliary battery for starting and lighting internal combustion engine vehicles. Stempel urged GM research and development chief Kenneth Baker to think of OBC technology not simply as a battery but as a multielement energy storage system that could serve every possible automobile propulsion format. Baker himself had promoted the hybrid and fuel cell electric formats in his 1994 presentation to the GM President's Council, the automaker's main decision-making body, in justifying the restart of the Impact car project.[21]

These appeals bore no fruit, and Ovshinsky found GM's seeming disinterest in OBC technology incomprehensible. He saw potential applications of OBC batteries everywhere in the automaker's industrial empire, from the buses and locomotives the company then manufactured to forklift trucks, standby power, and industrial robots. At times, the inventor expressed impatience with and even contempt for what he interpreted as an antiscience ethos embedded in GM's corporate culture. After a visit to GM's research laboratories, he wrote to Stempel, lamenting the automaker's "minimal" knowledge of advanced materials. To Ovshinsky, the self-taught materials genius, it was "obvious that we can be a problem-solving resource to serve GM's plans for new products as well as improve their older technologies."[22]

A CAR FOR CLIMATE CHANGE

Stempel personally lobbied Harry Pearce to accelerate GM's electric car programs. In an August 13 meeting with the vice chair, he warned that GM risked being outmaneuvered by Toyota unless it took action. Over the course of 1997, Stempel had surveyed global industrial and environmental politics with growing concern. In June, he attended the Summit of the Eight in Denver, hosted by Admiral Richard H. Truly, director of the National Renewable Energy Laboratory, and had been taken aback by the blunt language

of Secretary of Energy Federico Peña, the keynote speaker. Peña's assessment was that the Clinton administration had no policy going into Kyoto, a situation that was going to create a great deal of confusion in the treaty negotiations because the other industrial powers were expecting leadership from the US. The energy secretary believed that things could continue as they were or that the US could develop a comprehensive plan. On an ad hoc basis, Peña and Vice President Al Gore's office were mustering representatives of US industry, including Stempel, to help formulate such a position.[23]

In Stempel's view, Toyota was going to use the Kyoto summit to position itself to dominate the global automobile industry by offering its commercial hybrid electric car as the solution to the problem of climate change. The automaker's message would be that better fuel economy equated to lower emissions of carbon dioxide, a substance that was not then subject to controls. Indeed, noted Stempel, Japanese and German automakers were already working hard to lobby against specific reduction targets at Kyoto. In the technopolitics of smog, the local air quality regulator held most of the cards; in the technopolitics of climate change, much of the authority on what counted as green swung back to the automaker. In building the market for the sustainable automobile, Toyota would rely on consumer acceptance, not public policy targets. This was the challenge facing Detroit, argued Stempel. GM could still regain the initiative, he continued, if it altered its relationship with OBC. Stempel proposed to restructure OBC as a stand-alone company through an initial public offering, allowing the automaker to purchase OBC shares and gain direct access to its technology.[24]

This was not to be, but with Kyoto only months away, GM felt it prudent to maintain some level of support for OBC. In September, the automaker approved the Ovonic Product Development Program, providing $16.4 million for research to cut costs and increase the energy of batteries for hybrid and all-battery electric cars. In a letter to Baker, Stempel opined that this was not a lot of money, but it allowed OBC to maintain operations, and he hoped that it also signaled a commitment to support the company's product lineup. Stempel added that OBC could also help meet GM's requirements for hydrogen fuel cells. OBC had yet to develop such a technology, but it had an important component in metal hydride storage, a key enabler of the nickel-metal hydride battery.[25] Stempel's mention of the hydrogen fuel cell was a sign that the executive was aware that the all-battery electric format was in real jeopardy.

KYOTO CARS

By the end of the year, OBC batteries were installed in some thirty GM vehicles, mostly S-10 conversions as well as a handful of EV1s. At Solectria, James and Anita Rajan Worden were using OBC batteries to achieve important range milestones, including mileage records of 216, 249, and 373 miles on a single charge.[26] OBC had helped make GM the most progressive of the US automakers in alternative propulsion systems, and Ovshinsky's celebrity ascended accordingly.[27]

As impressive as these accomplishments were under the circumstances, they were completely overshadowed by the debut of the Toyota Prius as the world's first commercial passenger hybrid electric car. Toyota devoted the entire fall of 1997 to the rollout. Initial production started in September, and the automaker officially introduced the car at a special event in Tokyo in October, thereafter promoting preproduction models at a series of high-profile venues, including the Tokyo Auto Show and the site of the 1998 Winter Olympics at Nagano. Priuses were also on hand at the climate summit in Kyoto, where they shuttled officials and dignitaries between venues. On December 10, the day before the climate treaty was signed, Toyota held a ceremony for the Prius lineoff.[28]

The Prius was a triumph of social as well as physical engineering. The program illuminated the intimate industrial-technological relationship between Japan and the US, highlighting contrasting approaches in public policy. Jack Smith would later claim that Toyota had developed the Prius with the help of a public subsidy, a hint that trade sanctions might be forthcoming should the vehicle be exported to the US.

However, the US national developmental and regulatory state had also been involved, directly as well as indirectly, in virtually all the alternative propulsion vehicle projects under development for the US market. Energy and environmental policies forced most automakers to build cleaner and more efficient cars for this market, and the national developmental state supplied US automakers with science and technology resources to help them accomplish these goals. Ironically, some of these stimulus initiatives were modeled on those said to have been deployed by Japan's Ministry of International Trade and Industry (MITI), the planning agency that to many American pundits and policymakers was antithetical to the principles of capitalist fair play and emblematic of Japan's industrial rise. From

the mid-1980s, US officials set aside their ideological assumptions and tried to emulate the imagined Japanese model in research consortiums such as Sematech (the DARPA-organized association of US semiconductor manufacturers), the USABC, and the PNGV.[29]

A double irony was that MITI had no more power to compel or control domestic automakers than the US research consortia did. Japanese car companies managed to maintain their independence from Japanese state planners and had initiated their electric car projects largely in response to regulatory developments in the US market. Like the US federal science and technology complex, MITI long supported the research and development of various aspects of electric vehicle technology. But the ministry followed Toyota's and Honda's lead in hybrid electric technology, only indirectly contributing research relevant to parts of the hybrid drivetrain, including the permanent magnet motor.[30] It was in the manner of the provision of financial assistance that the Japanese national developmental state differed from its US counterpart. Toyota initiated the Prius project without the direction or aid of MITI but the ministry subsequently subsidized cars purchased by Japanese corporations, a form of stimulus that American entrepreneurs of electric cars and electric car batteries had long asked of the US government.[31]

The way in which Toyota introduced the Prius also illustrated that the company had far grander imagination and ambition in technological dramaturgy, not to mention a willingness to coordinate with government in staging it, than its peers. Years later, the G21 member Satoshi Ogiso claimed that the Prius production deadline had been moved up one year precisely so that the launch would coincide with the signing of the climate treaty.[32] Toyota president Hiroshi Okuda made this decision nearly seven months before Kyoto was formally announced as the site of the Third Conference of the Parties of the UN Framework Convention on Climate Change (UNFCCC) in July 1996, and so had been privy to negotiations at the highest level.[33] Pundits were skeptical that hybrid electrics could make money, but if the Prius had been intended solely as green propaganda, it was propaganda on an unprecedented scale.

On December 23, a judge in the US District Court for the District of Delaware announced a verdict that GM, OBC, and ECD knew was coming: Matsushita's lawsuit was finally dismissed. Where nickel-metal hydride rechargeable technology for electric vehicles sold in the US market was

concerned, Matsushita and Panasonic EV Energy (PEVE), as Matsushita's joint battery venture with Toyota had been known since January, were restricted to a battery with relatively low energy density called the MHI-BX, which had been covered under a previous agreement with ECD, and they could not use OBC technology to improve it. Over the course of the year, OBC had spent $3 million in scarce capital in defense of its patent rights, a victory that may have seemed pyrrhic in light of the Prius.[34]

Age of Auto Electric

Environment, Energy, and the Quest for the Sustainable Car

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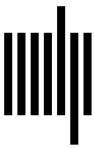

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