THE PRIUS

THAT SHOOK THE WORLD

HOW TOYOTA DEVELOPED THE WORLD'S FIRST MASS-PRODUCTION HYBRID VEHICLE

ORIGINAL BY HIDESHI ITAZAKI

TRANSLATED BY ALBERT YAMADA & MASAKO ISHIKAWA

Table of Contents

Preface

September 28, 1998. That was the day Toyota Chairman Shoichiro Toyoda stood before a crowd of journalists in Pavilion Gabriel, an exhibition hall often used to hold fashion shows near Place de la Concorde in Paris. Outside, the early autumn day was cold. Winter was approaching. Inside, there was a rising heat of expectation. He was there to personally introduce Toyota's new "litercar" Yaris which was to become available in Europe starting in the Spring of 1999 and which would be manufactured starting in 2001 at a new plant still under construction in northern France. The Paris Auto Salon (show) was starting the next day and two days later Toyota's new showroom on Champs Elysees would open. More than 400 journalists from Europe and all over the world filled Pavilion Gabriele to hear what he had to say. They were all eager to learn about Toyota's strategy in Europe. With Chairman Toyoda were Executive Vice President Akihiro Wada, Toyota Motor Manufacturing Europe (TMME) Executive Vice President for Sales Juan Jose Diaz Ruiz, and Member of the Board and Development Supervisor of Yaris, Shuhei Toyoda who was not known to the media representatives. They gave a general presentation on the Yaris and then settled down to answering questions. Basically, the 5 journalists wanted to know only two things: Where was Yaris designed? How much more expensive is the European version compared to the one sold in Japan? Toyota executives could not believe what they were hearing when the questions quickly started to change. Journalists now wanted to hear about Prius, Toyota's hybrid vehicle. They asked, "We understand that Prius will be introduced in Europe in year 2000. What will be the price in Europe?" "How many Prius must you sell to make a profit?" "What is the technical difference between Japan's Prius and the one for the European market?" One after another, European journalists were asking questions about the Prius. Their questioning made the executives acutely aware of Europe's interest in and high expectations for Prius. They quickly became convinced that Prius would be a milestone in automotive history and that it would lead auto technology into the 21st Century. Prius was launched in Japan in December 1997 and its innovative mechanism and overwhelming fuel efficiency immediately caught the attention of auto makers and journalists around the world. Then President Hiroshi Okuda announced in July 1998 that Toyota would begin exporting 20,000 units annually to North America and Europe starting in 2000. The European public fell in love with the car. "Toyota - Hybrid vehicle - Prius"-Apparently those words described the impression many European journalists 6 had of the company. However, they did not really explain what Toyota was doing. There are several types of hybrid systems. One type is propelled by an electric motor while generating electricity with an internal combustion engine. Another type uses power from both engine and motor to move the car. Toyota's Prius, however, utilizes an entirely new driving technology that uses the advantages of two types of hybrid propulsion. During acceleration or driving downhill when engine efficiency is low, the car runs on the motor alone. During normal driving condition, the car uses both the engine and motor, storing extra electricity in the battery. When cruising at high speed, the car runs almost entirely on the engine, and the generator is kept off. When extra power is needed to accelerate while cruising, electricity is drawn from the battery to give more power to the motor. When braking, the car decelerates by using the motor as a generator, and the produced electricity is collected in the battery as regenerated electricity. When stopped, the engine is turned off except for times when the air conditioner is used or when the battery is extremely low and needs to be charged. These complex modes are controlled by nine on-board computers that exchange information. The power--partitioning system equipped with a planetary gear distributes engine power to the wheels or to the generator. This system uses the engine and the motor in their 7 most efficient states, so as to allow the Prius to achieve the miraculous fuel economy of 28 kilometers per liter (66 mpg; Japanese 10-15 city driving mode). Consequently, only half as much CO_2 is created, and the emission of toxic chemicals such as NO_X also is reduced to one-tenth of the legal requirement.

For Toyota, however, fuel economy is not the only good thing about Prius. The new body package allows sufficient cabin space inside a small body. Moreover, Toyota was able to design and manufacture most of the units and parts within the company from scratch. Hiroyuki Watanabe, Member of the Board and Electric and Hybrid Vehicle Engineering Division General Manager, emphasizes. "Not just the combination of engine and motor but the very technology to combine different power sources will become the core technology of the future. The fact that we have accomplished this within the company is extremely significant." "The technology to combine different power sources will become the core technology" - what does it mean? How did Toyota develop this technology? Is Prius really a 21st century car that may change the history of auto development? How did Prius affect world auto makers, such as the Big 3? 8

Having watched Toyota for four years, I interviewed many people involved in the development of Prius in the course of six months to get answers to those questions. I would like to thank especially Mr. Shinji Miyatake and Mr. Shoichiro Ohtsuka of Toyota Motor Corporation's Nagoya Public Affairs Division for their help with my project. I also would like to thank many others at Toyota for their cooperation and help. April 1999 Hideshi Itazaki *Toyota Motor Corporation merged with Toyota Motor Sales in 1982 and became the present day Toyota Motor Corporation. Except in a few instances, the name Toyota refers to the consolidated company. **Titles and positions used throughout this book, including addenda in parentheses, are as of original publication date: April 20, 1999. 9

Chapter 1 Eiji Toyoda's Order - Project G21

Even as the bubble economy was at its peak in 1990, Toyota Chairman Eiji Toyoda (now Honorary Chairman) repeatedly expressed his sense of crisis at every chance. At the regular Board meetings he would ask, "Should we continue building cars as we have been doing? Can we really survive in the 21st century with the type of R&D that we are doing now?" The new models being introduced by auto makers during the bubble economy period had grown fancier and larger, loaded with excessive features and accessories. Toyota had applied its best technology towards developing sedans that could compete with the top luxury cars of the world such as Mercedes-Benz and BMW, and that had culminated in the introduction of the Celsior. With every model change, other Toyota models, such as Mark II, Corona, and Corolla, had become more luxurious. Corolla, which initially had been designed as a popular sub-compact car, now cost close to two million yen, and was nicknamed "mini- Celsior" due to its long list of features and accessories, as well as its exterior design. Eiji Toyoda, who had led postwar Japan's motorization with fellow engineer Soichiro Honda (founder of Honda Motors), was concerned. "There is no way that this 10 situation will last much longer. There will be a rebound some day. If we fail to implement proper R&D, we will eventually suffer the consequences." Toyoda grew more and more wary, and he wanted young engineers to think of cars that would be truly appropriate for the 21st century. However, during the bubble-economy period, trying to implement new R&D programs in general was difficult because everyone was too tied up with what had to be done immediately. Nevertheless, Toyota repeatedly stated this opinion at every Board and study group meeting.

Yoshiro Kimbara, then Executive Vice President in charge of R&D (now Advisor at Aisan Industry Co., Ltd.), concurred with Toyoda's view. Consequently in September 1993, Kimbara founded G21, a project committee to research cars for the 21st century. "G" was for "globe," but many employees thought it stood for Kimbara's "kin" (which means "gold" in Japanese), since Kimbara was known for his eccentric personality. Kimbara advocated a small-size car with a large cabin as the most important prerequisite for the 21st century car. Fuel-efficiency would be necessary since traffic congestion would become an inevitable chronic urban condition and fossil fuels would begin to deplete. The first and immediate prerequisite was "a small-size car." 11

Introduction of the Center System Most of today's passenger cars are powered by either of the two major driving systems: the FF system (engine in front, front-wheel drive) or the FR system (engine in front, rear-wheel drive). The FR system had been more popular but the FF system has replaced it because that layout allows a flat floor and larger cabin space due to the absence of a driveshaft under the cabin floor to connect the engine to the rear wheels. Recently Toyota has reintroduced compact FR models, such as Progres and Altezza, because many consumers enjoy the sporty performance of FR cars. The 90s, however, was the era of FF models and nearly all compact and sub-compact models were FF models.

In 1992 and 1993, Toyota implemented the largest organizational reform in its technical history by introducing the Center System, which divided the technical department into R&D departments for each individual model, FR and FF systems, and commercial vehicles. Until then, new-car development was supervised by the General Product Planning Division, a very large organization. A Chief Engineer (CE) was assigned per model -from Starlet to Century - to manage R&D. There also were individual development and design divisions for every key component, such as engine, chassis 12 or drive train. A CE would select the best component for his model from each of such departments. A CE controlled every stage of the development of a new model, from the engine to the exterior design. When there had been fewer engineers and fewer models to develop, each CE had the authority to develop unique and attractive products by selecting the suitable new technology. As the company grew larger, many problems began to surface. (At that time, Toyota had 12,000 engineers including 22 Chief Engineers, supervised by an Executive Vice President, two Senior Managing Directors, and more than 10 Directors.) It began to take longer for any piece of information to penetrate the organization. It also took longer to coordinate tasks. Engineers had difficulty grasping the bigger picture because the organization was too specialized. Any decisionmaking required a longer process. It was difficult to pinpoint who was responsible for what. These were all typical problems of a large corporation. In addition, the Chief Engineers, whose primary duty was the planning of a model, became swamped by coordination tasks, such as negotiating with other departments and so on. To solve the problem, the technical division was reorganized in September 1992 into the Vehicle Development Center I (R&D of FR models), the Vehicle Development Center II (FF models), and the Vehicle Development Center III (commercial and sports utility 13 vehicles). The Vehicle Development Center IV was established the following year specially for the R&D of units and new engines. Each of the first three Vehicle Development Centers included divisions for planning, design, and development and research for various components, such as vehicle, body, chassis and power train (engine). The Chief Engineer of each model was directly under the individual Development Centers. This basically enabled the development of new models to be completed within a Development Center. The first three Development Centers were each staffed with 1,500 to 1,900 people, and the Fourth Vehicle Development Center was staffed with 4,000 people. The organizations were now scaled down to the size of 20 years ago - the perfect size for the head of each Center to supervise everything and for individual engineers to clearly know their roles and targets. Executive Vice President Kimbara commented on the results of introducing the Center System in the April 16, 1997 issue of the Nikkan Kogyo newspaper: "The consciousness of our engineers has changed from focusing on function alone to optimizing a car. It has become easier to develop a better car." The key players in the implementation of this massive engineering reform were Mr. Akio Matsubara, General Manager of Technical Administration Division (now Member of the Board), and Mr. Takeshi Uchiyamada, who 14 later became the Chief Engineer for Prius.

Official foundation of the Project

When Kimbara decided to establish G21 in September 1993, he thought that the development of the new compact car should be handled by the Vehicle Development Center II. When the Division General Managers from the Vehicle Development Centers attended a meeting to make progress reports, Kimbara said to Mr. Fumio Sugiura, Director and General Manager of Vehicle Development Center II (now President of Trinity Industrial Co.): "I'm sure you have heard about it already, but we are now officially founding a project to pursue a car for the 21st century. Since it is most likely going to be a FF compact car, I think that it would be ideal for the Vehicle Development Center II to handle the task. Would you be willing to take care of this matter?" Sugiura was unable to reply immediately because Japan was then experiencing its booming bubble economy. The Vehicle Development Center II had many R&D issues lined up. Since the core passenger models were now mostly built on FF design rather than FR of the past, the Vehicle Development Center II was super busy. Sugiura felt that his organization had no extra human resources to start up a new project. 15 In addition, Sugiura had heard that the project was endorsed by Chairman Toyoda. It was imperative that the project be considered very seriously. Sugiura was in a quandary and he said, "Please give me some time to think." Time passed, but Sugiura was still unable to reply positively. "Mr. Kimbara, I would be interested in taking over the project, if I may." Unable to watch the days go by with no progress, Risuke Kubochi, General Manager of General Engineering Division (now Executive Vice President of Toyota Auto Body Co., Ltd.), stepped forward. As the General Engineering Division General Manager, Kubochi had attended every progress report meeting of the four Vehicle Development Centers, and had listened to the dialogue. Kubochi had been directly involved in R&D in the past, and had been the Chief Engineer for the development of the Celica. However, after becoming the General Engineering Department General
Manager, he became skeptical about the effectiveness of the current development system. Although he often gave people the impression that he was not very friendly, he had the strong determination to accomplish every task that he took up, and was looked up to by young engineers. After a Silence, Kimbara responded. "Okay. My initial intent was to have the Vehicle Development Center II take charge of it. However, you have access to every 16 technology. Since the Vehicle Development Center II is too busy to take up the project, I will assign you to it." Kubochi prepared a report to submit to the Board, and Project G21 was officially started under his leadership to study the Toyota car for the 21st century. Under Kubochi were 10 hand-picked middle managers such as General Manager Matsubara of the Technical Administration Division, General Manager Masanao Motonami (now Director) of the Vehicle Engineering Division I, and General Manager Hidetaka Nohira of the Engine Engineering Division I. Another 10 people such as Satoshi Ogiso were selected from Motonami's divisions as working group personnel. Out of the 1,000 people involved in developing Prius, Ogiso was the only engineer that handled the project from the beginning of G21. There is a good reason why most of the working group people were selected from the Vehicle Engineering Division I. This department develops bodies and basic chassis parts, such as wheels from an ergonomic standpoint, and is placed one step before the development of specific products. Since G21 had hammered out the primary concept for future cars as "small body, large cabin space," Vehicle Engineering Division I, which had been developing cars based on the same concept, took on the central role. However, the Vehicle Engineering Division I lacks engineers that specialize in power trains (engines and transmissions). So, several engineers from the Engine 17 Engineering Division II and Design Division at Vehicle Development Center IV were called upon to simultaneously work on the project. The middle management personnel and the working group personnel mostly held separate meetings. Although neither was given a name, the middle management committee, whose role included reporting to Board members, came to be called *"Kenjinkai"* ("Committee of Wise Men"), and this name was used in the meetings' records. The working group committee was simply called the "G21 Working Group.

" **A friendly beginning** Toyota's development facilities are located in two places: The technology department at the Toyota Head Office in Toyota City, Aichi Prefecture, and Higashifuji Technical Center

(Susono City, Shizuoka Prefecture) near the Gotenba Interchange on Tomei Expressway. The main role of this Research Center, which is located about three hours on the Tomei Expressway from the Toyota Head Office, is basic research and development. The technology department at the Toyota Head Office develops products by using the technology developed at Higashifuji Technical Center. Kenjinkai was held weekly at the conference room of General Technology Department in Toyota City. On the 18 other hand, the Working Group consisted of people working at either location. So, the location for the Working Group meeting alternated between Toyota City and Higashifuji. When the meeting was held at Toyota City, the conference room of the Design Division was used. Since the early-stage meetings for developing new models were typically held at the Design Division, the group followed the custom. Kenjinkai was in charge of making the decision on general framework and principle as well as reporting to the Board. Although active work was divided between Kenjinkai and the Working Group, Motonami was usually interested in what his men were up to. Whenever the Working Group meeting was held in Toyota City, he would often drop by. At this time, there had been no mention of a hybrid vehicle. The G21 project team was given two assignments. The first was to think of a new method of building cars for the 21st century, which was related to the product idea advocated by Kimbara. The second was to review the method of developing cars and to venture into a new method. The project team considered the first assignment as that of packaging, and decided to work on minimizing the size of the car while maximizing the cabin space. Even when working with a new concept, the basic rule was to consider how a person actually fits inside a car. After several discussions, environmental and safety issues 19 emerged. "If the fuel economy of a basic Corolla is 13 kilometers per liter (30.8 mpg), we should aim at improving it by 50%." "Then, are we talking about 19 kilometers per liter?" "Let's plan on 20 kilometers per liter (47.5 mpg), since it's a nice round number.

By the 21st century, engines with such high fuel economy should become available." After discussions like that, the group generally agreed to aim at a fuel economy of 20 kilometers per liter. Ogiso, who joined the G21 project from its genesis and was involved in the product planning throughout the development of Prius until its market-launch, looks back and says, "We thought that that was already a groundbreaking target." Needless to say, every member already knew of the hybrid system. However, they thought the system would not be ready for the G21 project. In other words, they thought that a real hybrid system would never become available to the public within this century. The members began studying the existing items to achieve the new fuel economy target. "I've heard the direct-injection engine performs very well." "How about a CVT (continuously variable transmission)?" The members agreed to try out many items from the 20 Vehicle Engineering Division. Since the Working Group operated under a committee system, each member was simultaneously involved in other tasks. Each member considered the weekly meetings as a stress-free study group meeting, and the meetings proceeded in a friendly atmosphere. Ogiso was in charge of organizing the meetings. Since most meetings were held with certain subject matters to discuss; for example individual functions of a car such as transmission and passive safety; each member arrived at the meeting with guests who were experts on the selected subject. There were times when close to 30 engineers attended the meeting as guests, depending on the subject matter. "It is good that everyone can speak frankly in the meetings, but it seems so disorganized," thought Ogiso, who felt somewhat unsettled and anxious. As for the individual engineers who were facing many limitations such as performance and cost in the daily work of their expertise, G21 was a dream-like project, and was also an ideal opportunity to relieve their stress. This very freeflowing idea was the aim of the G21 project, but something was not working out. On the other hand, the Kenjinkai was taking place weekly from about 7:00 p.m. Uchiyamada, who later became the Chief Engineer for Prius, attended the Kenjinkai every two or three meetings. He belonged to the Technical Administration Division at the time, and was simply viewing the project from an administrative 21 standpoint as an engineering project. He attended the meetings simply because his boss Matsubara told him, "Think about how to position this G21 project within the company, in case the organization is to be reestablished as an official development group in the future." Nevertheless, 1993 was coming to its end, and it was time for the G21 project team to present a conclusion. From time to time, Kubochi, Motonami, and Matsubara reported to Executive Vice President Kimbara and others, who were the founding fathers of the G21 project. However, the team was facing a deadline in preparing a final report to be presented to interested Board members as a concluding activity. for 1993.

The first progress report The meeting was held at the Vehicle Design Review Room on the third floor of the Ninth Engineering Building in Toyota City. The Design Review Room is generally used for reviewing the design, by bringing the actual car into the room. About thirty people including Executive VP Kimbara and Member of the Board Masami Konishi (now Chairman of Fujitsu Ten Ltd.) attended the meeting. Since the G21 project worked on concepts and did not have an actual car, the team prepared a half-scale design blueprint and a summary. Ogiso had assumed that his 22 manager Kubochi would be making the final report and organized the presentation. He pasted the design blueprint on the dry-erase board, and handed out a copy of the summary for each person present at the meeting. Kubochi already had been briefed on the presentation proceedings. The G21 Working Group members took their seats immediately behind the Kenjinkai members. The meeting began. As Ogiso was about to prompt Kubochi to start the presentation, Kubochi turned to Ogiso and said,
"Ogiso, I would like you to make the report. "What, me?" Kubochi smiled a bit, and immediately turned back to the audience. Ogiso, a 32-year-old youngster who had just been promoted to a *"tanto-in"* (engineer-in-charge), equivalent to an Assistant Manager in other companies, took several deep breaths, pulled himself together and stood up. "Uh, my name is Ogiso. With your permission, I would like to proceed with the report." Ogiso was somewhat tense, but he began his speech in front of the top executive in charge of the engineering division. "When we were discussing how the 21st century passenger car should be, we began considering the package of a car." The idea of a 21st century passenger car put together by the early G21 project team was as follows: 23 1. A roomy cabin space will be achieved by maximizing the length of the wheel base. 2. The seat position will be set at a relatively high position to facilitate getting in and out of the car. 3. The exterior design will be aerodynamic, and the height will be around 1,500mm, not quite as tall as a minivan. 4. The fuel economy target will be 20 kilometers per liter, which is 50% better than the other passenger cars of its class. 5. The power train is based on a small horizontally placed engine equipped with various items such as an efficient automatic transmission. There was no opposition to this report. As far as the package was concerned, all the ideas were within the parameters that everyone had in mind. Kimbara encouraged the group, saying, "You have finally climbed to the start line. Keep up the good work so that we can achieve our goal." He had a hunch that the project would turn into something quite interesting. As for Ogiso, he did not remember any of the comments from the Board members. He had cared only about meeting going smoothly, so now he was taking deep breaths of relief. At this meeting, nobody talked of when to launch the model. Since the initial idea was to launch the model within the
20th century, most people understood that the 24 deadline was the end of 1999. After finishing the report, Ogiso smiled and thought to himself wryly, "Damn, he did it to me again." This was not the first time that Kubochi had put him on the spot. When he was still at the Chassis Engineering Division, Ogiso was involved in the development of the first generation FF Celica whose Chief Engineer was Kubochi. Back then, Kubochi often used the same trick to have Ogiso give the presentation at the last moment at department meetings. "I would have guessed that he would do it again if this were a department meeting. How was I to know that he would use the same old trick at the project's final report?" Ogiso had had no idea. However, by being placed in the desperately critical situation to give the presentation, he learned to organize issues in his head as he spoke, and acquired a sense of confidence. Indeed, this was Kubochi's unique method of training his men. Ogiso was born in Tokyo in
1961. He received a mechanical engineering degree from Tokyo Institute of Technology in 1983, and joined Toyota. He had belonged to an automobile club at the university, and had worked on the off-road dirt-trial day in and day out. In dirt-trial racing, the so-called drift-driving method is often used, which encourages the car to skid so that it can turn corners more swiftly. An FR car is a better choice than an FF car for that purpose. Ogiso worked on tuning the chassis for FR cars every day in college. 25 Ogiso was determined to start working for an auto maker, but the auto industry seemed to be turning from FR cars to FF cars. For example, Nissan had just switched its core sedan Bluebird from FR system to FF system at the time. Ogiso chose to work for Toyota mainly because he thought there would be a greater likelihood that he would work on FR systems. After joining Toyota, Ogiso worked on designing

the chassis for Celica, Camry and Tercel until 1992. Ironically, however, the company had already decided to switch Celica from FR system to FF system, and Ogiso worked on three generations of the FF Celica. Ogiso moved to the Vehicle Engineering Division I in 1993, and worked on chassis predesign. Ogiso had realized the necessity for a new package for a car and was about to begin the pre-development phase when he was called to work on the G21 project.

Paying back the debt to the old home The first-generation G21 project team was disbanded after the final report meeting, and a new group was organized in January 1994. The package concept for the 21st century-automobile was set so the new G21 team's mission was to draw the specific blueprint of a car ready for launch by selecting the optimal engine and transmission based on the concept of creating a fuel 26 efficient and environment-friendly passenger car. The structure of the project team also was upgraded from a committee system to a permanent project team with engineers selected from different departments to work together as an independent unit. Technical Administration Division's Uchiyamada was chosen to be the group leader. This choice surprised everyone, especially Uchiyamada himself. "I had heard that someone would take charge of the project, but I never expected myself to be the one," says Uchiyamada. The purpose of the new G21 was several steps ahead of the previous one, whose mission was to draw up a concept, and was very similar to that of a new car development project. It was evident to everyone that the project would eventually evolve into a Z (product planning) project if all went well. Naturally, it would have been more appropriate for a newcar development expert or experts in body design or chassis design to be selected for the post. However, Uchiyamada started out in the Vehicle Evaluation & Engineering Division II. After working on vibration research for many years, he had moved to the Technical Administration Division. As mentioned earlier, he had contributed to the reorganization of the engineering departments, namely the introduction of the Center System. After finishing the task, he had intended to return to research. 27 Uchiyamada had thought, "I would one day like to return my debt to the research department which had nurtured me to become a capable
research engineer." By temporarily leaving his old post and viewing the entire engineering division from a third-person standpoint, he was able to realize many problems he did not see when he was on the inside. The tasks in research largely depend on the potential of the individual researcher. A researcher's job is to analyze the experiment results, look for problems, and find solutions and countermeasures. If the research division lacks the ability to compete with the rest of the world, the finished design would not be internationally competitive. In other words, the ability of the research division is the very essence of Toyota's engineering ability. The research division is a group of highly specialized experts in various fields. Toyota can nurture a truly capable research engineer only by training a researcher in each field for a very long time with great care. On the other hand, the research division is often affected by the immediate tasks directly linked to product development, and lacks the long-term attention needed to nurture great researchers. Whether the division is doing an optimal job with the current issue is irrelevant to its long-term well-being. In addition, since the management for the research division was constantly being switched with new people from other departments, there was, in
reality, nobody who could 28 continuously supervise the division. However, Uchiyamada did not believe that the importance of the research division was fully understood inside Toyota. "The research division is doing very well these days; they are able to solve problems very quickly," commented the other divisions. On the other hand, Uchiyamada thought, "We are simply enjoying the potential of our existing researchers. It is quite uncertain whether or not the next generation of researchers would be as capable as the current generation of researchers." Uchiyamada received the same impression from the young researchers in the division; they all had a sense of a vague anxiety towards the future. Hence, Uchiyamada was thinking of implementing his vision to "nurture young researchers and scout people who would eventually supervise the whole research division in the long term." When the introduction of the Center System was completed at the Technical Administration Division, he had expressed to management his desire to go back to the research division. 29

A bolt out of the blue

In mid November of 1993, Uchiyamada was called by Technical Administration Division General Manager Matsubara to come to his office. "I remember you had requested to return to the research division. Unfortunately, you have been assigned to succeed Kubochi to supervise the G21 project. You are now the Chief Engineer." "Why, me? That's impossible. I have zero experience in product planning. The position should go to someone who is an experienced Chief Engineer elsewhere." "That's true, but the management has already made the decision." It was a bolt of lightning out of the blue. A few days later, Uchiyamada was called by Shinichi Kato, Member of the Board in charge of technical management (now Senior Managing Director), and was officially assigned to the position. Uchiyamada asked Kato. "Why on earth was I chosen? What is your expectation?" "As you know, the mission of the G21 project is to build a car for the 21st century. However, that is not our only intention. We would like you to establish a new method of developing a car through this project." "What do you mean?" 30 "Well, since there is no existing car to refer to for this project, you have all the freedom to come up with a new method. You can try out anything you like." Kato refrained from saying anything further. "Oh, by the way, Kubochi also agreed that you would be the best candidate." That moment, Uchiyamada remembered the time several years ago when he had a discussion with Kubochi. Uchiyamada's appointment was decided by four superiors; namely, Senior Managing Director Akihiro Wada, Member of the Board Kato, Uchiyamada's boss Matsubara, and General Engineering Department General Manager and the first G21 leader Kubochi. It was Kubochi who particularly pushed Uchiyamada to take the position. Wada, Kubochi, and Uchiyamada had worked together many times before. When Wada was the Chief Engineer for the Celica, Kubochi worked under him supervising the group while Uchiyamada was in charge of the vibration and noise experiments. At one point, Uchiyamada had come up with an ingenious idea to reduce vibration, and had suggested it to Kubochi. However, Kubochi immediately rejected the suggestion, "No, I don't want to do it." Offended by Kubochi's reply of "I don't want to do it" instead of "I can't do it," Uchiyamada pressed Kubochi further for an answer. "Why can't you do it?" 31 Kubochi explained. "I think that your suggestion is a very good idea, technically speaking. However, I am not confident that we can try out the method now and finalize it before the new model is completed. If we are only able to do it half way, and if we make a habit of doing things half way, I would lose the confidence of the younger members. I have the confidence of my people because they believe and have seen that I am a man of my word. That is why I refuse to do it this time." Uchiyamada could not help but feel vexatious. However, he had nothing to say, because he had witnessed repeatedly throughout the years that Kubochi would accomplish anything that he put his mind to by leading people with all his capability. Kubochi had often supported his people by convincing Board members and other managers who opposed the group's idea. "I had no idea that completing a new model in the product planning stage was so difficult...." Uchiyamada was finally convinced, and said to Kubochi. "I will implement this method in the next opportunity." Kubochi smiled. Kubochi, who knew about the difficulty of product planning inside and out, was the very person who pushed Uchiyamada to become the next G21 project leader. However, Wada, Senior Managing Director in charge of 32 development, opposed the idea in the beginning. "Whatever you say, Uchiyamada has no experience (in product planning). Wouldn't it be too risky?" "That is the very reason why I strongly recommend him to the position. This project needs an open mind. He should be able to introduce a new method." Wada had often witnessed how the two worked together when he was their Chief Engineer. He was also very familiar with their personalities. "Okay, I will take your word for it. We'll see how Uchiyamada will do," Wada agreed. On the other hand, Member of the Board Kato had a different point of view. In fact, one day in October, Kato had a discussion with Matsubara. "How is Uchiyamada? You have worked with him on the major project of introducing the Center System. Now, we are interested in how much he can do by himself. If everything goes well, he might prove to be someone that could lead Toyota's engineering division in the future. Would you be willing to assign him to development?" "He still has a lot of work to do at the Technical Administration Division," Matsubara replied. "I understand that. Actually, we are thinking of having him take charge of the G21 project. Could you give him a chance?" "If that's the case, I should. He has learned about management at the Technical Administration Division. He is the one that knows best within the company about 33 which department to contact to get what piece of technology. In that sense, he would be very suitable for the position." Matsubara agreed to assign Uchiyamada to the G21 project. Thus, Uchiyamada was appointed to his new position, Vehicle Development Center II Planning Department Chief Engineer, and became the leader of the re-structured G21.

Two generations of Chief Engineers Uchiyamada was born in 1946 in Okazaki City, which lies adjacent to Yasaku River across from Toyota City. He grew up building plastic model cars and reading the biography of historical figures, such as Thomas Edison. One day, young Uchiyamada read a biography of Doctor Porsche, and discovered that the creator of the famous racing car had also designed the VW Beetle. Since then, he became more interested in popular cars, such as the Beetle and the Ford T-Type rather than luxury cars and sports cars. Uchiyamada began to think, "I would love to build cars like that some day." Around that time, his family bought their first family car, a Toyota Corona, further fueling the boy's dream. He had also read about Sakichi Toyoda, founder of Toyota and inventor of the Toyoda style automatic loom, from a collection of biographies. 34 Uchiyamada studied engineering at the local Nagoya University with an emphasis in applied physics. Uchiyamada's father was instrumental in his selecting this field of engineering. Uchiyamada's father, Kameo Uchiyamada, had also worked for Toyota as the Chief Engineer for the legendary third-generation Crown. The Uchiyamada family was the first family to produce two generations of Chief Engineers for Toyota. The father later served as the General Manager of Technical Administration Division. Uchiyamada, who grew up watching his father work, decided that he would work for Toyota in the future when he was a middle-school student. When he was trying to decide in the last year of high school which field to choose in college, his father told him, "There are many mechanical engineers at Toyota. It may be more beneficial for the auto industry in the future if you studied something other than mechanics." Hence, he chose to study applied physics. Because he had no interest in research and experimentation since his high school days, Uchiyamada had little difficulty selecting the research lab in college. He selected the automatic control lab because it was "the only lab through which I could obtain a degree without doing experiments." Today, automatic control engineers are highly sought after by auto makers for research in Intelligent Transport Systems (ITS). Back then, however, the technology was a little too advanced for the industry. 35 When Uchiyamada began looking for a job, it turned out that Toyota was not looking for any automatic control engineers. Back then, an auto maker had no need for an engineer with background in applied physics. An auto maker would generally employ engineers that were recommended by the professors of individual labs. Today, as a countermeasure to eliminate the typical problems of a huge corporation, Toyota is trying to attract a wide range of talents by taking job applicants through a more open recruiting process. Back then, however, Toyota had an employment tradition of taking a specific number of people from pre-selected engineering labs every year. Uchiyamada, who was determined to be hired by Toyota, visited Toyota's Human Resources Department, explaining that his lab had not received job offers from Toyota. He asked to take the company entrance exam. He was given permission to take the exam because of his enthusiasm, passed the exam, and finally was hired. 36

I want to work on cars Toyota had some difficulty figuring out where to post this applied physics major engineer. For the time being, Uchiyamada was placed in the Technical Computing Section (now the Information Systems Division). For four years, Uchiyamada worked on a project for molding intricate metal shapes using computer assisted numeric control (NC) machinery. Uchiyamada was certainly not familiar with computers when he joined the section. He was placed there simply because the fresh-from-college workers had to be assigned to each field of engineering as a company practice, and also because the Technical Computing Section had been expecting a new worker. This project team later succeeded in completing the largest NC system. Uchiyamada began working with computers quite unexpectedly, but was able to do satisfactory work. Coincidentally, he would later work on Prius, which would be extensively equipped with computers. However, Uchiyamada felt, "I didn't come to Toyota to work on computers; I want to work on cars." He requested to be transferred to an engineering department. Fortunately, there was an engineer who wanted to move from an engineering department to the computing department at the time. Uchiyamada was told that there was an opportunity to switch positions with this engineer. 37 Before moving, Uchiyamada asked a senior engineer for advice as to which field he should go into. "I am interested in working in a field where I can have a good overview of a car." "In that case, you should look for a position in body design or chassis design. However, experience is crucial in both fields. You are already four years behind your colleagues, and that is a major handicap. On the other hand, if you decide to go into research, you have a chance of catching up by working harder. If you go into vibration research, you will be able to deal with the entire car. With this advice, Uchiyamada decided to ask for a transfer into the research department. Back in his college days, he would do anything to stay away from research in a lab. This time, the situation was different. After the transfer, Uchiyamada spent 16 years and six months in the research department. Uchiyamada built his career by developing insulation material for the Crown and studying and setting an evaluation method for the anti-vibration sub-frame, which later would become a mandatory item for all FF luxury cars. The #-shaped anti-vibration sub-frame was completed by meticulously studying American cars. At the time, Toyota and other Japanese auto makers considered European auto makers, such as Mercedes-Benz and BMW as their chief rivals. In the meantime, American auto makers succeeded in drastically improving 38 the performance of their cars and in reducing noise. Since Toyota did not own any American cars to study, Uchiyamada led a research team to the United States to thoroughly study cars there, thereby displaying his executive ability. Uchiyamada then worked for four years at the Technical Administration Division before he was selected to take the helm of the G21 project. It was a quarter century after he started working for Toyota. 39

Chapter 2 **Sedan Package Revolution - Body**

Toshiharu Ishida of Planning Division II, Vehicle Development Center II, was assigned to the G21 project at the end of 1993. Ishida studied fluid dynamics at Kyushu Institute of Technology, and began working for Toyota in 1983. His motivation behind joining Toyota was a little different from others. He was interested in drafting, and wanted to do drafting for the best-selling industrial product in Japan. The Corolla was his choice. After joining Toyota, he was assigned to the Body Engineering Division according to his wish, and begged his boss to let him design for Corolla. Contrary to public notion, Toyota has traditionally respected the will of individual workers. Ishida also received the blessing of the tradition, and was put in charge of designing the instrument panel for Corolla. Ishida was appointed to the G21 team through a recommendation from his boss. Ishida later was put in charge of the interior design for the Soarer, and the Chief Engineer at the time was Seihachi Takahashi (now Director). Takahashi strongly recommended Ishida to Uchiyamada. Uchiyamada and Takahashi had been friends in sailing, and had kept in touch. 40

An uncertain departure

Ishida, who was assigned to Uchiyamada, started working on the project with the progress report meeting of the first-generation G21 team. In January of the following year, the new G21 team took off. However, there were only two people on the team at that point. The two met in a large conference room at Planning Division II. "Now, Ishida-kun, since we are officially beginning the project in February, let's think about what we should do before that. First, we need to recruit people and find office space. Then, let's see.... That's right, we should discuss with experts. It is safer to do that than us trying to think afresh, " said Uchiyamada. It was a rather uncertain departure for the team. Although the concept for the G21 car was decided, the structure was completely blank. The two went to receive a lecture from the person who had the most knowledge about the individual units and technology such as seats, transmissions, multimedia components, and headlights. They also made trips to the Higashifuji Technical Center, and studied the basic structure of a car for one month. Through his experience in introducing the Center System, Uchiyamada had the knowledge regarding what type of engineers were found in which departments. The two also had to promptly select project team members. Uchiyamada himself selected five people that 41 he had in mind, and directly went to their superiors for permission to get them reassigned to his group. Ogiso, who made the progress report presentation in December, was one of them. Uchiyamada asked the General Managers of each department for recommendations to find another five members. Ishida also needed to find office space. Fortunately, there was an open conference room that had been used for special Board meetings on the sixth floor of the 3rd Engineering building. The room had red carpeting throughout, and there also was a

reception desk for administrative assistants. Back when motorization was at its peak, many legendary cars must have been planned and discussed in this very conference room.... That is the kind of impression that one would receive from this room. Uchiyamada negotiated with the Technical Administration Division and obtained the room. Since this room was located away from the rest of the engineers, it was an ideal place to work on the special project. Now that the members were appointed and the office space was obtained, the two had to look for office equipment and supplies. Since it was a secret project even within the company, there was no way for the members to borrow computers from other departments for designing. They definitely needed their own computers, at least for CAD (computer-aide design). They eventually managed nevertheless to obtain two CAD 42 computers from other departments. At Toyota, each department is allotted annually with both personnel and facility. The company never grants unscheduled facilities except on very rare occasions. G21, however, was a project endorsed by top management, so needed facilities were specially made available within the Technical Administration Division's budget. Back then, while some people were familiar with G21 and understood the importance of the project, others were completely uninformed. "Have you seen the weird bunch that are congregating in the red carpet room?" People began to talk about the secret project team around this time. After obtaining information from each department, office space, equipment, facilities, and team members, the first meeting was held on February 1 in the 10th Engineering Building because the red carpet room was not yet furnished. The following 10 were at the meeting: Project Manager Hiromi Yoshimura of the Power Train & Chassis Components Production Engineering Division; Assistant Manager Kazuhiro Miyauchi of the Vehicle Production Technology Department; Assistant Manager Ogiso, Assistant Manager Naoki Okada and Assistant Manager Tatsuya Hattori of the Vehicle Engineering Division I; Assistant Manager Takeshi Sakai of the Body Engineering Division II; Assistant Manager Katsuhiko Aoyama of the Engine Engineering Division II; Assistant Manager 43 Makoto Funahashi of the Drive Train Engineering Division; Assistant Manager
Ishida of Planning Division II; and Chief Engineer Uchiyamada of Planning Division II. Uchiyamada was the only one to speak at the meeting. "This project is something completely new to us. You are all encouraged to absorb new ideas. Go to many places, meet new people, read various and different books, and open up your horizons." Ogiso was surprised that Uchiyamada was a very different type of leader from others. Ishida, who had spent the last month with him, was thoroughly impressed by Uchiyamada's wealth of knowledge and by his ability to continue talking at length about various subjects. By the end of the meeting, each member had introduced himself. No one did anything unique or showy, and everyone was equally nervous about the new project. Thus, the new G21 project began. As Uchiyamada indicated in his opening remarks, every engineer was to work individually. Some went back, therefore, to their previous departments to collect information and data, while others visited outside of their departments. Every project member met at least once a week to report on their progress. The members, however, kept in close contact with each other even on days when there were no meetings For example, the member in charge of the engine would drop by at the bodydesign engineer's office to check up on things. At this time, the members had ample time 44 and were free of mental stress, and were generally happy that they were "able to do what they liked." The management had guaranteed two things to the new G21 project team. First, they did not have to worry about the model competing against Toyota's existing cars. Second, they would be allowed to develop all new parts if necessary. The first guarantee implied that the team was allowed to develop any-size car they wanted and use any component available in Toyota. In other words, it granted the team the freedom of design. However, the second guarantee implied that the team had to explain in detail why the existing part or component could not be used if the team decided to develop a new one. Although the new G21 started by organizing the blueprint drawn by Kubochi's first G21, problems began to emerge and
difficult decisions had to be reached. For example, they were unable to come up with clear justifications for the dimensions of certain parts, or whether or not a new transmission was needed. The team could not even decide whether the engine placement should be FF, FR or mid-body. When it came to deciding which engine or transmission to use, every engineer supported the one he was working on. It was the same with suspensions. Those problems persisted for some time. 45 The keyword for the 21st century

The red carpet room on the 6th floor had a nice view and on a clear day the mountains of the Mikawa region could be seen. Uchiyamada would gaze outside whenever he had worrisome problems to think about. "Ishida-kun, come take a look," Uchiyamada might say. "There is smoke coming out from there today. I wonder what it is." Ishida was always a little perplexed when Uchiyamada talked to him like that. He knew Uchiyamada was a shy daydreamer. What could he be dreaming of in his imaginary world? One day, when the discussion on the selection of hardware was deadlocked, Uchiyamada, who was staring out of the window, turned around and said, "Let's stop this. Let's stop focusing on hardware." Everyone stopped talking and listened. Uchiyamada told them, "We engineers tend to focus on hardware. However, what we need to do with this car is to focus on the `soft' aspects, not the hardware. Let's forget everything about hardware and review from the beginning the concept of the car that we are trying to build from the ground up." The discussion now returned to the basics. Someone said, "What we need is some sort of a guideline in order to clarify the concept so we can decide 46 what kind of product to make." "Okay, then, let's look for keywords that indicate what is needed for the 21st century car," Uchiyamada suggested. He also said, "It could be anything. What should a car be? Or what kind of a car do you want in the 21st century? There should be many books and articles on this subject available in the market. Let's all look for concepts and draw up a list of keywords that strongly relate to the automotive society of the 21st century." Several days later, many keywords were offered: "Increased traffic accident fatalities," "increased population of the elderly in developed nations," "decreased childbirth and more women in the workplace in Japan," "rapid development of multimedia," "more serious traffic congestion," and so on. Ishida then put together a report on those keywords. After many brainstorming sessions, two key words remained: "natural resources" and "environment." Those key words were especially meaningful at that time because auto
makers were focusing on the depletion of the ozone layer due to the use of CFCs (chlorofluorocarbons) in air conditioning systems. Also, Uchiyamada recently had overheard his wife and his elementary school age daughter talking about how to sort trash for the various waste disposal methods his daughter had learned at school. After listening to the discussion, Uchiyamada realized that he lived a life far more detached 47 from environmental issues than his family and that concerns over natural resources and the environment would one day become major social issues. Eventually, the team narrowed down the concept and settled on building a car that would be resource- and environment- friendly while retaining all the benefits of the modern car. In other words, the team acknowledged the original G21's goal to build "a small, fuel-efficient car." As a first step, the team reviewed the first G21 team's vehicle package design, and recalculated the measurements so as to take into account
statistics of average human body dimensions. Since the main prerequisite of the car was to comfortably transport four adults, the team decided to design to the measurements of those between the 5th percentile Japanese female (height of 148 centimeters or 4 feet 11 inches) and the 90th percentile American male (190 centimeters or 6 feet 3 inches). The team was already anticipating an eventual introduction of the car into foreign countries. There are many methods to design the packaging of a car. When designing from scratch, the most common way is to first determine the driver's position based on ergonomics. The team, therefore, began their discussion from this very basic and fundamental standpoint. "Let's first set the position of the driver's buttocks." Discussions began under the leadership of Vehicle Engineering Division I engineers who specialized in 48 ergonomics. What seat height would facilitate getting in and out of the car? By assuming the passenger's height to be between 148 centimeters and 190 centimeters, the comfortable height for the seat was determined to be between
550 millimeters and 600 millimeters. The position of the buttocks was put at 575 millimeters by taking the average of the two measurements. Next, the team considered the seating position. What is the most comfortable seat form at that buttocks position? When a person is seated, there is a particular range of angle for the leg joints that minimizes impact on the feet. Experts call that the "comfort angle range." The team decided the comfort angle range seating position by setting the buttocks position for everyone in the above average height range. When the driver's position was set, the team then worked on setting the distance between the driver and the passenger next to the driver. Since the team wanted Prius to have as small a package as possible, they wanted the distance between the driver and the passenger to be minimal. However, if the driver and the passenger are too close together, they may feel cramped. In order to determine this distance, the team relied on the reactions of two large males

actually sitting in various body buck seating configurations rather than rely on published data alone. How close were their heads to the framework of the car's body when they began to feel cramped? The dimensions of the cabin space were determined through 49 such experimentation. When the positions for driver and passenger were decided, the position of the accelerator pedal and the dimensions for the wheelbase and tires were also decided. Finally, the position of the engine was set. A full-scale side view of the most recent version of the car was always pasted on the wall of the red carpet room. That was Uchiyamada's idea. Engineers commented, "I see, this is where the roof lining will be," and "The engine compartment seems fully functional," as they began to get a good feel for the height and the size of the car. Usually development engineers would have a one-fifth-scale drawing of the car on their desk but the life-size drawing proved to be extremely helpful in getting a firm image of the car. 50

Designing a car from scratch Every auto maker uses this method to determine the packaging of a new car, but auto makers also would pay attention to market evaluation and customer complaints and go through a series of model changes to meet consumer demands. Toyota had not built a car from scratch for a while, and most younger engineers had never experienced the process. "How did they decide on the current Corolla's dimensions? Why is this part on Corona designed to be this size?" Even though the team decided to try out the most fundamental design procedure, the predominantly young G21 team still did not have a good understanding of the existing designs. The team decided to actually compare the dimensions of their car designed from scratch to those of existing cars. "If they are drastically different, we might be wrong or we might be doing something revolutionary." The team members were both nervous and excited. Starting with Toyota's own sedans, the team took measurements from well over 30 models, including newly introduced minivans and cars from other auto makers. Even some Toyota cars proved to have very different measurements from their concept car.
As they had expected, the dimensions of most existing cars turned out to be different from their car. In order to find out why there were such differences, 51 the G21 members went to see the designers for Corolla and Corona, and asked how they had arrived at the particular measurements. "How did you come up with the measurements of this part?" "We received many requests to extend this part from the previous model by 20 millimeters." Next the G21 members went to visit the designers of the previous models and asked the same questions. "I believe we compared our designs to the previous model. ..." If a designer could not get an answer, he hunted down the previous designer. In the end, the G21 team found that there were no clear reasons as to why the designers had selected the existing measurements. Because of their research, G21 members became quite confident of their design, and they finalized the general dimensions and framework, such as the body and the suspension, of the new car. The suspension was chosen after an in-company design competition.

"Designing a car from scratch is a very rare experience. We should try to make our experiences accessible to everyone else in the company. Let's put everything down on record," Uchiyamada suggested, as the team was getting ready to create a clay model. Nobody disagreed. The team compiled a 200-page 52 document, detailing how the decisions were made and what procedures were used. Although the document describes the developmental process for the Prius, it is not available to anyone outside of the company. Even within Toyota, special permission is required before anyone is allowed to browse through it. Every month, the team reported to Executive Vice President Kimbara and in turn they received some directive from him at every meeting, but they were never told to make drastic changes. Kimbara retired in June of that year from the Board, but was appointed a Director of Toyoda Central Research & Development Laboratories, Inc., which does basic research for the Toyota Group. Senior Managing Director Wada succeeded him as Executive Vice President in charge of development. Since the team was unable to come up with final answers and decisions, Wada often nudged them, saying, "You guys, how long do you have to discuss all this? The world will be over before you are finished."

Trying out a new unit

When the decision was made on the packaging, the team then proceeded to discuss what to do with the engine and the transmission. In the first-generation concept car proposed by Kubochi and others, neither the engine nor the 53 transmission had been selected. Needless to say, there had been absolutely no mention of a hybrid system. The team that had reached agreement only about the packaging of the car and the numerical targets for power output and fuel economy. The fuel economy target was vague so as to be at least 50% better than existing (Corolla class) cars. Finally, the group began to address the questions of whether or not they could achieve the performance target by using existing parts and how many new parts needed to be developed from scratch. The team agreed that it would design a new platform, engine, and transmission. Since they had selected a new seating position, they also had to design the seat from scratch. The team members armed themselves with the rather coercive argument that they must try new units since they are designing a car for the 21st century. They also decided to try electronic power steering to further improve fuel economy. Electronic power steering was used only on mini-cars and on certain passenger-cars at the time, and still had some problems in terms of cost, reliability, and performance. In theory, however, it was capable of improving fuel economy by three percent. "It is evident that it will become an essential item in the 21st century. It is definitely worth it to start trying it out," Uchiyamada said, so electronic power steering was included in the new car. Most functional parts, therefore, were to be designed from scratch, but the group had not 54 yet dealt with specifics, such as engine displacement or transmission type. After keywords describing the design were selected, the overall process moved more quickly. Uchiyamada's personality was also a major factor. Toyota's engineers usually understood "immediately" to mean "in a week." Uchiyamada, however, would say, "Oh, you can get it done right away? How about in three hours?" He managed to maintain a busy and productive atmosphere with the team members who otherwise would become unfocused from their tasks at hand.

Running a prize competition for suspension design

It was the suspension that remained undecided long after the packaging had been selected. The performance of the suspension that connects the wheels to the body of the vehicle directly affects driving comfort. It was the single element that required utmost care and attention in the selection process. Less weight was definitely better for fuel economy. Smaller was better too because in keeping with the new package for the 21st century car, the team wanted to maximize cabin space as well as trunk space and provide more room for the fuel tank. The team needed a suspension system that would accommodate those conditions. The team had decided in the beginning that the front 55 suspension would be a lightweight, high-performance McPherson Strut Type System. The team looked everywhere in the company and found nothing that would fit the new Prius platform. A suggestion was offered by Uchiyamada at a G21 meeting. "What do you think about running a prize competition for the suspension? Rather than having the engineers bring different suspensions one after another, we can have them presented at the same time under the same conditions." "That's a good idea. That way they won't have any grudges against each other. We might be able to find something better by having all ideas public." Ogiso, who mainly supervised hardware at G21, agreed. Ishida who was in charge of "soft" aspects of the project also had no objections. The team immediately notified related departments of the competition. Competitors were from the Pre-Development Group at the Vehicle Development Center IV and the Chassis Engineering Division II at the Vehicle Development Center II. The Vehicle Development Center IV specializes in developing non-conventional technical software as the predevelopment group. The Vehicle Development Center II is in charge of developing products related to auto development. Hiroyuki Shimatani of Vehicle Engineering Division I from the Vehicle Development Center IV had worked with the G21 starting in 1994, and had been studying 56 suspensions for Prius. The Vehicle Engineering Division I is in charge of proposing the general concept for a new car as well as specific ideas, such as packaging and frame, to the product development departments of Vehicle Development Center I through III. G21's Ogiso was mainly in charge of vehicle planning, while Shimatani was in charge of developing the next-generation rear suspension of an FF car. They were well into their work when the competition came up. "The Vehicle Development Center II is probably ahead of us in developing suspensions, but we too would

like to propose a new suspension as a pre-development team." Engineers at the Vehicle Development Center IV agreed, and began looking for a suspension system they could submit to the competition. One of the suspensions developed at the Vehicle Development Center IV was the Diagonal Beam. It had been independently developed there from the Trailing Arm- Type Coil used in past models of the Landcruiser Prado. While this suspension provided a comfortable ride and stability during high-speed maneuvers, it was large and took up space from the fuel tank to some extent. Nevertheless, the group decided to submit to the competition their newest Diagonal Beam design that already had been patented but not yet put to use. In the meantime, Vehicle Development Center II proposed to compete with "the same Torsion Beam as that 57 of VW Golf." At that time, there were about 20 different types of suspensions available for the next-generation FF car. After test-driving many cars, the group selected Peugeot 306 and Peugeot 406 as benchmark cars that provided a good balance between comfort and maneuverability. Both of those cars were equipped with Full Trailing Arm-Type suspension on an anti-vibration sub-frame. However, since the structure of the suspension system was larger than others, fuel tank capacity and size would have to be significantly reduced to make room for it. A very different suspension utilizing a Torsion Beam was used in the Golf While this suspension excelled in terms of maneuverability, the horizontal strength of the arm needed to be reinforced by stiffening the [rubber] bushing used to secure the arm. When that was done, the ride became rougher and riding comfort had to be sacrificed. This type of suspension was often used in European cars and contributed to the general notion that European cars had a stiff ride. The group was torn between the two. "Peugeot has far more comfortable ride, and the balance between comfort and maneuverability is better." "But, then we cannot meet the conditions set by the packaging because we would have to sacrifice trunk space. It would be more practical to improve the ride comfort using the Torsion Beam." In the end, Vehicle Development Center II proposed 58 the same Torsion Beam suspension as the Golf. Satoshi Murata was in charge of its design. Full Trailing suspension was also considered along with Vehicle Development Center IV's Diagonal Beam and Vehicle Development Center II's Torsion Beam. General Manager Motonami of Vehicle Engineering Division I, General Manager Shigeta Mikoshiba of Chassis Engineering Division II, Kubochi who had been appointed in September 1994 as Member of the Board in charge of the Vehicle Development Center II, and G21's Uchiyamada
discussed merits of three systems. They looked at the technical issues, but were unable to reach a final decision. They agreed to disqualify the Full Trailing system as being too large to fit within Prius' compact packaging. Kubochi persisted in favoring the Torsion Beam, and Uchiyamada insisted on the Diagonal Beam because of its novelty. The final decision, however, was made by the General Managers of Chassis Engineering Division II and Vehicle Engineering Division I. It was the Vehicle
Development Center II's Torsion Beam that was selected in the end because it was: "Conventional, and highly reliable. There is ample room for the ride to be improved. Provides sufficient trunk space." The two also pointed out, "The ride may be improved by applying the advantages of the Diagonal Beam." In January 1995, Shimatani was assigned to the Vehicle Development Center II Chassis Engineering Division II. His mission was to apply the advantages of 59 Shimatani's Diagonal Beam to the Torsion Beam. Uchiyamada asked him, "Shimatani-kun, I feel rather awkward, but would you help us out in the mass-production division? We really need the Diagonal Beam technology that you developed." "Please, don't worry about it. I don't bear any grudges about the decision because we thoroughly discussed each system and I said everything there was to say. But this is a chance to mass-produce a part of the technology that I've developed. I am very glad that I can help." Shimatani was honestly happy that his Diagonal Beam technology, on which he had once given up, would be used in Prius. Most of the pre-development of conventional cars had been handled by Vehicle Development Centers I through III, while most of the pre-development for Prius was done at the Vehicle Development Center IV. It was impossible for G21 to be completed as a product without the help of engineers from the Vehicle Development Center IV After moving to the Vehicle Development Center II, Shimatani test-drove the Golf (which had the Torsion-Beam) many times, and acknowledged that the ride was not very comfortable. Especially when the car was going over very rough surfaces or large bumps in the road, he experienced very unpleasant sensations of being pushed up from below. Because many Japanese customers chose cars for ride comfort, he wanted to improve the suspension's response to rough road conditions as well as 60 improve the general riding comfort on regular road conditions. If the bushing is set at a lower resistance level to lessen the harsh ride, the wheels would yield to side (lateral) forces thereby affecting the rotational capability of the wheels through curves. In order to solve this problem,

Shimatani attached an additional component called the Tow Control Link used in the Diagonal Beam. With the new configuration, the lower-resistance bushing would absorb the shocks from rough road surfaces and bumps while the Tow Control Link controlled and adjusted the wheels from leaning outward due to lateral forces on curves. In other words, Shimatani added the advantages of the Diagonal Beam to the Torsion Beam. "With this new system, we can have confidence in competing with European cars. Okay, Torsion Beam with Toe Control Link is rather redundant. We should come up with a better name," suggested Shimatani. He immediately sent an E-mail to each suspension engineer on a mailing list designated "VD mail." Established in 1995, it was the forerunner of Toyota's current in-house mailing list. He received about 40 comments from within the department and 30 E-mail replies. He selected 30 names to submit to the Naming Committee. Sponsored by the Technical Administration Division, this committee was an organization that gave official names to new technology. The name selected for the new suspension was the "H-Beam," 61 using the Greek letter "H" (pronounced "eta"). This was for the simple reason that when viewed from above, the suspension looked somewhat like the letter "H". "The letter `H' can have a risque meaning here in Japan and is thus not exactly acceptable, so how about using a Greek letter for H?" It was actually Shimatani who came up with the name. "It probably isn't a very good idea for me to design the suspension and also name it. But, oh well, I guess it means that I knew the most about this suspension," he joked.

Experiment-less and Backup-less The developmental process for Prius came to be seen as an ideal way for designing a car from scratch. Another aspect of the ideal system was the experimenting with new ideas for manufacturing. The team proceeded "experimentless," which minimized prototype building, and "backupless," which indicated that no backup plans were made. When the framework of the car was decided, Wada came to the G21 room and said, "With Prius, try not to make any prototypes. If you build something, you get tied up with improving it and get stuck there. Make the first prototype after thoroughly discussing the design and 62 calculating the structure. Don't ever try to build a prototype until you are absolutely sure, based on theory." When a team member indicated his disagreement, Wada looked outside the window and continued. "Take a look at this. Have you ever seen a general contractor make a prototype of that bridge or that building? They build it one time only. Even with airplanes, they build only two prototypes, one for endurance tests and another for approval. We are the only ones that are building prototypes one after another only because a car is small and easy to make. That's why we have no progress." Wada was well known for that view. Uchiyamada agreed with Wada. Uchiyamada minimized the need to build prototypes when sufficient experience and data were available, especially in case of making improvements on the body. Since the development period for Prius was short, there would not be enough time to build many prototypes. In case of something new like the hybrid system for which Toyota had no prior experience, a sufficient number of prototypes would be built. Complete prototypes, including the body, were built at the end of 1995, in April 1996, in February 1997 as the official prototype, and in June for final approval. Twenty to thirty prototypes were built each time, and the total came out to be around 100. That number is exceptionally high for a new model of an existing car. But 63 most of the prototypes were built for the purpose of testing new components, such as the hybrid system and the battery.

Cutting off the retreat The other idea of "backup-less" was taken even more seriously. Typically, when a new technology is scheduled to be used in a new car, a backup development plan is implemented simultaneously just in case a problem might arise with the new technology. This helps to disperse the risk and launch the car on time. In case of Prius, there were no simultaneous development plans and no backup plans. Known for its extremely cautious business practices, Toyota in the past definitely would have taken every precautionary measure in a project like G21 that is burdened with uncertainties. Past Toyota managers had believed precautionary measures to be the basis of risk management. Uchiyamada, however, instructed his staff, "Don't prepare any backup plans since we have to do this much new development in such a short period of time. If you have time to think of a backup plan, use all the resources instead to develop the main technology." There were two reasons. First, it would be wasteful to divide up personnel and work assignments. With one backup plan, half of the people would end up working on 64 a task that eventually would be cancelled. With two backup plans, 70% of the resources for development would be wasted. Another reason was that the pe ople involved in the main development program would lose inte nsity because there would be a backup plan to fall back on. Extraordinary efforts can be coerced only by cutting off all opportunities for retreat. An example was development of the electronic p ower steering. Under normal procedures, the development work would be done within the company while a subsidiary company would be commissioned to simultaneously carry out the same task. Electronic power steering would appear to be only a small part in its relationship to the entire vehicle but failure to develop it would greatly affect the launch date for Prius. Although people from various offices advised Uchiyamada to have backup plans, he refused to listen. Under normal circumstances, and it would have been impossible for an experienced Chief Engineer to stick to such policy. Although backup plans were not prepared, concept changes were often implemented. The team would continue R&D based on one concept, until they came to a dead end when they would promptly agree to a change in concept. That approach helped the group to stay together, and also allowed everyone to start something new with a fresh attitude. In addition, the members shared a sense of 65 crisis and concentrated more on their work because they thought, "We have less time now because we used up time on the previous concept." The team, therefore, was able to focus all its resources and efforts into one project, thereby allowing for efficient development. The G21 team was beginning to find answers for the other task of developing a new car using new methods. 66

Chapter 3 Selection of the Hybrid System - THS

After compiling the development progress of the new concept car in a report, G21 Phase II team was to be disbanded by the end of July 1994. No special meeting was held to present the report. Each member returned either to his original department or another similar department to begin work on designing specific parts, such as chassis to implement the concepts included in the six-month progress report. Meanwhile, Uchiyamada, Ishida, and Ogiso who was transferred from the Vehicle Engineering Division I to the Product Planning Department of the Vehicle Development Center II as of August 1st, remained with G21 and continued working towards production in the red carpet room. G21 Phase III began. The speed of development for the production of the hybrid vehicle Prius accelerated from this point. Even with the holidays in mid month, August was spent reviewing the blueprint designed by G21 Phase II. The team still had difficulty choosing the main structure of the car: the power train. Of course, the hybrid system was a candidate for the G21 car. Uchiyamada disagreed, however, with the use of the hybrid system for the following three reasons. 67 1. Work on developing the technology for the various components had not been finished. In particular, the performance of the batteries then available was hopeless. 2. Toyota's hybrid system was ready only for research. The infrastructure of the design and assessment departments also was not ready for the production phase. 3. The cost was too high. In September, the G21 members held several discussions on the power train with Executive Vice President Wada and Managing Director Masanao Shiomi (now President of Araco). The hybrid system came up for discussion, but no conclusion was reached. Every member simply thought, "It would be pretty difficult if we had to really start working on the hybrid system."

Launch a hybrid vehicle at the Motor Show

Three G21 members were given another task besides continued development for production. They were assigned to develop the concept car for display at the Tokyo Motor Show in October 1995. The concept of this car for the Tokyo Motor Show was the same as the concept for G21: a compact passenger-car that sets the standard for the 21st century. It also would 68 serve as a production tryout vehicle prior to the production of Prius. The team, therefore, planned a car with a conventional engine and a highly efficient automatic transmission in an appealing package. Their plans had to change quickly, however, when their mandate suddenly shifted. When Uchiyamada and Ishida went on a Friday in November 1994 to brief Wada on the recent progress of G21, Wada said to them, "By the way, your group is also working on the new concept car for the Motor Show, right? We recently have decided to develop that concept car as a hybrid vehicle. That way, it would be easy to explain its fuel economy. We are not talking about production here, so show us your best ideas."

Tokyo Motor Show is the premier opportunity for auto makers to show concept cars based on their ideas for future automobiles. G21's car was going to be one of the major attractions at the coming Motor Show. With less than a year to go before the Motor Show, the team now had to design each unit from scratch. Even though concept cars are only for show, creating them means serious work. As a matter of fact, the group would have had more time to develop a hybrid vehicle if its production were scheduled for year 2000. Shocked by what he had been told, Ishida ran back to the red carpet room.
"Hey, Ogiso. We have a major problem." 69 Ogiso was surprised to see Ishida in such an excited state, but he too was equally shocked to hear the news. The group now had to complete a hybrid system, with which they had zero experience, in just several months. The three met at work the following weekend and began to look at the various types of available hybrid systems. After doing their research, the three selected a system that would use the directinjection 4-stroke gasoline engine "D-4" currently being developed by the Power Train Engineering Division II, an electric motor developed by Electronics Engineering Division III, and a CVT (continuously variable transmission). The D-4 engine achieves fuel economy improvement of more than 30% over conventional engines by directly injecting fuel into the cylinder and creating an extremely lean combustion mixture with the ratio of air to gasoline up to 50 to 1. Mitsubishi led the auto industry by introducing "GDI" in August 1996, and Toyota followed the following December with its own direct-injection engine on the Corona Premio. CVT had been under research for many years, and was almost ready for production. The team decided to build a system by combining the direct-injection 1,500cc engine and the CVT with Electronics Engineering Division III's motor and a capacitor (condenser) for charging batteries. Since they were all almost ready for production, the team decided to use them for the Motor Show. 70 The design of the show car progressed smoothly, and an acceptable model emerged. The team, however, came to feel that it did not want to emphasize the term "hybrid system" because Toyota had decided to use a hybrid system in a preproduction car in June. The team members wanted to make sure other companies would not learn about the new product. Hence, the propulsion system for the show model was named "TOYOTA-EMS
(Energy Management System)." The body packaging of the model was touted as being "a realization of a mobile space by pursuing comfort and convenience," while the engine was simply explained as: "A motor assists the engine during acceleration to reduce engine load, achieving fuel economy of 30 kilometers per liter (Japanese 10-15 city driving mode)." The word "hybrid" was not mentioned or used in any publication. Despite the secrecy, the car was named Prius - which means "prior" in Latin - to indicate that the model arrived prior to the 21st century. Although still a concept car, Prius was in fact a new car. The exterior of the concept car came from the Design Division in Toyota City, but Prius as a whole was designed elsewhere.

Uchiyamada later described what he thought about the first-generation Prius. "Although we had decided on using a different hybrid system for production by the time of the Motor Show, we received good reviews for the car's concept and packaging, which fueled our 71 confidence towards production."

No, you must double that As 1994 was coming to an end, the team resumed its discussions on the choice of the propulsion system for the production car, while simultaneously developing the hybrid system for the Motor Show. G21 members led by Uchiyamada met with Wada and Shiomi, and recommended a system that improved fuel economy 50% by combining a direct-injection engine with a new transmission. "No, that isn't good enough. You understand that we are talking about a car for the 21st century, right? The fuel economy shouldn't be just 50% better. You must double it." "But, that's outrageous!" "Then, come up with another system so that it won't be outrageous." It was at that point that Uchiyamada started thinking about a hybrid system. Wada and Shiomi continued. "Since you are already developing a hybrid vehicle for the Motor Show, there is no reason not to use a hybrid system for the production model." Ogiso then realized what the two executives had been intending to do. "I see. They prepared us with the 72 Motor Show so that we wouldn't be too shocked about having to develop a hybrid vehicle." Uchiyamada still resisted. "It is too risky." "If you can't do the hybrid system, G21 will have to be dismissed," Wada gruffly replied. Realizing that Wada was serious, Uchiyamada gave in, but thought to himself, "This is a rare opportunity to design a car for the future. We cannot dismiss it simply because of problems with the power train. Okay, then, I shall negotiate the conditions." Uchiyamada asked: "Mr. Wada, I have one request. The G21 team alone cannot handle the hybrid system. Since the new hybrid system will be the first system for production in the world, we must select the best system for our future. I would like you to put together a team of the finest engineers at Toyota to discuss which system to develop." "Okay, I will take care of that immediately," said Wada, accepting the counteroffer.

BR-VF In the fall of 1994 when G21 Phase III was discussing body design for the 21st century, Toyota's engineering division was about to launch another project to research ideas for future cars. The project was designated "BR-VF," [73] and its purpose was to study the use of hybrid systems in the future. "BR" was one of the terms used in the Engineering Department to describe business reform projects. The creation of four Development Centers in 1992 and 1993 produced many positive results but also introduced some negative aspects later. Because the reorganization had divided the Development Division into small groups, administrative functions weakened. The division also lost its edge in planning and setting concepts for the future. There also was a need for the Centers to further improve automotive technology. The Technical Administration Division formally noted those weaknesses in 1994, and decided to introduce small, short-term projects to work out solutions. Such projects were designated BR for "business reform." The Technical Administration Division found 11 problem areas for the engineering division as a whole and a total of 64 among the departments. "Value analysis," which is used to reduce cost by analyzing the value of existing technologies, was introduced as "BR-VA," while "value engineering," which is used to reduce cost by similarly analyzing value from product planning to pre-production, was started as "BR-VE." The "BR-VF" (for "vehicle fuel economy") was yet another BR project which was implemented to study the hybrid system as a technology of the future. Uchiyamada's request perfectly matched the objectives of BR efforts. BR-VF was given a new directive: select [74] the most practical system in the short term. BR-VF was to be done in three clear steps, with Phase I spanning between February and July in 1995, Phase II starting in July 1995 and ending in March 1996, and Phase III lasting from March 1996 to April 1997. In the end, BRVF was consolidated with the Electric Vehicle Division of the Vehicle Development Center III. It was established as a permanent organization in April 1997 as the Electric and Hybrid Vehicle Engineering Division within the Vehicle Development Center IV As expected, the task of BR-VF Phase I was to select the hybrid system for G21.

Kato, who was promoted to Managing Director, took charge of BR-VE The month of December 1994 was spent selecting personnel. General Manager Yuichiro Fujii of Electric Vehicle Division was assigned to simultaneously serve as the General Manager of BR-VF. In addition, Project General Manager Nobutaka Morimitsu of Engine Engineering Division I, Staff Leader Hideaki Matsui of Drive Train Engineering Division, and Project Manager Shoichi Sasaki of Future Project Division I were selected as full-time members. Takeshi Kotani was also selected as a part-time member, together with three electrical engineers, Hatsuo Nakao, Toshifumi Takaoka, and Yasutomo Kawabata. The team met in a large room on the third floor of the 3rd Thermal Research Building. The room also housed the Electric Vehicle Division which was separated from the rest by a partition. [75] Fujii was assigned personally by Executive Vice President Wada and Managing Directors Kato and Shiomi to lead the group. Electric Vehicle Division was in the midst of developing RAV4EV so it was working extensively with motors and batteries. It also was the group involved in work that most closely resembled the hybrid system that combines an engine and a motor. Fujii asked Wada, "Please give me six months for planning, since it is brand new technology." Wada replied, "Finish it in three months." The system was finally selected in June that year, so the selection process actually took four months. Nevertheless, the project team was pressed for time. At the time, Fujii had agreed to lead the group even though he had little insight into whether the project would succeed. "I did actually think that the system might be put into production, but I hadn't been told anything concrete. I simply worked on selecting a system for possible use." Members of BR-VF were not informed of the work underway at G21, so they knew the G21 team "as the weird bunch in the red carpet room." 76 [1]

Using the system on the Camry? BR-VF members in charge of selecting the hybrid system began meeting frequently in January and February with G21 members led by Uchiyamada. The joint meetings began by first discussing the basic outline of the car. According to the original plan, they were supposed to select a system to use in a G21-designed passenger car of the future. Due to the fact that the G21 car had a small body and large passenger compartment, the engine compartment was exceptionally small compared to other passenger-cars of its class. The BR-VF team, therefore, suggested, "Our current hybrid systems are all fairly large. Uchiyamada-san, they may be too large for G21's compact car. Let us discuss the possibilities of using a Camry-class car which is two levels larger." Size was not the only reason for the BR-VF team to suggest working with Camry. A larger car with inferior fuel economy would benefit more from a fuel-efficient hybrid system. The amount of fuel saved would be greater than in smaller cars, and using the hybrid system on a model with high production costs would be more cost effective. Simply put, installing a hybrid system on Camry would produce many positive results. A larger version of Camry was manufactured abroad so that would facilitat e Toyota's launch of a hybrid version internationally. 77 But, Uchiyamada disagreed with BR-VF team's idea. "We are trying to build a car for the 21st century, and our work isn't about applying the hybrid system on existing models. If we take the conventional method of `first trying out the system in a large car,' we would end up making too many compromises in terms of cost and size. There would be less waste if we worked with a smaller car from the beginning." Unable to reach an agreement with Uchiyamada, BR-VF began its research using the Camry as its basic platform. Kubochi, G21 Phase I leader, had been appointed as a Member of the Board in September 1994, and had become General Manager of the Vehicle Development Center II. He was supervising the G21 project again, this time as the person in charge of developing FF models. Kubochi also had doubts about using a hybrid system at that time. Even with all the work that had been done so far, there were no engineers who thought that a hybrid vehicle would eventually go into production. BR-VF engineers, such as Fujii, took the idea of putting the hybrid system in a model based on Camry to Wada and Shiomi. The two executives turned down the proposal as being foreign to the G21 concept. The BRVF group finally had to acknowledge that the hybrid system would be used on a car designed by the G21 team. In the meantime, the G21 team conducted thorough discussions, but no one had any confidence in hybrid 78 systems. "It seems so risky no matter how we think." "Then, how should we back up the plan?" The three from the G21 group felt increasingly burdened by their assignment as the days went by. At that point, BR-VF's hybrid system was nothing more than a design concept in theory and simulation data on paper.

Series-type and Parallel-type For purposes of general discussion, hybrid systems can be divided into "series-types" and "parallel-types." As used in the automotive sense, the word "hybrid" means "composite," and hybrid systems use both an internal combustion engine and an electric motor to power the vehicle. While an internal combustion engine cannot achieve sufficient power and torque unless a certain level of revolution (RPM) is achieved, it can function very efficiently once that certain rpm level is reached. In contrast, an electric motor generates its maximum torque from the very moment it is turned on. Consequently, an electric motor is suitable for achieving rapid acceleration. However, when a car is powered by an electric motor at highway speeds, both internal combustion engine and electric generator must stay engaged to supply the motor with electricity. When engine output is converted to 79 electricity and then again turned back into mechanical power, overall energy efficiency declines. A hybrid system takes advantage of the merits of both types of propulsion and also compensates for their shortcomings. A "series-type" system runs the generator with the (e.g., gasoline) engine, and uses the generated electricity to power the motor to turn the wheels. A small-output engine can operate steadily at an efficient range and store t electricity in a battery, while a motor powers the car. Only a small engine for generating electricity is needed, and the entire system is relatively simple. With a 1,500cc-class engine and a motor, a quiet, clean, and fuelefficient system can be built for cars as well as for small buses. In contrast, a "parallel-type" system uses both an internal combustion engine and an electric motor to power the wheels, using either of the two depending on various factors, such as speed, road grade, number of passengers, and so on, to achieve the most efficient result. The motor is used to start and accelerate the car, and the engine is used for highway speed cruising. It is also capable of charging the battery while cruising on engine power. The control system for this type is complex, however. BR-VF began discussions on which hybrid system had the most potential. The concept of a hybrid system was relatively old, and Uchiyamada found that many systems had been 80 introduced in the `70s. Auto makers around the world, such as General Motors in the United States, had studied various system many times. Nevertheless, the prevailing notion in the auto industry was that a hybrid system could not be developed for commercial production because no one had solved the technical problems relative to the battery, control system and software.

Four candidates The BR-VF members reviewed about 80 varieties of hybrid systems that had been introduced to the world. There were far more variations of the parallel-type system than the series-type system. Some of them were considered to be not worthwhile and were disregarded immediately. In addition, since improvement to fuel economy was of the utmost importance, series-type systems that cannot be specifically controlled according to various driving conditions also were disregarded. Thus, the team ended up focusing on parallel-type systems, partly because Toyota had been developing a mini-bus, Coaster, using the series-type hybrid system, and had sufficient know-how on series-type systems. About ten varieties remained. The team carefully discussed the theory behind each one and selected four. 81 The four varieties the team selected are believed to have been: 1. A system eventually used in Prius consisting of an engine, two motors, and a battery, with a planetary gear to electronically control power partitioning. 2. A system fundamentally the same as 1 but with a different method of connecting the planetary gear to the unit. 3. Same as 1, but using a partially mechanical control system instead of a planetary gear to partition power. 4. A unit based on the 1995 Motor Show model with an engine and a motor with a CVT. The systems that were selected for 2 through 4 are just assumptions, since Toyota has not yet disclosed any information about them because of the likelihood of bringing them to production sometime in the future. Now that the four candidates were chosen, the team had to evaluate each system. It was practically impossible to build a prototype for each system and run tests in only three months. It was too time-consuming and costly. Moreover, there was no certainty that the team would be able to make prototypes that actually worked. The team then decided to create a virtual system on computer and run simulations to select the most fuelefficient system. Sasaki took charge of the first system, Matsui the second, Kawabata the third, and Kotani the 82 fourth. The four systems were studied simultaneously. Meanwhile, part-time members in electric engineering discussed which type of database was necessary to run the simulations. Since fuel economy would fluctuate according to the performance of each component, the output of the engine, the motor, and the battery was predetermined, as was the car's ability to accelerate. Toyota has an enormous database on engines and gears from past models. The Electric Vehicle Division also has a fair-sized database on batteries and electric motors. The parameters of each system were determined based on those data. However, every system needed software to control the driving mode in the virtual system. None of the BR-VF members could figure out how to write the software, and were at a standstill. It was Sasaki from Future Project Division I that worked on the first system, which later would be selected as the hybrid system for the project. Sasaki was interested in the future of automobiles,
and joined Toyota in 1974 after receiving his Masters degree from Tokyo University in Electrical Engineering. After working in the Auxiliary & Electronic Experiment Department, Sasaki worked from 1980 to 1994 on energy management using motors at the 11th Research Department at the Higashifuji Technical Center. He was in charge of controls for the FCEV (fuel cell electric vehicle) in his final year there. 83

A savior arrives While the whole BR-VF team was working on control methods, Sasaki one day remembered that his colleague Akira Ohbatake, who he had met during his last year at Higashifuji, was an expert in controls and was using readily available software for controls to simulate the ride of the FCEV. Sasaki called Ohbatake and asked for the name of the software. The software was called "Matlab" and made by an American company called The Mathworks. Ohbatake explained to Sasaki,

"You only need to input the data of the system to run a simulation, since most driving conditions are already included in the package." After telling Fujii about the software, Sasaki begged Managing Director Kato and Technical Administration Division General Manager Matsubara to buy the software right away. Sasaki also dared to request a workstation and a debugger so that complex simulations could be run on the computer. Since this was a project for the future hybrid vehicle, Kato quickly gave his consent to buy a system that cost more than 30 million yen. The money came out of Technical Administration Division's buffer budget. The workstation arrived shortly. When Sasaki cautiously turned it on, the computer started unexpectedly smoothly. The experience was similar to that of a novice photographer who is handed a compact, fully automatic 84 camera just as he is trying to figure out the components of a professional, single lens reflex camera, saying "Here is the focus, this is the shutter speed, and the subject depth is..." When he saw how well the computer was running, Sasaki felt, "This should allow me run all the simulations I want." In due time, the four virtual systems were completed. Sasaki then entered various conditions, such as driving modes and speed. As for fuel economy, it
could be derived instantaneously under any condition. He felt that the simulation would be completed in no time at all. A problem surfaced, however. Sasaki's work came to a standstill when he tried to figure out which control method to use to monitor fuel consumption. Many driving conditions were simulated
in the beginning, and the results were entered into the database. The conditions included heavy city traffic, relatively open suburban traffic, expressways, and winding mountain roads. In real life, however, a car is exposed to far more variables, such as varying numbers of passengers, rough drivers, mellow drivers, and so on. Climate conditions also may affect fuel economy. A method to simulate large numbers of driving conditions soon proved to be impossible to find. Sasaki felt there was no way for
him to include every driving condition in the simulation. He also felt that without a huge database to use in the simulations, the results might prove to be drastically different from real-life fuel 85 economy.
"This is no good. I'll have to figure out an absolute algorithm that provides for every type of driving in any condition. How am I to do that?" Sasaki spent a week searching for an effective method. The algorithm in this case refers to a program that determines how to control the engine, the motor and the generator. Day in and day out, even while he was showering, Sasaki continued to think about how he would write the algorithm. He had no easy answers and he felt he was going nowhere. "I should forget about everything and take a different approach." Just as Sasaki decided to change his mind, a savior appeared. Yoshihide Nii of Electronics Engineering Division III who had worked with Sasaki on FCEV at Higashifuji, visited the BR-VF office during a trip to the Toyota Head Office. Arai had done research on other hybrid systems, such as the control system for the previous-generation Prius developed for the 1995 Motor Show. Since his boss Nakao was a part-time member of BR-VF, he was keenly interested in the project. When Arai came to the office, Sasaki as usual was deep in thought in front of his computer. Arai looked at Sasaki and said to him, "What's wrong? You look very serious. Is your
Matlab working okay?" "Hello, Arai-kun. Actually, I'm having some 86 problems. I don't seem to be able to figure out how to partition power among the engine, the motor and the generator. I can get it to a certain point, but it is definitely not good enough." "Oh, I know a good method," said Arai nonchalantly. "You can derive all conditions by setting the engine at a certain power output. That is the method we used in simulations for the last Prius." Arai continue to explain. There are only four factors that determine driving condition. First is the acceleration and braking information coming from the driver. Second is the weight and angle of the car, or information on how many people are in the car and whether the car is going downhill or uphill. The third factor is the speed of the car at any given time. The fourth is information on how much power is left in the battery, a condition unique to a hybrid system. Arai explained that driving conditions of a hybrid vehicle could be analyzed by combining these four factors. The driver has control only over the first, which indicates the rotation of the engine. When the power output of the engine is known, the method of controlling the engine can be set, then the methods of controlling the motor, and finally the generator can be set also. An algorithm was created
by simplifying driving information as much as possible. "I see, the only information we need is that of the engine. Thanks for the tip. I promise to take you out 87 to dinner one of these days." Thanks to the help from Arai, Sasaki was able to write an algorithm in just three days. "Since the concept is very
simple, the rest of the work is so easy." Sasaki was very impressed with how things had come together. "I can't believe I spent so much time trying to figure out something as easy as this." Sasaki ran simulations for a month straight on the new computer to make up for the lost time.

A seamless drive

Simulations using the new algorithm showed that fuel economy was very similar for three of the four systems. System number two was dropped. Since there were no significant differences among the remaining three systems in terms of fuel economy, which was the main objective, the next important factors were potential for production and maturity of technology. It was important to select technology that could be adapted easily for use in cars and that mass production would be possible and easy. In addition, the team looked at whether the system had possibility for growth and whether it could become standard technology. The selection process for the three remaining systems focused on the control method for the drive train. One 88 was electronically controlled, another was partially mechanically controlled, and the other was controlled with a CVT. If the emphasis was to begin production as soon as possible, the mechanical control method was the best choice by far because of previous knowledge and experience. The CVT control system also was a good choice because it already had been built once for the 1995 Motor Show. On the other hand, Toyota had little experience with electronic control. One had been developed for EVs so there were some prospects for success, but it was not cost effective, because it needed two motors and an inverter. There was hope that electronic controls eventually would become much cheaper to produce since ICs, such as semiconductors, were dramatically getting more powerful. The control unit itself would be compact because it would be controlled only with a decelerator, without a transmission. In addition, there was a possibility that electronic control systems would be used in future FCEVs, as well as in hybrid vehicles. Discussions to select one of the three systems continued but the three engineers who were in charge of the three systems were beginning to develop a bias towards their own system. Matsui, who had built the second and already disqualified system, had been assigned to BR-VF from the Drive Train Engineering Division. Born in Osaka, he 89 had studied Thermal Dynamics at Gifu University's Mechanical Engineering Department, and had joined Toyota in 1971. After working on combustion research and emissions regulations at the Higashifuji Technical Center, Matsui was assigned to drive train predevelopment work and to such basic research as CVT, and finally had become a member of BR-VE Matsui cautiously examined and compared the three systems by focusing on "seamless driving" and the "takeoff mechanism." An automatic transmission (AT) changes gears
according to pressures to the accelerator pedal. Since the RPM of an engine will change abruptly when the gear is shifted, a driver will feel a jolt. Although recent ATs are much smoother than those in the past, a slight jolt is inevitable. On the other hand, a CVT uses two pulleys to connect belts instead of gears so it achieves seamless driving during acceleration and deceleration. It is especially noted for its smooth, continuous acceleration. An electronic control also can achieve seamless driving, since it functions as a stageless transmission by controlling the rotation of the generator and smoothly changing engine RPM. Matsui thought, "Since we are proposing a car for the 21st century, we should strive for a car that offers an entirely new driving experience." Matsui's other focus of interest was the
"take-off." 90 Manual transmissions (MT) use clutches, while AT and CVT use torque converters to start a car moving. Designing the clutch mechanism can be rather difficult. Since Matsui had researched CVTs and was thoroughly familiar with them, he was also well aware of the disadvantages.
"If we are looking at efficiency alone, primarily mechanical CVT would be better. On a hybrid system, however, it is more difficult with a CVT to start and stop the engine when the car is in motion." While he was partial to its simple design, as a drive train expert, he also was slightly disappointed that it was unable to perform better as a transmission. After weighing all these considerations, Matsui gave his support to the first system. Almost all members of BR-VF also were attracted to the first system rather than to the old system used in the Motor Show car. The engineers were exhilarated by the choice. Two meetings in May and June would determine which system to propose to the G21 project team. One was a meeting to confirm technology, and the other was for the engineering division to make its decision. If an agreement could be reached on technology at the meeting, it would become in effect the
decision of the company. BR-VF decided to prepare design drawings for each of the systems prior to its presentation at the meetings. The purpose was to verify that all of those systems would fit inside the limited space in the engine compartment of the G21 car. The group agreed to do the drawings for the 91 first system. When the drawings were finished, the design looked good and they decided to propose that, and only that, system. "Let's make this the *de facto* standard of the hybrid system." Everyone

agreed. Consequently, neither concept drawings nor design drawings were prepared for any of the remaining systems.

Development code name is decided On June 30th 1995, G21 members attended the final decision-making meeting. It was the meeting that would decide everything about the development project - from people to goods to money. All Board members involved in engineering attended. The outcomes of the meeting always determined the future of new car development. Even Department General Manager-class managers get nervous about attending. Since the Technical Administration Division sponsored the meeting, Member of the Board Shinichi Kato in charge of both that department and BR-VF served as chairperson. Kato had been briefed in detail about the components of the hybrid system to be presented that day. Uchiyamada gave a report on the progress made up to that point. After the report, Executive Vice President Wada asked a few questions and praised the team. Shiomi in charge of EV was pleased. Shiomi is 92 known as a "radical" within Toyota's engineering division because of his innovative ideas. He is a bold engineer who created a new package for a one-box-type wagon by placing the engine horizontally inside the Estima minivan. Shiomi supported Wada's decision with a little joke, "I used to think that I was bold, but Wada-san has coerced a hybrid system out of the team in just a few months. He is much bolder than I am. He has put me to shame." Naturally, everyone at the meeting knew that Shiomi was the most avid supporter of EV and hybrid systems. Kubochi, who had looked after the project as General Manager of the Vehicle Development Center II, listened to the presentation with much satisfaction. He was relieved that the project had progressed so far. Development of a hybrid vehicle was officially approved at the meeting and a code name "890T" was assigned. The hybrid system was named "Toyota Hybrid System (THS)." The first phase of work assigned to BR-VF was done. The next step was a technical review of the hybrid system starting in July, and the work of BR-VF Phase II would begin. Its members temporarily returned to their old posts to recruit additional engineers for the hybrid team, and they became the design team for various components. The organizational structure for development work was officially established. BR-VF
would be responsible for planning the hybrid system and overall controls in THS. Planning for the 93 hybrid system would include planning the development of specific technology for each component, as well as drawing the scenario for its future growth, especially in regard to how it might affect society and what its position might be in society. Technology development for each component would be assigned to different groups. The engine would be developed by the Engine Engineering Division II. The hybrid transaxle would be developed by the Drive Train Engineering Division. The battery and motor would be developed by the Electric Vehicle Division (which was consolidated with BR-VF in April 1997 and reorganized as Electric and Hybrid Vehicle Engineering Division). The brakes would be developed by the Chassis Components Engineering Division II. In addition, auto evaluation engineers of Vehicle Evaluation & Engineering Division II and others were to work jointly with BR-VF Production technology groups, including the Power Train & Chassis Components Production Engineering Division, the Production Engineering Development Division, and the IT Engineering Division would have direct involvement with BR-VF, contributing as the second development division for creating THS. Electronics Engineering Divisions II & IV and Hirose Plant were to take charge of the development and production of inverters, including semiconductors. The G21 group (reorganized as Product Planning Group "Zi" in January 1996) led by Chief Engineer 94 Uchiyamada was to take charge of coordinating the work of all the groups so they could be applied to the new car.

Backing up with theory Morimitsu came to BR-VF from Engine Engineering Division I. He had worked on the "Engine Scenario" project which takes the "bigger picture perspective" of such things as the future of motors and reciprocating engines. The BR-VF team had looked at the role and importance of the hybrid vehicle as an ecofriendly car for the future, and had created a "hybrid scenario." Its role was to provide the theoretical rationale for the first production hybrid vehicle in the world. Increased emissions of the greenhouse gas carbon dioxide (CO_2) and the threat of fossil fuel depletion have compelled global auto makers to change their ways of doing business. Industrial production has increased dramatically since the Industrial Revolution that took place in England, and the 20th century was the century of the auto industry. In the past, long distance transportation had been limited to railroads and ships. Automobiles, however, have enabled people to travel to any place they like. Automobiles have helped to increase human potential. On the eve of the 21st century, however, more and more people are starting to focus on the negative aspects of motorization, such as traffic accidents, traffic 95 congestion, and pollution. It has only been several years since auto makers began taking the issues seriously and developing safer cars that cause fewer accidents and inflict less severe injury on both passenger and pedestrian in case of an accident. Moreover, environmental issues, such as global warming, are unavoidable issues for auto makers if they are to continue their business into the 21st century. Internal combustion engines that generate power by burning fossil fuels, such as gasoline, create CO_2 during the combustion process and emit gases, such as carbon monoxide (CO), hydrocarbons (HC), and nitrous oxides (NO_X). Today, automobiles account for a little less than 20% of all CO_2 from man-made sources. However, only one-fourth of the world's population enjoys the benefits of automobiles. If all developing nations experience motorization in the future to the level of developed nations, the total CO_2 emissions would be considerably greater than today. Developing cars that emit less CO_2 and other gases and creating a plan to introduce more such cars into the market are missions of social importance for automakers and also the only way for them to survive in the 21st century. Toyota's first concrete strategy for reducing CO_2 emission is to improve conventional engines and technologies. Even though fossil fuel depletion and global warming are harmful realities, the vast majority of automobiles in use on this planet are powered by gasoline 96 or diesel. Even though environmentally friendly cars like electric vehicles have been developed, they make up only a small fraction of the total car population. Improving fuel economy and reducing emissions from existing engines can improve the environment immediately. It is critical, therefore, to develop technologies and materials that help improve fuel economy, e.g., lighter weight materials, leanburn or directinjection engines, and Variable Valve Timing with intelligence (VVT-i). Diesel engines, which are popular in Europe, achieve better fuel economy and, hence, emit less CO_2 but they emit more particulates, smoke and NO_X. In order to eliminate those disadvantages, Toyota has been studying various technologies, and has developed the common-rail injection method that reduces vibration, noise and emissions by injecting fuel at extremely high pressure.

The next engine The next issue is to search for cleaner and more efficient motors with alternative energy sources, such as EV, CNG (compressed natural gas), and hybrid. The public has high expectations for pure EVs to replace internal combustion engines and to become the key ZEV (zero-emissions vehicle) of the future. However, engineers are having a difficult time making them practical or easy to own. 97 That is to say, there are no solutions currently available for the two issues of infrastructure and driving range per charge. Unless using an EV becomes more convenient through changes in the infrastructure so that there will be a sufficient number of battery-charging stations and the driving range increases to at least 400 to 500 kilometers between battery charging, an EV cannot succeed even after these last ten years. If an eco-friendly car does not provide all the conveniences of today's cars and is also consumerunfriendly, consumers will never support it. A CNG car achieves better fuel economy using a highpressure fuel supply, and has lower emissions of CO_2. In certain areas of the world, CNG is more readily available than petroleum, and has great potential. However, CNG cars suffer from the same problems as EVs, with limited infrastructure for fuel supply and limited travel distance between fuel supplies, thus making it undesirable as a replacement for existing automobiles. The FCEV concept is based on the electrolysis of water into hydrogen and oxygen. Energy is extracted as electricity from the chemical reaction of hydrogen and oxygen and the electricity powers the motor.

In other words, an FCEV is an EV with a small internal power plant. By reacting oxygen in the atmosphere with hydrogen stored on the car, an FCEV can generate power to move yet release only water vapor as emissions. However, it too has many problems, such as lack of infrastructure to supply hydrogen and safe methods to 98 store hydrogen. Researchers are currently testing various methods, including a method of storing fuel such as methanol on the car and extracting hydrogen from it. In the last example, there will be some emissions in addition to water. Still, the potential for its success is higher since methanol may be made available through existing infrastructure for gasoline. There are high expectations for FCEV to be one of the ultimate ecofriendly cars that may one day replace the existing internal combustion engine. However, its production is not likely to begin until the beginning of the next century, and the FCEV may not become the predominant power source for automobiles for another 10 to 20 years. Environmental problems need immediate attention. The longer it takes for an alternative technology to be introduced, the higher the level of CO_2 and the greater the severity of global warming. Hybrid vehicle technology is one of the solutions offered by Toyota.

It is fair to say that a hybrid vehicle is the only eco-friendly car without the disadvantages of the other alternatives that can be brought into production using only today's technology. Since gasoline is the only fuel needed, it requires no new infrastructure. The travel distance with a full tank of gas is easily 50% greater than ordinary gasoline cars. Since it is fuelefficient, CO_2 emission is less. Since the gasoline engine is used only within its most efficient range, 99 it is not subject to undue loading so that emissions of toxic gases, such as CO, HC, and NO_X are drastically reduced. That is why the development of Prius is significant. In addition, if Toyota succeeds in bringing it into production, Toyota will set the global standard for hybrid vehicles. Toyota may succeed in getting a step ahead of the industry in global competition for environmental technology in the 21st century. G21 project was significant because it was paving Toyota's future.

Start as soon as possible BR-VF's Matsui returned to the Drive Train Engineering Division immediately after the meeting that officially launched the development at the end of June. Although his assignment was to start in August, he could not wait until then, especially considering the tight schedule. He visited General Manager Seitoku Kubo of the Drive Train Engineering Division with BR- VF leader Fujii. "We would like to start designing the transaxle as soon as we can, because the hybrid system has been approved. Can you help us?" Fujii asked Kubo. "Okay, our department will take care of things all the way through assembly," Kubo accepted willingly. Matsui immediately contacted several young engineers of the Drive Train Engineering Division and got three of 100 them to join his office. Matsui and the three took openended tasks and began to work. In 1996, two design engineers, a controls engineer, and three evaluation engineers joined the group, thereby creating a 10-person team. The Drive Train Engineering Division handled the transaxle for the hybrid system. It consists of a power split device, generator, motor, and decelerator. Acting on instructions sent from the hybrid computer, the power split device partitions power created by the engine between the motor/axle and the generator. It also functions as an electronically controlled continuously variable transmission that smoothly varies engine RPM by controlling the generator's RPM rate. This transaxle is unique because of its use of a planetary gear. Planetary gears, in general, have been used for a very long time. In its center is the sun gear, and on the outside is its ring gear. Attached in between the two gears are four planetary pinion gears. All of this is attached to the planetary carrier, which resembles a satellite
orbiting around the sun. The shaft of the planetary carrier is connected to the engine, and the power is conveyed to both the ring gear and the sun gear via the pinion gear. The shaft of the ring gear is directly connected to the motor and conveys drive power to the wheels. The shaft of the sun gear is connected to the generator. The combination of these gears helps start the engine, and partitions power between 101 generator and axle or conveys power only to the generator.

The transaxle is one of the components of a hybrid system. The BR-VF team was interested in performance. The Electric Vehicle Division worked on making the motor that includes a rotation sensor, and the Drive Train Engineering Division took care of everything else. Even though BR-VF made the decisions on overall system structure, the transaxle group tried many times through trial and error to select the dimensions for building a prototype, especially since the unit needed fit inside the small engine compartment of the Prius. Since two separate groups were designing the unit, Matsui constantly contacted Electric Vehicle Division's Staff Leader Kaoru Kubo who was responsible for the motor. The two called back and forth negotiating sizes of parts. Since the length of the engine compartment was very limited, the engine and transaxle had to be connected and installed sideways. Hence, the group had a very difficult time figuring out the width. It was around this time that the motor's dimension, which was agreed at 106 millimeters, was reduced by five millimeters. Many shapes were considered to shorten the length. Since the damper, generator, power split, and motor all connected to the engine in a row, the finished design turned out to be too long. If there had been enough room, the decelerator would have been placed somewhere 102 in between. Unfortunately, the engine compartment was not big enough. After several trials, the decelerator was detached from the power split device and was connected with a chain drive. A 20mm-wide chain was used. Although the width was increased by only 20 millimeters, the unit barely fit within the specified space.

No layout changes With this layout, work on the unit for the November 1995 prototype was completed. Five more prototypes were made after that, but the original layout was never changed. In most cases, when a new model is created, the auto development group puts finishing touches on the model unit provided by the pre-development group. With the Prius, the process was changed because both the body and drive unit were developed from scratch. Since the development period was short and there was no time to redesign parts over and over again, the Drive Train Engineering Division carried out its design work with extra care. Even in the prototype stage, the group that created it would usually wait for evaluations to come out before building the next prototype. Since an evaluation usually takes two to three months, there was no time to wait for 103 one. Since all groups ran various tests with the newest prototype, the newest units had to be installed to get the latest results. Designers, therefore, made small improvements on their own before the evaluations were done. Once an evaluation was ready, designers began working on the next prototype. Since Toyota had a wealth of know-how on mechanical parts, the unit's layout required no major changes throughout the prototype stages. 104

Chapter 4 Sudden New President - Hiroshi Okuda

It was exactly 2:45 p.m. on August 10, 1995. There was an unusual feeling of heat and excitement in the seventh-floor conference room of Toyota's Nagoya Building located just north of Nagoya City's largest commercial center, Sakae-cho. Just one hour earlier, every major media company in the city had been called by Toyota's Public Affairs Division and told, "At 3:00 p.m. today, we are holding a press conference to release the names of our new Board members." Although that was the only announcement from Toyota, reporters known as "Toyota Guards" because they covered automotive news immediately understood the situation. "Damn, they did it. They are introducing the new President..." Shoichiro Toyoda's younger brother Tatsuro Toyoda was the President at that time but he had been ill for some time. After a visit to China in February, he had fallen ill and had been unable to work. Although the illness had been official described as "a condition due to high blood pressure," the nature of his actual illness was not known. Tatsuro Toyoda had cancelled all of his public appointments and had been rumored to be in "serious condition." Nevertheless, the company had given out 105 only optimistic news, saying, "Mr. Toyoda's condition is improving" and "He may come back to work by summer." Tatsuro Toyoda had gone to China on an important mission. At the time, compared to many other Japanese companies, Toyota was lagging behind in establishing its presence in China. Some time back, the Chinese government had contacted Toyota about possibly starting a joint venture company. Toyota had turned down the offer, explaining that the market was still premature for auto production. Later, however, when Toyota sought to begin production in China, it had trouble getting the Chinese officials to work with them because the Chinese wanted to work with those "who dug the well in the beginning." In the past, however, Sakichi Toyoda had built a plant in Shanghai as a sign of Japan-China friendship to manufacture Toyoda-style automatic looms. Before World War II, Kiichiro Toyoda who had founded the car company, used to manufacture trucks on the Chinese mainland. The Toyoda family, therefore, had great affiliation with Asia, particularly with China, and was eager to begin auto production there. Tatsuro Toyoda had gone to China with that mission before he got sick. 106

Public Relations vs. the media

The media had been getting increasingly aggressive by the day to learn more about Tatsuro Toyoda's health and about the possibility of the company naming a new President since virtually all of Toyoda's official duties had been assumed by others. The chairmanship of the Japan Automobile Manufacturers Association (JAMA) had been taken over by Vice Chairman Masami Iwasaki (now Senior Advisor to Toyota). Toyota Chairman Shoichiro Toyoda served in Tokyo as Chairman of the Japan Federation of Economic Organizations (Keidanren), and Toyota's five Executive Vice Presidents Toshimi Ohnishi (now Advisor to Toyota and Chairman of Hino Motors, Ltd.); Masaharu Tanaka (now Advisor to Toyota and Chairman of Chiyoda Fire & Marine Insurance); Hiroshi Okuda; Iwao Isomura (now Vice Chairman); and Akihiro Wada handled Toyota's management through a process of close consultations. At that point, the Japanese auto industry was facing an extremely difficult situation. Japan and the United States were in the midst of trade negotiations involving automobiles. Since Japanese auto exports accounted for more than twothirds of the $60-plus billion annual trade imbalance between the United States and Japan, the United States government was demanding that Japan open its market to American goods, especially autos and American-made auto parts. The United States was also 107 trying to set numerical targets for American exports that Japan would buy. U.S. Trade Representative Mickey Kantor met on June 28 with Japanese Prime Minister Ryutaro Hashimoto in Geneva, Switzerland, for bilateral trade consultations and presented three demands. They were to increase procurement of American parts by Japanese auto makers, expand
the sales network for American autos, and deregulate the auto repair industry. Japan was requested to set a concrete numerical target in parts procurement by the following day (June 29). At the same time, USTR Kantor announced that a retaliatory 100% import duty would be imposed on Japanese luxury cars, such as Lexus, Infiniti, and Acura, if no agreement was reached. Early in the morning on June 29, barely in time to stop the retaliatory measure, Nissan, Toyota, and the Government of Japan individually announced comprehensive voluntary plans to improve auto trade. Toyota's plan proved to be exceptionally action-oriented, including dramatic increases in auto production in the United States, a

plan to build a new assembly plant in North America, increased local content, purchases of American parts, and sales of American passenger-cars in Japan. Toyota used this opportunity to increase offshore production, the only area in which Toyota was behind Honda. Neither the Japanese government as a whole nor the 108 Ministry of International Trade and Industry (MITI) contributed to organizing efforts to stop the imposition of retaliatory measures. Toyota enabled the agreement to be reached by taking advantage of the weaknesses while still saving face for the United States. Toyota Executive Vice President Hiroshi Okuda had played a vital role in putting together the agreement in the absence of President Tatsuro Toyoda. The difficult auto negotiations were long over, but now in August there were still press inquiries about President Toyoda's health. Public Affairs Division General Manager Takashi Kamio (now Director) had been telling reporters who had persistently asked him about the President's condition, "It's only August, and we are still in the middle of the summer. No need to be so impatient, everyone. When the weather begins to cool down, our President should come back well rested and refreshed." Furthermore, on August 9 (a day before the announcement of the new President), Kamio had told reporters, "I am planning to take a week off from the day after tomorrow to go vacationing in Turkey. So, everyone, please relax and take your break also. We are expecting a lot of work when we come back." Contrary to the impression given to media representatives, Toyota was planning to make an emergency announcement the following day on August 10. Reporters were completely put off the scent by Kamio. They simply assumed there would be no new, important 109 announcement the day before the national *Bon* holidays, since a press conference would not be held without the Public Relations General Manager. They thought the announcement would be made after the holidays, and they had left or were about to take off on vacations.

"If I were ten years younger...." At just before 3:00 p.m. on August 10, two chairs were placed at the square conference table. They presumably were there for Chairman Shoichiro Toyoda and the new President, which indicated that President Tatsuro Toyoda would not attend. Numerous TV cameras were set up in the room, and news service reporters whose main duty was to get the information out as quickly as possible were standing near exits, ready to take off as soon as possible. It already was long after the deadline for evening newspapers. In fact, it was about the hour for early evening editions to be delivered to train station kiosks. Reporters waited, however, because the announcement of Toyota's new President was important news to the people of Aichi Prefecture and for all 70, 000 Toyota employees, their families, related companies, business partners, dealers, and others affiliated with Toyota in Japan. Local papers, such as Chunichi and Asahi, delayed printing their evening editions,
and were preparing to carry the 110 appointment of the new Toyota President on the front page. A minute before 3:00 p.m., the door opened. Everyone stared. The room was filled with tension. "Is it Okuda, Isomura, or someone else?" The tension suddenly broke and laughter filled the room as a Mainichi Shinbun reporter appeared, huffing and puffing in a summer sweater. This reporter had planned to leave on his vacation that day and was about to step out of his house when his office called him with instructions to cover the Toyota news event. He had had no time to change out of his vacation attire. A minute later, however, Shoichiro Toyoda and Hiroshi Okuda arrived in the silent and anxious conference room. The two were met by a torrent of questions. "When was this selection made? What was the reason?" Shoichiro answered, "A few days ago, the President (Tatsuro Toyoda) contacted me, saying, `It will take me a little longer to regain my health. Since we are in the midst of critical times, I would like to step aside and let someone else take the position. I think that Okuda-kun is the most appropriate person for the position since he has a wide background in business, including sales in Japan and abroad, accounting, purchasing, and so on.' We discussed the matter with the Honorary Chairman (Eiji Toyoda) and Vice Chairman Iwasaki to come up with the decision." 111 "Mr. Okuda, how do you feel about the appointment?" "I was very surprised. I would have been happier if I were ten years younger, because the work is strenuous both mentally and physically at my age. However, we are at a very crucial point in time. I will do my best." "What are the issues that you plan to handle?"
"First, the matter of delay in product planning. Second, reduced domestic market share. Also, our speed in offshore expansion has been slow." "You will be the first President who is not related to the Toyoda family." "I don't feel that I am a special case just because I don't belong to the Toyoda family. I respect the Toyoda family, but our personnel selection will be fair." About that time, Toyota was starting to face changes and challenges. Its domestic market share was steadily declining, and a heavy cloud

of concern was hanging over its dealerships nationwide. The company had grown to be a huge organization, and management was working hard at treating its huge-corporation-syndrome by introducing the " Center System" for the Development Division. Almost all Toyota employees, however, felt the company would never decline. They lacked a sense of crisis and that was the weakness with Toyota. Although Toyota out-performed other domestic manufacturers in terms of sales and profitability, the majority of the profit came from exchange rate gains. In terms of growing its 112 consolidated business, Toyota was behind Honda which had increased its offshore production. Okuda was being appointed President at a time when the company's progress seemed to be stalled. Okuda first worked in what had been Toyota Motor Sales, and had spent many years in the accounting department, including an assignment of six and a half years in Manila. In 1982, when Toyota Motor Corporation merged with the domestic sales arm, Toyota Motor Sales, Okuda at the age of 49 became a Member of the Board of the newly consolidated Toyota. Since then, he had been assigned to all key sectors, including offshore operations, public relations, finance, accounting, purchasing, and domestic
sales. Okuda's open style of voicing his well-balanced opinions had assured him his position within and without the company, and had resulted in his appointment to succeed Tatsuro Toyoda.

Speedy management Speed was Okuda's management style. In September, immediately after his appointment, he increased Toyota's equity participation in Daihatsu to 33.4%, thereby gaining control of its management. In November, he quickly secured the location for Toyota's third U.S. assembly plant, which was one of the pledges that Toyota had made in its voluntary plan that helped 113 finalize the U.S.-Japan auto agreement. Okuda then proceeded to speed up business in Europe and Asia. He also stimulated domestic business by introducing new systems to encourage workers to move to other sectors and start venture businesses. He introduced the concept of Head Offices in the sales department, aimed at establishing five domestic sales channels as individual businesses. Okuda's aggressive and self-confident management style (as seen in the establishment of the fourth U.S. assembly plant, the decision to start production in India and France, and the merger of KDD and Teleway financed by Toyota in the area of communications) stood out prominently in the recession- plagued economy of Japan. His "speedy management" style also was very evident in the area of product development. In August when Okuda was appointed President, the G21 project to develop a car for the 21st century, and the BRVF project to carry out research on hybrid propulsion systems had progressed to the point there were discussions about specific details because the general engineering meeting in June had firmly put them on track. BR-VF leader Fujii had his own version of the development schedule in mind. He intended to build a prototype car within the year, followed by a year of thorough research of the system, then another year of predevelopment, and yet another year to complete the production model. In other words, he targeted launch. 114 date was the end of 1998. To him, that was the best-case scenario if everything went well. Others in the group agreed the car could be launched by the end of 1999 at the latest. However, at the end of 1995, Okuda who had been in office for four months came up with a request that seemed impossible to fill. During a recess at a conference held in a hotel, several Board members in charge of technology were gathered around Okuda who said to Wada. "Say, Wada-kun, when is that hybrid vehicle going to be ready?" "We are scheduling it to come out in December 1998, if everything goes well." "That is too late; no good. Can you get it done a year earlier?" "Since it is an entirely new technology, I wouldn't be sure. We cannot afford to have any problems." "There will be great significance in launching the car early. This car may change the course of Toyota's future and even that of the auto industry. If we delay things by being overly cautious, we will never finish it. Tell Fujii kun to get it done a year earlier." . Wada had sensed that both the Chairman and the President were not happy with the launch schedule for Prius. He had never thought, however, that they had such strong feelings about the car. Wada now realized that as head of development, he had to prepare himself for a lot of difficult tasks ahead. Quality problems would 115 not be tolerated. Even with all the challenges, Wada felt exhilarated.

Shoichiro Toyoda's intention The decision to release Prius early was partially the result of Shoichiro Toyoda's strong will and determination. Decisions involving important issues at Toyota are made at high-level management committee meetings attended by Members of the Board and related

Department General Managers. In December, a development committee meeting was held to discuss the hybrid vehicle. Chairman Shoichiro Toyoda, who had devoted most of his time recently to serving as the Chairman of Keidanren, was at the meeting. He was extremely interested in Prius, and had managed to attend the meeting despite his busy schedule. A progress report on development was given, as well as a report on the plans to launch Prius at the end of 1998. As soon as the reports were given, Chairman Toyoda spoke up, "That is no good. It is too late. We will miss becoming the first company to launch a hybrid vehicle. Toyota has been second too long. Can't you have it done earlier?" A Board member who attended that meeting said later 116 that he felt "the Chairman, as leader of Keidanren, had been aggressively advocating deregulation and globalstandard management performance so that he was now concerned Toyota's rate of reform was too slow." The views of the two top executives Okuda and Toyoda coincided. It was inevitable, therefore, that the launch date for Prius would be moved up.

When Fujii was informed by Shiomi that the launch date for Prius had been changed, he was stunned. "Uh, we haven't even built a prototype yet." "I understand that." Shiomi, who had been at the conference with Okuda and had been asked by Wada to inform the project team, remembered a comment he had heard before: "Since presidents with experience in business are no experts with technological matters, they tend to listen to their instincts to judge who is right and which is better. Toyota has had such instances in its past." The comment is based on an actual story. Kenya Nakamura, who was Chief Engineer for the development of the first-generation of Toyopet Crown, was responsible for the introduction of an independent suspension system for the Crown, thanks to the support of then-President Taizo Ishida, despite objections by Eiji Toyoda, thenMember of the Board in charge of development. Eiji had serious doubts about the safety of the suspension system because many taxi cabs with the same type of suspension 117 were having quality problems. Nevertheless, Ishida instinctively supported Nakamura's position that "comfort is indispensable for a luxury car like Crown." Ishida's decision thereby helped to bring about the enormous success of Crown. Ishida was not a technically trained person but he is usually credited for thoroughly establishing the idea of streamlined, waste-less business practices at Toyota. This story also shows that historically Toyota's product development has been made more successful by the instincts of Presidents with nonengineering backgrounds. As a matter of reality, Okuda's decision to speed up the development process probably created a greater challenge than in the case of Toyopet Crown. In effect, Okuda had given the team an ultimatum to complete Prius before the end of 1997. It propelled' the development of Prius, and the early launch of the vehicle embarrassed America's Big 3 auto makers. 118

Chapter 5 California's CALTY - Design

At the end of 1995 when the first tiny steps were taken to create the pre-pre-prototype, the team began discussing body design. Another new car development project was underway at the time and it was attracting the attention of Chief Engineer Uchiyamada. The project was Raum, an FF compact car developed in the same Vehicle Development Center II. Raum was also intended to be a new-age passenger car with a small body but large passenger compartment, and sliding doors. Initially, the team tried to design a three-box (engine compartment, passenger compartment, and trunk), 4-door sedan. Uchiyamada was especially interested in keeping abreast of how the design work was progressing because the basic concepts were the same as for Prius, except for the sliding doors. Designing a well-balanced car proved to be difficult since Raum was short in length and, at the same time, tall. Seven consecutive designs were rejected by a jury of Board members in charge of the project. Because designs reach this level only after thorough reviews, they are seldom turned down at this point. It is even rare for cars to be turned down two or three times. The situation with Raum, therefore, was extremely unusual. 119 Isao Tsuzuki, Chief Engineer for the Raum model, had theorized that "since Raum is a family car that is comfortable for both the elderly and children, a sedan type would be most appropriate." He held onto the sedan design as long as he could, but finally gave up and switched the design concept to a two-box type, station wagon vehicle without a trunk. This time the design was approved at once because the design had been thoroughly scrutinized. The Raum available today is the result of the design change.

Uchiyamada had carefully watched the process, and had become convinced that obtaining the approval for a three-box sedan would require much work and his strong conviction that his design selection was correct.

Design Facilities of Japan, the U.S., and Europe

Toyota's design division is divided into four locations. They are the Design Division at Toyota's Head Office in Toyota City, Tokyo Design Division, CALTY Design Research in California, U.S.A., and the European Office of Creation (EPOC) in Brussels, Belgium. The design division in Toyota City is further divided into four autonomous sections: an independent Design Division within the Technology Division, Design Division I in the Vehicle Development Center I, Design Division II in the Vehicle Development Center II, and Design Division III 120 in the Vehicle Development Center III. The Head Office Design Division in Toyota City specializes in model molding and pre-development. It is in charge of designing motor show concept cars, and had designed the 1995 auto show Prius. It also is responsible for managing the three design centers in other locations. The Design Divisions of the three Development Centers are in charge of designing mass-production models. Although they are capable of pre-development design, they work mostly on future mass-production models. Only the Head Office Design Division handles concept cars. Toyota's design division is unlike those in other companies because the designers also are involved in designing the packaging. Designers used to draw the interior placement by hand, whereas today the plans are drawn using CAD at the Product Planning Division. Unlike most other companies, Toyota's tradition is to have the packaging work done by designers rather than by exterior (body) stylists. The most important factor to consider when designing a passenger car is to provide ample space for people and trunk space for luggage. There had been passenger-car designs in the past that sacrificed space for passengers by lowering the profile for the sake of exterior design. Today, however, there are few cars with this type of design. Since designers themselves have the knowledge and knowhow of total vehicle packaging, they never sacrifice 121 passenger comfort for design. The result is a shortened development period. Every design division and department also looks at ergonomic packaging. Designers and engineers were asked to select-on the basis of the G21 design concept - the basic package for Prius. G21 initially had shown its design requirements to the Design Division II at the Vehicle Development Center II and had requested a packaging design. About 100 designers at Design Division II work on body, interior, and color. A team under Staff Leader Takekuni Saito was selected to design the body, and a team under Takeshi Tanabe was selected for interior design. Saito had worked on the body design of Sprinter, Cresta, and Crown, and recently had worked on the pre-development of concept cars.

A major task

Masanori Sawa of Design Division II had been at EPOC in Europe from August 1989 to August 1993 and had worked on designs for cars to be sold in Europe, as well as collected local color trends. After returning to Japan, he worked on the interior for Carina E which is manufactured at Toyota's plant in Great Britain (TMUK). In December 1995 when the assignment was finished, his boss Masayuki Chikazoe asked him to work 122 on the interior for Prius. "Seriously? That is a major task." Sawa had had some knowledge of the G21 project and had been thinking, "It may be interesting to work on since it is a very innovative car, but it would be a lot of work if I should be assigned to it." He heard from Saito that the project was an extremely difficult one with only limited time to finish. In January, Sawa collected a group of mid-level engineers to form a team. Uchiyamada told Sawa, "We need a breakthrough design that is different from conventional Toyota designs. We will stick to a 4-door sedan, the quintessential passenger-car shape, but would like all conservative and negative aspects of the sedan design removed." A sedan that is even smaller than Corolla is very difficult to design. "How shall we do this?" Saito and Sawa talked about the design concept repeatedly and finally selected
some keywords they agreed fit the image they had in mind. In fact, that was the same method used by the second G21 team. While there were positive views, such as "un-Toyota," "challenging the potential," and "ambitious," there were also negative views such as "stocky," "tall," and "bumpy." By studying these keywords, the team decided to build upon the following three impressionistic concepts:

1) how one feels about the future, 2) an efficient form with purpose, and 3) an artsy car that is fun to see and drive. 123

RV boom and "Sedan Innovation" A new trend was emerging in Japan's auto market. The popularity of sedans was declining and recreational vehicles (RV) were replacing sedans. Many RV type vehicles, such as minivans, station wagons, one-box wagons, and offroad four-wheel-drive (4WD) cars, were introduced one after another, and became hit models. One of the reasons they became so popular was the advantage that many passengers could fit into the roomy passenger space. Another important reason was the reaction among younger consumers to the tradition of gradually obtaining larger and more luxurious sedans as one climbed up the social ladder, e.g., starting with Corolla and gradually switching to Corona, Mark II, and eventually Crown. Sedans came to be seen as *"oyaji"* (old man) cars. The popularity of RVs spread beyond young consumers and caused the slowdown in sedan sales Furthermore, the age of consumers buying Toyota cars began to rise, with the largest number of people favoring Toyota cars being in their 40s and 50s, while there were fewer people liking Toyota cars as the age dropped to the 30s and 20s. The public also perceived Toyota as a corporation in a similar way. Toyota buyers who had loyally purchased one sedan after another with the dream of one day owning a Crown were becoming older, and the average age of a Corolla owner was over 50. In contrast, Honda had succeeded in gaining the support of young 124 consumers by its successes in motor sports. Honda also had triggered the RV boom. In October 1994, Honda launched the Odyssey, which had been specially developed for the Japanese market but based on the minivans (engine in front with three rows of seats) that were popular in the United States. Up to that time, RVs in Japan had been one-box wagons, station wagons, and off-road 4WD cars. With Odyssey, Honda had introduced a new category of RVs into Japan. Generally speaking, new-car sales start to soar immediately after introduction and then gradually decrease after reaching a peak. In the case of the Odyssey, sales started very slowly, but as the car's novel concept gradually penetrated into the market, sales rose steadily and monthly sales reached 10,000 units for the first time in March 1995. Monthly sales continued to stay at around 10,000 units for a long time, and Odyssey became a huge hit. Toyota had developed a similar minivan, Ipsum, before Odyssey was introduced but Toyota's management postponed its introduction because they were not sure that such a vehicle would be welcomed by Japanese consumers. Before minivans were introduced in Japan, Toyota had led the market in one-box wagons and Toyota was second in station wagons (behind Isuzu's Legacy). Toyota had launched a variety of such wagons, Scepter, Caldina, and Sprinter Carib. With off-road 4WD vehicles, the market was divided between Mitsubishi Pajero and Toyota 125 Landcruiser. Toyota's management, therefore, had decided to launch a unique minivan before other auto makers came up with similar offerings. Toyota, however, felt that its priority was to bring life back to its sedans to stimulate the domestic market. In the summer of 1996, Toyota launched its "Sedan Innovation" campaign with the fully model- changed Carina. Other ambitious sedans, such as Windom (Lexus ES300) and Mark II, were introduced one after another. Designs for Prius began immediately before the campaign's inception when expectations for sedans were at their peak in the company. Early in 1996, several design ideas were submitted by Saito's team at Design Division II. None of the designs seemed to please Uchiyamada. All were either too conservative or eccentric, and did not fully convey feelings of a new era and the concept of a new hybrid system. In other words, the designs were either too conventional, like Corolla-type cars, or too sensational, like concept cars of motor shows. Uchiyamada's view was that the team had simply changed the dimensions of existing cars and had been unable to break away from past designs. None of the designs were better than the previous benchmark Prius of the 1995 Motor Show. (The 1995 Prius had been designed by the Head Office Design Division Advanced Design Team that specializes in concept cars.) 126 Uchiyamada, who was determined that a new concept for a sedan would be necessary in the post-RV era, admonished and encouraged the design team by saying, "G21's concept should be translatable into a good design because its package makes sense as a car," and "when Rover Mini and VW Beetle were introduced, they were seen as heretics. Only time will tell the true worth of a car. Uchiyamada told himself, "If we give up and say that something is good enough, we will never get beyond the 1995 benchmark Prius." He restrained himself from compromising and held on for the arrival of the perfect design.

A competition by **seven teams** Uchiyamada decided on a new approach. "We shouldn't depend only on our own Design Division II. We should instead have all of Toyota's design divisions compete against each other for the design." Uchiyamada contacted the Head Office Design Division and requested that it organize the competition. Head Office Design Division, Tokyo Design Division, Design Division II, CALTY of California, EPOC of Europe, a team of contractor designers at Toyota, and the Design Division of Toyoda Automatic Loom Works (which is a Toyota Group company) submitted designs. 127 As far as he was concerned, Uchiyamada wanted to ask design studios outside of Toyota, such as Italy's Carrozeria, to enter the competition, because he wanted to see how contestants from Europe - known for leading designs in automobiles and style - would digest G21's concept. He was interested in seeing if Europeans would submit designs superior to those of Toyota. Board members disapproved the idea for fear of leaking of top-secret information. Uchiyamada gave up the idea. Although he was disappointed at the time, he later confided after finishing work on the Prius,
"Having completed such a difficult design within the company, Toyota's design division gained a lot of confidence. It was definitely a good thing that we did it internally."

The participants were excited about being able to submit their designs for Prius. The competition stimulated them and they produced one innovative idea after another. The first round of judging sketches was held in mid-February of 1996. At this point, the judges were looking at how the competing designs expressed Toyota's view of the future and the company's progressiveness. They were trying to get a feel for the range of possible ideas. More than 20 sketches were submitted, and the judges divided them into three categories: relatively conservative designs, spaceshiplike futuristic designs, and those in-between. Uchiyamada was surprised to see that designers had wide differences of 128
opinion about the future even when they started with a common set of assumptions. Designers at EPOC in Belgium asked, "Mr. Uchiyamada, we think that a car based on this theme should be a two- box car. That way, we can create a better design. Why do you insist on a three-box car?" Most subcompact cars in Europe, e.g., VW Golf and Fiat Punto, are two-box cars. Even with mid-size cars equipped with 2000cc-class and higher engines, Europeans prefer 5-door hatchbacks that look like sedans from the outside (e.g., Citroen Xantia). Convenient and userfriendly cars are preferred over good-looking cars in Europe, while Japanese consumers generally feel that a sedan should have a trunk. The differences were due to how people view cars. Europeans consider cars only as a means of transportation. On the other hand, Japanese people attribute values, such as joy of ownership and individuality to their cars. That is why the design approach was vastly different among the competitors even though they were based on the same theme. Although EPOC's design displayed innovative ideas in various areas, it lacked coherence as a three-box sedan and was rejected. CALTY, another overseas contestant, submitted a sketch accompanied by a photograph of a one-fifth-scale urethane model. Irwin Lui, its designer, created the form from a pure egg-like shape to produce and emphasize the futuristic image. He slowly applied pressure from the 129 two ends of an egg until it almost fell apart then used that shape. In that way, he was able to complete a three-box design with a mono-form profile. This three-box design with a new form takes on many different aspects depending on the angle of light and how shadows are cast on the form. Lui sculpted the model himself and took the picture so that he could accurately present to the judges the delicately curved surfaces of his design. This design caught the attention of Kubochi, General Manager of the Vehicle Development Center II. When the team members gathered to discuss which design most appropriately expressed G21's concept, Kubochi favored the CALTY design. No decisions were made at this time because there was a feeling the design lacked something special that would raise it above other designs.

A rule violation Five designs were selected during the first-round sketch review. In the second round, contestants were told to submit a life-size model in May. Four clay models were submitted in

May, and two of them were deemed exceptional. The two were from the Head Office Design Division which emphasized familiarity and from CALTY which submitted Lui's design. 130 Judges divided into two camps because both designs had imperfections in packaging. The Head Office design was very coherent and unique, but lacked the futuristic feel. The design team was requested to emphasize the novelty and further refine the design. CALTY's design was progressive with a strong sense of the future but required improvements because many aspects of it made mass-production impossible. Lui's design had actually violated one of the competition's rules. One of the basic conditions was to be a three-box sedan with a trunk, but CALTY's design was not exactly a three-box sedan. At first glance, the design seemed to have a trunk, but the side surface that connected the top of the rear seat area to the tail end (Cpillar) created a different curved line from the rear window. The design, in fact, was a 5-door hatchback, with the hinge of the trunk at the top of the rear window. Lui was clearly aware of the violation. He felt that a conventional three-box design would not express futurity, and had decided to create a powerful impression with a *trompe l'oeil-like* design. Furthermore, he had concluded that the design could be revised before mass-production to include a trunk while retaining the basic form. Both designs lacked definitive distinction so another interim review was to be held for the two designs. The next review was to take place two months later in July. Although it was called an interim review, it was in fact to be the final round. Members of the Board and 131 General Managers of departments in charge of technology, production, production technology, and sales, as well as Executive Vice President Wada, were to be present at the review. A panel review also was scheduled. Several hundred panelists chosen from non-technology sections in the company were to judge by scoring the designs, based on 20 or 30 criteria. The selected design would become the official design after receiving the approval of the President and the Members of the Board at the final review in September. A vehicle design is almost never rejected at the final review, so that the occasion is in fact a presentation of the final design. The panel review method is said to have originated in the United States, and today many auto makers are using the method for design decisions. It is considered to be the only way to achieve an evaluation of a design that is close to one achieved by using consumers. Since companies want to keep confidential their designs in the development-stage and are not willing to show them to the public, a review by panels of company employees is deemed closest to a review by a public panel. The panel consists of people in many different age groups from young workers to those near retirement age. They work in many different areas from management to factory floor, and there also are many women on the panel. A panelist does not necessarily have to have a driver's license. To keep the process strictly confidential, 132 panelists remain anonymous. Objective
evaluation achieved through this panel review is the most important factor in the decision process. Irwin arrived in Japan prior to the July interim review. His task was to provide certain car-like elements to the design while retaining the futuristic look. He specifically needed to improve the lines and shape around the trunk by adjusting the C-pillar a little more upright. Irwin's design was, in one word, sculpted. He thought he needed to introduce a new sweeping line so that this midget-like car that in fact sits higher than a Corolla would have a fresh look. He used two "character lines" (lines to accent the body form) for that purpose. As a general rule, a character line visually connects the front to the rear of a car, but, in this case, Irwin introduced sharp sculpted lines above both front and rear wheel arches. His intention was to create a strong sweeping movement in the limited space by introducing light and shadow with the two lines. Irwin said that he completed the sculpted lines by treating the body as a painter's canvas. He achieved this only through the delicate curves on the surface without using any other details. His design was either enthusiastically supported or rejected. It was, nevertheless, a challenge against the conventions of automobile design. Since Irwin was unable to travel back and forth between Japan and California, Saito of Design Division II 133 was called to help. Saito's design unfortunately had been rejected at an earlier round, but his next role was to take over the selected design and improve various aspects of it so that mass-production would become feasible in terms of safety and manufacturing capability. At Toyota, pre-production design is done by individual Design Divisions, not by the original designer. For example, Design Division II handles FF cars, Design Division I handles FR cars, and Design Division III handles recreational and commercial vehicles. The exterior design of Prius, therefore, was to be handed over to Saito's team, and Saito was anxious to get directly involved in Prius. On the other hand, as the Section Leader in charge of exterior design, Saito had to coordinate between the two candidates prior to the interim review. He found himself struggling at times in this delicate position.

The exciting Center Meter concept While the Toyota Head Office team was battling one-on-one against the CALTY team in exterior design, Sawa's interior design team was trying out many new ideas. The management had already decided that the Design Division II's interior design would be used in Prius, without running a company-wide competition. The interior design models were prepared in sync with 134 the exterior design selection process. When the sketch review for the exterior designs was held in February, the interior design team also submitted sketches on two ideas, and completed dashboard clay models. Two more ideas were offered in May, and another two ideas were presented in September for the final selection process. The first thing a driver notices in the Prius is its Center Meter. In an average car, the dashboard (or instrument panel) with speedometer and tachometer is behind the steering wheel. In Prius, there is no conventional instrument panel, only a smoothly curved panel. All instrumentation (meters and gauges) is placed in the center of the vehicle, not where it would be normally. By placing all the instrumentation in the center, an unconventional but symmetrical instrument panel is possible. A driver getting inside the car would immediately notice the excitement of the dramatic layout and also feel comfortable due to the more ergonomic placement of the instrument panel that requires less driver eye movement. Because of those two reasons, the Center Meter concept was adopted. The decision also was due to Uchiyamada's intense involvement. "Since we are placing the hybrid system - which is something new - inside an exceptional package, we should provide an optimal interior. The driver's seat should allow the driver to touch and feel the novelty and futurity of the car." Sawa's team was now highly motivated to 135 fulfill his requests. The Center Meter concept raises the question of whether it is or is not ergonomically superior. There is a department in Toyota that studies the placement of gauges and meters from the viewpoint of ergonomics. That department has been conducting research on the optimal placement of visual information devices, such as meters and car navigation screens. Since car navigation systems have become so popular in the 90s, ergonomic placement is a major issue. The department had reached its conclusion that the navigation screen is most comfortable to look at if it is placed in the center, approximately one meter in front of the driver. The concept of the Center Meter has been around for quite a while, and European auto makers, such as Alfa Romeo, Rover, Renault, and Lancia have introduced several products furnished with Center Meters since the 60s. Their purpose, however, was not to introduce an ergonomic dashboard, but to facilitate export by designing a convenient dashboard that could be used for both righthand drive and left-hand drive models. The meters and gauges are conventionally placed 70 centimeters from the eyes of the driver at a 17-degree angle, and are not necessarily in a comfortable position for easy viewing. The ideal placement is one meter from the eyes, but that would be directly in front of the windshield and practically impossible to place a meter. At one time, Toyota had introduced a Crown
136 furnished with a virtual-image information system located about one meter in front of the driver, but it had failed to gain recognition and the system was eventually discontinued. However, in the Prius, the windshield is pulled far forward so that it is possible to place the meters and gauges about one meter in front of the driver. "If we can't install this on Prius, it would be totally impossible on any other car," Sawa said. General Manager Wahei Hirai of Design Division II advised Sawa who was working on the Center Meter, "Interior designers tend to make decisions without actually driving the car. Instrument panels, on the other hand, are used while driving. You must make your decisions based on actual driving experiences." Sawa decided to test the effectiveness of the Center Meter concept by verifying the visual recognition under actual driving conditions. Several interior designers posted numbered pieces of cardboard on their cars' windshields to test during their drives to and from work. Sawa also tested the Center Meter concept during his one-hour commute from his home in Nagoya to Toyota City. Several days later, everyone agreed the Center Meter was in fact much easier to see. Now, the team continued working on the Center Meter with firmly grounded confidence. Sawa also was concerned over the diagonal line created between the resin panels in two different colors behind the steering wheel and wondered if it would be distracting to 137 the driver. As a test, Sawa pasted a chloroethylene board painted with the same colors on the instrument panel of the Estima, a one-box car. Its instrument panel is recessed, far deeper other cars. He drove it around a test course. Sawa wanted to drive the Estima on city streets, but decided against it because the painted board would cover the speedometer. In the end, every member of the interior design team testdrove the Estima and felt the two colors were not distracting. People from other departments also test-drove the car. Finally,

the team was confident enough to try out the new instrument panel. Another challenge for the team was the gun-grip, column-type automatic transmission shift lever. Column-type shift levers are usually placed sideways, and the motion range is in two directions. On Prius, the shift lever moves only in one direction. Although the device proved to be more comfortable to use than other types, it was not immediately approved. Design approval remained pending because there was not much room around the lever.

Hitting two birds with one stone Another problem came up around the same time and it could have destroyed the idea of designing symmetrical instrument panel. In the original design, the vents at the center of the instrument panel were in a 138 fan-shape opening towards both sides. At one point, Uchiyamada test-drove a prototype with that design, and noticed that the air-conditioner was blowing air directly onto his face. "There is too much air blowing against my face. This vent is not perfect. Doesn't it bother you?" Uchiyamada asked the designer who was in the passenger seat. "Not particularly." The perception of force or strength of air flow from the vent is a matter of individual sensitivity, and the impression of force varies from person to person. Nevertheless, the team then came up with an experiment to test how individuals feel about airconditioning so that optimal vent placement could be verified. The team decided that an outside temperature of more than 100 degrees Fahrenheit, similar to that of Arizona in summer, would make a person more sensitive about the way the vent was blowing out cool air. The team asked the prototype department to remove the instrument panel from an existing car and in its place install a special instrument panel on which the air vent can be moved around. This car was placed in a 100-degree hot-air tunnel. Sawa and engineers in charge of airconditioners then tried to determine the position for optimal vent placement. After trying many positions, Sawa concluded that the best place for the vent was 30 millimeters to the left of the 139 current design. It also was the optimal placement in terms of air-conditioning performance. However, it would be quite difficult to move just the vent, so Sawa requested the instrument panel designer to move the center of the entire unit to the left. The designer, however, replied, "This design is possible only because its symmetry provides spaciousness and unity. Moving the center of the panel is unacceptable." When Sawa and the team actually built a prototype with the center shifted to the left by 30 millimeters, nobody noticed that the design was off-center, and the design stayed intact. In addition, extra room was created to the left of the steering wheel, thus giving plenty of space for the gun-grip column-type AT shift lever. Sawa's design idea solved two problems at once. Designers realized then that they had allowed their vision to become narrower as they focused only on their tasks. At Toyota, the interior of a car is designed after the ideal locations of switches and levers are determined. Design never sacrifices performance. Since the development period for Prius was extremely short, design and performance were considered simultaneously. Such a circumstance would never arise with other models. Thus, by the beginning of July, decisions on the interior design had been made. Details, however, were to be slightly revised as the exterior design neared completion. It was not rare for the interior design to be decided before the exterior design, but Sawa and his team were anxious to 140 see which body design would be chosen.

Anticipating the Toyota design Meanwhile, Uchiyamada had anticipated that the design by the Toyota Head Office might be selected because it was closer to completion and the delicate curves in CALTY's design would have been extremely difficult to put into production. He also felt personally closer to the design submitted by the Japanese team. Uchiyamada had been drawing design plans based on Toyota's design, and already had been working on the details. For example, design alone cannot tell whether the windows would open properly or whether the body shape can be successfully stamped. Each part needs to be drawn in detail to determine whether the design will function properly and whether it can be mass-produced. Sometimes dimensions need to be altered due to safety concerns. Uchiyamada had anticipated that Toyota's design would be selected, and had contacted and given instructions to Design Division II, Body Engineering Division II, Production Technology divisions, and to others. Engineers in charge of development often mention in interviews that the development period of such and such model took so many months. This development period 141 refers to the period

from design approval until line-off when the model actually goes into production. In the past, this period used to be around 24 months. If an auto maker is able to shorten this development time, it can quickly inject cars into the market that meet consumers needs and derive sales advantage over its competitors. To achieve that, auto makers have introduced CAD / CAM systems and methods called "concurrent engineering" ("simultaneous engineering" at Toyota) to enable different departments to work together from very early stages of development. At the time Prius was under development, the development period had been shortened to around 18 months. The line-off date for Prius had been set for December 1997. Since the final design would be decided in July, the development period would be only 17 months. Moreover, the official design review would be in September, so Prius had to be developed in an unprecedented short period of 15 months. With other models, the basic features of a car would be completed by the time the final decision was made on design. The remaining development time would be used to make additional improvements. Prius, on the other hand, had issue after issue that continued to need a solution. Such matters as starting the engine, minimizing the abrupt stopping of the motor, battery performance, and cooling needed to be addressed even though some prototypes had been built. That was why Uchiyamada 142 wanted to get to work as soon as possible and had decided to go ahead and draw plans based on the design by Toyota's team. Then, the unexpected happened. **An unexpected result** It was finally time for the July interim review, or the actual final review. Uchiyamada attended the review with some anxiety. Two life-size models were presented. Toyota's design portrayed a new type of luxury, but with conservativeness. CALTY's design was something entirely new to Toyota. Both designs went far beyond the 1995 Motor Show model. Board member opinions were split. Contrary to the previous review when both designs lacked something, this time
both designs were excellent and it was impossible to tell which was better than the other. When the Board members agree on a selection, the decision was to be made on the basis of the Panel Evaluation Committee's survey result. Scores in various categories, such as innovation, futurity, women's views, views by panelists aged 40 and over, and so on, were presented to the Board. Just like the opinions of the Board members, the scores from the panelists were close, but clear. Panel review often produces one-sided results, but this review produced clear results even by category. CALTY's total score turned out to be just a little higher than that of 143 Toyota. Moreover, CALTY's design won in terms of innovation and had the support of younger people. Wada said to others, "They are both innovative, but CALTY's is even more innovative. It appeals to young people, which is to Toyota's advantage, and the overall score is higher. There is the verdict." The design for Prius was chosen. Uchiyamada immediately thought, "It would be pretty difficult to catch up." He did not care very much that he had guessed wrong but he was concerned about whether or not he could catch up. "No use crying over spilled milk. This is the decision by the whole Toyota Board. I must pull this through." He was thankful that he was optimistic by nature, and repeated to himself, "This is just like when I am about to capsize in my sailboat. How would I reset my sails? There is very little time...." Irwin's design was taken over by Saito as planned. Since Saito had been helping with CALTY's design while working on details for Toyota's design, he had mixed feelings. Uchiyamada built his career conducting experiments so he had no experience in car development. He was a complete novice when it came to design. He could not understand how designers felt when they had to give up their own and take over someone else's design. He was concerned about the morale of his crew, and casually asked Sawa, who he had come to know better through the vent testing process. "How is the morale of the Design
144 Division II? Are you all okay?" Slightly surprised, Sawa smiled and said, "We're fine, because we're professionals. Even though our design was not selected, we'd still like to make the best product. We're really lucky to be working on Prius. It's a rare opportunity. As we refine the design, we can add our ideas to the finished product, too." Uchiyamada was impressed.

Having spent much of their time working out details for Toyota's design, the Body Engineering Division II was now in chaos. Engineers gave up their vacation plans and concentrated on drawing plans for CALTY's design. When the plans were drawn, making sure all the parts would fit and work together within the design specifications was relatively easy. That was because the pillar positions and dimensions on this revised design were much more feasible than the design submitted in May. The knowhow from having worked on Toyota's plan could be directly applied to this new design, and the team only needed to revise a few fine lines. September came, and it was now time for the final review. The site was the Design Dome at Toyota Head Office, the official place to hold ceremonies to endorse car designs. President Okuda and all key Board members attended the ceremony. Some Board members had not seen any of the interim designs, and were excited to see the CALTY design. The model arrived, followed by ohs and ahs of admiration. 145 The design was completely different from any of Toyota's existing sedans. The design suggested a futuristic spaceship while being witty, intelligent and stylish like European cars. It also created a warm, nostalgic feeling. Everyone was satisfied. When the design review was completed, Irwin came to see Saito. "This is greater than the original design by several notches. Thank you for elevating my idea to this level," Irwin said as he extended his right hand. 146

Chapter 6 Power Play - Engine

When the hybrid system was approved at a technology division meeting in June 1995, BR-VF immediately began the selection process for the engine to go with the new system. Toshifumi Takaoka of Engine Engineering Division II and Hiroshi Tada of Power Train Engineering Division II led the process, and decided to use an Atkinson Cycle engine as the base power source instead of the D-4 (directinjection 4-stroke) gasoline engine that was used in the 1995 Motor Show model. In Atkinson Cycle engines, combustion chamber capacity is smaller than in conventional gasoline engines, and air intake is limited by leaving the air-intake valve open until the middle of the compression cycle, thereby lowering the compression ratio. Since the expansion ratio is higher, exhaust is released after combustion pressure is diminished. Power from the combustion, therefore, is used with very little waste. Atkinson Cycle engines are seldom used, however, because they cannot achieve high power, even though the engine is efficient. Hybrid systems, however, can take advantage of the Atkinson Cycle. BR-VF, whose responsibility was to select the system, had already decided on the framework for the "Toyota 147 Hybrid System." The team reconsidered the appropriate displacement for the THS engine to be used for the G21 car. Simulation programs for engines between 1000cc and 2000cc were set up, and each engine was tested relative to the requirements of the THS system. There were three factors to be considered in selecting the engine: first, select displacement and maximum power output; second, achieve dramatic reduction in emissions through the use of three-way catalytic converter; third, minimize weight. By the end of August, the team concluded that a 1500cc engine would be the most appropriate due to the size of the car, fuel economy and compatibility with the motor and the inverter.

Pre-development of the new engine

Meanwhile, having initially decided on a compact car, the G21 team asked Engine Engineering Division II to develop a new 1500cc - class engine to use as the primary engine for its project. For its 1300cc to 1500cc small engine, Toyota, at that time, had the "E-type (4E & 5E)" engine used in Starlet, Tercel and Corsa. Although the engine is still in use (as of the end of 1998), more than 20 years have passed since it was developed. Consequently, it would not have been the appropriate engine to use in a car for the 21st century. That was why G21 wanted to start development of a new 1500cc engine 148 to eventually replace the existing E-type engine. At the Vehicle Development Center II that develops FF cars, the "New Basic Car (NBC)" project was under way at that time to create the global-strategy car for the 21st century. Its vision was a compact car with an engine of 1000cc to 1500cc, a small exterior profile but spacious interior, and superior crashworthiness features. Honorary Chairman Eiji Toyoda's third son was the project leader and his project was attracting a lot of attention as the first post-war "Toyota model produced by a Toyodafamily engineer." Shuhei Toyoda had been appointed to the Toyota Board in June 1998, and became Deputy General Manager of Vehicle Development Center II, where he was to supervise the development of "NBC." He also assumed the position of the General Manager of the Takaoka Plant to supervise the production of "NBC" and Prius. It is extremely rare for a Board member to supervise both development and production work at the same time. Shuhei took on the dual role because he was determined to be solely responsible for the "NBC" from development to production, and wanted to show that he could

successfully develop a "Toyoda" car. The two-box car Vitz, which is Shuhei's "NBC" equipped with a new 1000cc gasoline engine, was introduced to Japanese consumers in January 1999. Meanwhile, the same car was exported to Europe with the model name Yaris, and is also to be manufactured at 149 Toyota's new plant (TMMF - Toyota Motor Manufacturing France S.A.S.) in Valenciennes in northern France starting in year 2001. A three-box version sedan Echo will be exported to the United States starting fall 1999. Toyota also is planning to produce station wagons and coupes based on the same platform. "NBC" has been developed as Toyota's nextgeneration standard car, or as its standard world car in the sub-compact-class. The "NZ-type" engine, which was pre-developed for use in the hybrid vehicle in line with the request of the G21 team, also was going to be used in the high-end "NBC" model. An aluminum block was used in this engine to reduce weight and size. Takaoka and Tada improved the NZ-type engine's valve timing and compression ratio, and redesigned it as an Atkinson Cycle engine. The modification was relatively easy to make since only the valve closure needs to be delayed and the pistons can be modified to raise the compression ratio. The two engineers added an electronic throttle for the hybrid system, and improved piston rings to lower friction to achieve better fuel economy. When each component of the hybrid system, including the engine, was selected in March
1996, a seasoned engineer was called in to help the BR-VF team. The man selected was Senior Staff Engineer Takehisa Yaegashi, Toyota's top expert in emissions. 150

Three conditions Yaegashi supervised the development of all gasoline engines at Higashifuji Technical Center, and had been working with the THS Atkinson Cycle predevelopment team. He also had been helping with emissions reduction for Prius, and had been following the developmental progress of the hybrid vehicle. Early in 1996 when he was almost finished with the research work for the system, he had sent a memo to the Toyota Head Office: "The development is going rather slowly, and it is doubtful whether it will be finished on time. A strong leader should be recruited from the engine division." One day in mid-February, Yaegashi received a phone call from Member of the Board Masanori Hanaoka (now Vice President of Aisan Industry) in charge of engine technology. "My superiors told me to recruit you as the BR-VF leader starting March. Now that I have told you, I have finished my duty." "The final stage of developing THS requires a lot of energy and intelligence. You should find someone younger and more energetic than I am. I will do whatever I can to support the project." "Sorry, you have no choice." "No choice?" "The Prius project is not in very good shape right now. You have been commissioned." 151 Understanding that he could not reject management's order, Yaegashi visited Toyota Head Office the following day. He went to see the three Managing Directors in charge of technology: Masami Konishi (now Chairman Fujitsu Ten) in charge of engines, Shinichi Kato in charge of Technical Administration Division, and Shiomi in charge of EVs. These three had been responsible for recruiting Yaegashi to help with the Prius project, and were thoroughly familiar with Yaegashi's ability and personality. Kato had been Yaegashi's immediate superior during the last four years at Higashifuji. Konishi had been the Member of the Board in charge of Higashifuji prior to Kato. When he first went to work for Toyota, Yaegashi had reported to Shiomi who was the manager above
him. Yaegashi proposed three conditions to his former bosses. "I have come here with a certain resolve and I would like you to agree to three requests. First, we will have to buy time with money since we have very limited time. Second, we will have to make all of our young engineers work extremely hard and long hours, so I would like you to accept that. Third, I will need your support at every step of the way." "Okay, we will leave it all up to you. Do as you wish," Kato replied. At home, Yaegashi explained the situation to his flustered wife, then moved into the company dormitory the following week. 152
There was a reason for Yaegashi's acceptance of the position. Yaegashi had received his Masters' degree in engine combustion from Hokkaido University, and joined Toyota in 1969. He worked on clutch and transmission design for a while after joining the company, and was recruited to a special project team to work on emissions countermeasures in response to a new law in the United States to reduce air pollution. Since that point he had worked on emissions reduction for gasoline engines by using technology, such as three-way catalytic converters and electronic fuel injection (EFI). As the leader of a project to meet the new emissions standard for the State of California, he had helped develop and had selected a system for Toyota's ULEV (ultra low-emission vehicle) and in the process he also had acquired experience with VVT-i (Variable Valve Timing-intelligence). For Japanese auto makers, and Yaegashi who had worked hard to meet the environmental regulations of the United

States, the new American regulations made little sense. To them, the United States was excessively emphasizing the cleanness of emissions to such an extent that the regulations seemed to become totally impractical. At the same time, the United States had no effective regulation on the emission of carbon dioxide (CO_2), which is said to cause global warming. Since not controlling CO_2 emissions was the same as not mandating 153 improved fuel economy, the United States seemed to be granting extra time to the Big 3 to find ways to improve fuel economy for their cars. Because of that apparent unfairness in the regulations, Yaegashi wanted to develop the world's first hybrid vehicle to show the people of the United States that a car can be practical, attractive, clean and fuel-efficient. Later, Yaegashi said that when he accepted the position as project leader, his confidence level in regard to completing Prius was "not zero but less than five percent." He accepted the position despite his low confidence level because he wanted to show that a solution was possible for the United States market.
"As long as we have enough time, this system is possible. The hardware is simple, so there will be few problems. As long as we have reliable hardware, the control system will naturally follow. The problem is time. Even if we fail to finish the project by the end of 1997, we would at least be headed in the right direction. That alone would be a large step." He told that to himself repeatedly.

When Yaegashi took over as leader for BR-VF, he listed the specific tasks for the coming year. He assigned work to each team, and then explained steps he thought were highly important. The first step was to figure out "how to organize the reliability factor of the car up to that point." Staff Leader Mitsuhiro Nada of Engine Engineering Division I was appointed as the 154 section General Manager to supervise overall reliability. The second was to "put in place a special team to enable simultaneous coordination of THS and the car as a whole." Since engine experts were seen as not fully capable of handling this task by themselves, controls specialists from Higashifuji were recruited. The new team met with those who had developing THS, and asked that they put together the newest technologies for the controls. The team created a virtual model of the controls and conducted thorough safety analyses. The third step was to "create a special team to pick up any uncertainty." Through constant questioning and examination of every aspect of their work, the team began to see problems in the hardware. By getting his workers to focus on these three points Yaegashi tried to raise his confidence level above five percent.

A hunch Towards the end of February 1996, several young engineers of Engine Engineering Division II were absorbed in conversation over after-lunch coffee in the cafeteria of the Higashifuji Technical Center. "You know that hybrid vehicle, they say it is going into mass-production. I wonder which department is doing the engine." 155 "It's got to be the Power Train Engineering Division II, since it's a compact FF car. I'd love to work on the engine, since it's the first hybrid system in the world. But it's probably like hell right now. They have no actual engine, no materials and no know-how. They have nothing to work with." "I've actually heard that the new BR-VF leader Yaegashi-san was looking for some people to work on it." "Really? Then, they'll probably end up recruiting someone from our department (Engine Engineering Division II)." Shinichi Abe was one of the engineers at the table. The moment he heard the name Yaegashi, he got the feeling that "He might call me again...." His hunch proved to be right. He was designated by Yaegashi to work also as the Staff Leader for the hybrid engine group

starting in March. He was told to "supervise preproduction at Higashifuji for a while." Abe had joined Toyota in 1981. There are two areas of work in engine development. One is design, which is to draw the plans and to build the engine. The other is adaptation, which is to have an engine meet various regulations, car requirements, and consumer needs. Abe, who had worked on engine adaptation for many years, was dispatched to Toyota Technical Center USA (TTC) for three years starting January 1991. Since the California Air Resources Board (CARB) and 156 Environmental Protection Agency (EPA) were revising their emissions regulations at the time, Abe worked on legal
and public relations to express Toyota's views to both agencies and to the Big 3. Around that time, Abe chanced to meet Yaegashi, who was in charge of emissions regulation issues in Japan. They met at an

emissions conference in the United States. Yaegashi, who thought highly of Abe's coordination skills, often told him, "Abe-kun, I really recommend that you consider working at Higashifuji. It is very nice there." After working for three years in the United States, Abe had assumed that he would be returning to Toyota City, but he received an order to go to Higashifuji Technical Center. The assignment had been made at the request of General Manager Norihiko Nakamura of Engine Engineering Division III and Yaegashi, who had been developing the exhaust system for the low-emission vehicle (LEV) targeted for the United States. Abe had been working on exhaust systems for the U.S. before joining the THS engine team. On the upper floors of the Higashifuji Technical Center were two rooms, Gotenba and Numazu. Gotenba was occupied by those who were studying emissions regulations for massproduction cars. Numazu was used by those studying hybrid vehicles. Abe, who worked in Gotenba, often wondered what the other room was doing, but never thought that he would be working there one day. 157 By the end of 1995, the hybrid system was established and the first steps towards pre-pre-prototype were finally taken. The next task was for adaptation engineers. Unfortunately, there was simply not enough time or manpower to complete the project. In March, Yaegashi recruited a large number of experts so as to be able to complete the developmental work in the limited time available.

"We have an intense schedule, so I need engineers with good, solid background who can get the work done without being affected by the adversity we face. His recruits includ ed Nada, the reliability expert; Takeshi Kotani of Engine Engineering Division III; power electronics expert Sasaki; Tetsuya Abe and Akihiro Kimura in charge of base control; Vehicle Engineering Division's Satoru Niwa who was to work on coordinated control with brakes; Power Train Engineering Division II's Katsuhiko Yamaguchi; Engine Engineering Division II's Shinichi Abe and Akihiro Yamanaka; and Masaaki Yamaoka who had been dispatched from the Production Engineering Development Division to the Electric Vehicle Division. Yamaoka was sent to Higashifuji to work on the virtual model. Yaegashi scouted these people from their previous positions and then abruptly told their bosses, "Send him (them) here right away. If you need people, recruit young people." By fall, the number of engineers working for Yaegashi increased dramatically. He had no time to 158 submit official requests to the Human Resources Department so he physically brought engineers directly from their old posts and put them to new work under him even though they continued to keep their former titles. Finally, Yaegashi obtained more people by asking Board members to overrule usual procedures for transfers and requests for additional manpower.

Day-to-day management The engine adaptation team worked mostly at Higashifuji in 1996, but was transferred to Toyota City starting January in 1997. The engine alone could not improve fuel economy enough, so that cooperation was necessary among those who worked with motor, battery, and power split devices. For this purpose, it was more convenient for the engine adaptation team to be moved to Toyota City where the Electric Vehicle Division was located. Shinichi Abe and Takaoka also moved to Toyota City. Masahiko Hirose, who had just returned from Europe, came to Higashifuji, and reestablished Higashifuji as the research facility to work mainly on making emissions cleaner. While Toyota City worked on improving fuel economy, Higashifuji worked on improving emissions. In the beginning, the team consisted of only five engineers, including Tada, Takaoka, and three young 159 engineers, but the number grew. For example, there was a total of 20 engineers in Higashifuji and Toyota City, just counting those involved in adaptation work under General Manager Tatehito Ueda. Together with design people, the number eventually reached above 50. Fortunately, Toyota's tradition is to conduct specialized development with a small number of engineers until a certain critical point is reached, and then to mobilize a large number of people to complete the task. In addition, 12 or 13 people from BR-VF supported the engine team. Yasushi Nouno drew the basic design for NZ-type (1NZ), and Tada converted it to an engine for THS (1NZFXE). Hiroshi Kanai played a key role in reducing engine vibration during starting and stopping. Shinichi Abe was transferred to Power Train Engineering Division II, and his work was changed to preproduction, while he concurrently worked as the BR-VF Staff Leader and supervised the team on site.

Even with more manpower, development cannot progress unless there is an increase in the number of test cars. That might be true but test cars loaded with brand-new components are difficult to build.

Nevertheless, there was a ton of work to be done as part of the pre-production evaluation process. Testing was necessary on every component and every aspect of the new vehicle, including engine, noise, vibration, heat evaluation, electrical interferences, power performance, chassis. 160 Test prototypes also were built quickly. When a new component was developed, a new test prototype version also was built. Both sample and test prototypes were made every day because testing for production had to be conducted on the newest prototype. Everyone thought, "There would be less waste if we built and simultaneously tested a few of the same prototypes after several new units are ready." However, none of the teams had enough time to wait. In ice hockey and soccer, there is something called the power play" in which a team attempts to score quickly by mobilizing all players including the goalkeeper. Although the chance of giving away a point also is high the play allows a team to aggressively take advantage of every opportunity to score a point. Engineers adopted a power-play attitude and worked with it every day. Their view was that "If we don't do this right now, we cannot finish in time for production." Leaders of the various groups, including the one for engine development, began to grow impatient.

The midnight ghost "Can't we test the test vehicles more efficiently? We have so many people, but the evaluations are so slow" Young engineers of Power Train Engineering Division 1I and BR-VF began to voice complaints. 161 "Most of the test vehicles are unoccupied late at night or early in the morning. We shouldn't have that much time to let them sit idle. We should try to use them for testing on a 24- hour a day basis, every minute of the day," someone suggested. "Okay, we should start a 24- hour testing schedule." Shinichi Abe made up his mind. A seven-days-a-week 24-hours-a-day testing schedule was announced. Every group established its estimated test completion, and was expected to pass the test vehicle on to the next group. When developmental work was at its peak in June, July, and August, a Prius vehicle was constantly on the test course. In early June, a rumor started to circulate. It said that "a ghost appears at the Toyota Head Office" and that people were hearing whining noises at midnight. The stories started immediately after the midnight Prius testing began. The Prius prototype of that time emitted whining sounds (from under the hood) when it was running only on the electric motor. Team members knew of the midnight testing, but nobody else thought that a car was being tested because engine noises were not heard. Even at midnight, the test course was constantly crowded with six or seven Prius vehicles and that resulted in a loud chorus of whining noises. A few people were scared by the noise but some good came out of the latenight testing. Because of the 162 quiet at night, the whining noise from the inverter was very noticeable and team members pointed out that it would be objectionable.

By the time development work was finished, the whining noise was completely removed. Various groups, such as the engine group, BR-VF, and the battery group, were constantly running late night tests. Some of them needed just one test to estimate potential problems, such as vibration and noise, but others, such as powertrain, needed to run tests unique to the hybrid system. The latter groups had neither know-how nor experience, and the only way to learn about the system was through trial and error. The work was naturally timeconsuming, and the groups were forced to run tests at night. The time slots for their tests ended up between midnight and 7:30 a.m. They had a detailed testing schedule, but things did not necessarily go smoothly all the time. In emissions testing, there is a generally accepted practice of starting a test only when the water temperature is at 25 degrees Celsius. When the test vehicle was used throughout the night for other tests, the emissions group found it could not run tests in the morning because the water temperature would be at least 40 degrees. "Hey, engine people, can you make sure to finish your tests by six because we are planning a cold test tomorrow morning?" Even when the emissions group reminded the engine group the day before, the engine group's tests never 163 finished early enough. "The engine is not the only component of a car. Why can't you keep a promise?" Nobody wanted to offend another group by running late, but when promises were broken, conflicts occurred. Sometimes these conflicts would turn a bit confrontational. Late one night, Uchiyamada went to check on the testing group. An engineer bluntly told him, "Mr. Chief Engineer, you are distracting us by appearing so late at night. We will let you know the results in the

morning. Please leave us alone." Uchiyamada was taken aback, but smiled wryly to himself as he quickly left the test course.

Backing up the battery Even as the future of Prius began to look brighter, Yaegashi still had problems with the battery. The group was still unable to achieve the scheduled level of quality, and a prototype had not yet been produced. Yaegashi wondered, " What will happen if the battery can't meet the performance requirement at all?" He confided in Uchiyamada, "Uchiyamadasan, we might have to raise engine performance because we can't tell how much the battery's performance can be improved at this point." "How much more do you think we should raise it? More engine power means lower fuel economy." 164 "Our calculation shows it is now 40 kiloWatts, but I think we should raise it to 45 or 50. We should be able to adjust the fuel economy later." "Well, I want to avoid trading battery problems for fuel economy. Since the battery group is working hard, let's settle on raising the engine performance just enough so that the fuel economy remains about the same." The two agreed to increase engine output by 3 kiloWatts, and settled at 43 kiloWatts. Work on the battery was finished barely on time, but the result was not as good as Yaegashi had hoped. The 3-kiloWatt increase, however, was a big help. Especially when the outside temperature is high, repeated use of the battery sometimes caused the output to drop more sharply than had been initially estimated. The worst enemies for a battery are repeated exposure to high temperature, overcharging, and excessive output. Preventing those conditions extends battery life. Electricity use in the Prius, therefore, was reduced and engine use was increased instead. To increase engine output by 3 kiloWatts, many ideas were proposed, such as increasing the RPM. In the end, the 3- kiloWatt increase was made possible by closing the valve slightly earlier so that fuel economy would not be affected. This adjustment was possible within the tuning range of the engine. Without doubt, the battery group must have had the most difficult time testing at night since the group was 165 unable to meet the scheduled level of performance until the very end. The group faced many problems, including having the car suddenly stop in the middle of a test. Car engine history goes back a hundred years so the engine group had abundant know-how from past testing and experiences. Even though building a hybrid system was a new experience for the teams, the concept was based on physics and could be explained logically. The battery, however, is based on chemical reactions, many aspects of which were still unknown. At first, the battery group
failed to get the battery to reach both required and expected levels of performance. Nevertheless, other groups wanted to test-run the car as their work progressed. As the result, a test vehicle would often stop in the middle of a test due to battery loss. In the early stages, other groups accepted the problems, saying, "We don't know how to use the battery or how to control it." Later, however, when battery problems began to affect their tests, they became impatient, and accused the battery group of not knowing what they were doing. Even when the battery group was doing its best, they were - after all - trying to create something new to the world and there were no experiences or previous examples from which to learn. Everything, therefore, was guesswork. Although the group felt offended and hurt by the accusations from other groups, its members could not defend themselves because they were unable to develop a 166 battery that met the required performance level. The pressure was beginning to hurt the group.

Anguish "The battery gave out again. When can we ever do a real test?" A flustered young engineer complained during an engine test, but Shinichi Abe told him, "If you don't take good care of the battery, the whole system will be destroyed." In reality, Abe was quite concerned and felt that something had to be done. He met with the engineer in charge of battery development. "Please tell us the limits of the battery and what we should be doing to avoid problems. We will try to be careful with it so that we won't ruin it. If you could let us know how far you have progressed with your work, we would have a better understanding of where you are and what you are facing. As long as you keep us informed, we will know how to work with the battery." After that conversation took place, reports on the battery's development work and information on how to operate it were posted in detail on "G21 net," Toyota's Internet web page for Prius engineers. Information on testing problems turned out to be particularly helpful. Before the use of the Internet page, battery problems were written on paper and handed out to 167 each group. Such written information did not reach everyone quickly enough. In contrast, information on the Intranet reached everyone instantaneously, and questions could be fed back immediately. This process was so useful that everyone involved in the development of Prius now agrees that their work would not have been completed on time without it. In the development of new cars, this was the first time that the Intranet had been used for information exchange. Battery performance improved day by day, and the newest battery was always installed in the test vehicle. The Intranet page kept engineers informed as to which test vehicle had the latest version of the battery. All engineers now had easy access to every bit of information about the battery. Engineers now knew which test vehicle was equipped with the various batteries in different states of development and what precautions needed to be taken. Complaints directed at the battery group drastically decreased. Looking back on the experience, Abe said later, "Since we were developing a consumer product, we realized that we couldn't expect every group to be happy with each other. Also, we were lucky not to have any major accidents, and we also should take credit for that." 168

The leader's announcement About that time, the Public Affairs Division began to ask for test vehicles that were just starting to run properly. The cars were to be made available to reporters at test drive events and at product presentations for dealers. A young engineer said to Shinichi Abe. "I can't believe they are holding test-drive events considering the situation that we're in. Our priority should be to complete the car. What are the PR people thinking?" "What you're saying is true for ordinary cars. But Prius is special, so we have to accept that. The test-drive events were probably suggested by the Board," Abe replied, but was not convinced of that himself. Moreover, he was afraid the disruption and distraction from by such activities would cause his engineers lose their motivation. "Okay, I should go discuss this with Uchiyamada-san." On his way to see Uchiyamada, Abe came up with an idea. He returned to his office, opened his laptop, and began writing an E-mail. "This is Shinichi Abe in charge of engine development. I have an announcement to make. We are working furiously 24 hours a day to complete Prius. We cannot tolerate others doing unnecessary work like test-drive events and so forth. We understand that public relations is an important function of the company, but we don't 169 want it to deprive us of our precious test vehicles. What on earth is the company thinking? I hereby submit a complaint on behalf of my fellow engineers." He sent his e-mail to "G21 net." It was a declaration of war. "I don't think the situation would change even if I went to see the Chief Engineer in person. If that is the case, the engineers' motivation would drop, and they might lose their faith in our management. However, if I openly declare war against the Public Affairs Division, their motivation will probably rise." Abe's strategy worked. Seeing the Staff Leader's commitment to their work, the group bonded together stronger than ever. Concurrently, the E-mail put pressure on the Public Affairs Division not to waste anyone's time.

Use VVT-i Although the test vehicle's engine was improving, two technical issues came up. The first was to minimize the jolt of starting and stopping the engine while the car was moving; the second involved starting the engine when cold. These two issues needed to be resolved before production. Kanei joined the group with Shinichi Abe in March 1996. While Abe supervised the development of the 170 whole system, Kanei focused on the problems related to the starting and stopping of the engine. He was given the task in order to speed up the completion date. Kanei started by first studying why an engine vibrates. In the past, buses and trucks came equipped with a hand crank which needed to be turned to start the engine. When the pressure builds, the crank is initially hard to turn, and it releases suddenly when the pressure exceeds the requirement at the top dead center. At this point, the vibration is felt due to the ignition of the engine. Kanei thought, "Maybe vibration will decrease if there is less air during compression." This is the same concept as the part called decompressor in diesel engines. He came up with an experiment. When a lot of air is sent from the intake manifold to the engine, more power is needed for compression, thus creating more vibration. Kanei thought less power might be needed for compression and less vibration would occur if air was sucked out of the intake manifold. He tried using a commercial vacuum cleaner. "We might be able to stop the engine more quietly, if we stop it in this condition." The vacuum cleaner proved to be useless because the engine itself was an enormous vacuum. For his next experiment, he connected the test vehicle's intake manifold to another car's intake manifold. The second car was to act as a huge vacuum that sucked air out of the hybrid test vehicle's intake manifold. When he stopped 171 the engine, there seemed to be less vibration. Airflow can be changed by adjusting the opening and closing of the valve. When he tested again after altering the airintake valve timing and camshaft, there was a tremendous difference. "This is working," Kanei jumped in joy, and began looking at making specific changes.

Around the same time, a new technical item called Variable Valve Timing with intelligence (VVT-i) was completed and introduced in a product. It is capable of variably altering the optimal opening and closing timing of the air-intake valve from low revolution to high revolution. The item was used first in Crown that was model-changed in August 1995. The Chief Engineer for the vehicle was Hiroyuki Watanabe who succeeded Yuichi Fujii as Electric Vehicle Division General Manager in 1996 and later became a Member of the Board in charge of Electric and Hybrid Vehicle Engineering Division. The objective of VVT-i is to produce more power and "improve the feel of the engine." There are two side benefits as well: a reduction in nitrous oxides (NO_X) emissions because part of the emitted gas is reabsorbed by opening the air-intake valve earlier, and a drop in combustion temperature. Additionally, air-intake loss drops and fuel economy improves with VVT-i. The methods of altering valve timing already were available. "We can't have a product without this," thought Kanei, 172 and immediately requested permission to use it from Kumano who had worked on the basic engine design. Kanei wanted to use the VVT-i not for the original purpose but for closing the valve later to release the air that had been taken in. General Manager Shinzo Obuki of Engine Design Department No.24, Power Train Engineering Division II at Toyota City was able to rework the engine and quickly produced a prototype. It was ready by October, and was used for the Board's test-drive at the end of November. The only problem was that the engine might be difficult to start because of low compression. Internal combustion engines are designed to work better with higher compression. If compression is reduced by letting out air to reduce vibration as the engine is shutting down, there may not be enough air left to restart the engine, especially if the outside temperature is extremely low. Kanei ran tests. He adjusted the cam a bit at a time and tried to have the cam in position to close the valve as late as possible without creating a re-start problem. He was able to make the fine adjustments that achieved good results. Vibrations from starting and stopping the engine were reduced to the point they were hardly noticeable. In addition, Kanei determined the engine's center of gravity in order to mount it perfectly because less motion by the engine would cause less vibration. 173

Start the engine at negative 25 degrees Celsius The remaining problem involved starting the engine at low temperature. Normally, low-temperature tests were conducted only by engine experts. In a hybrid system, a computer tells the electric motor to use the energy from a battery to start the gasoline engine. This combination had to be taken into consideration in selecting the test team. The motor starts the engine which reaches a predetermined RPM. The computer injects fuel into the engine at specified intervals. Engineers in charge of engine, motor, and battery repeated tests at negative 25 degrees Celsius as they had discussed and they came up with a cold-weather solution by coordinating VVT-i timing, engine RPM, and the way to run the motor. This group effort was coordinated by Masahiro Ninomiya who had just been promoted to Engine Design Department No.24 as of January 1997. Shinichi Abe and Kanei, who were thrilled with the performance of VVT-i and could not imagine Prius without it, contacted Ninomiya in the summer of 1996. "Ninomiya-kun, this is the only thing we have. Please work out something to start the engine at negative 25 degrees." Six months later, coordinating motor, battery, engine and other components, Ninomiya came up with a solution that would routinely start the engine at negative 25 174 degrees. On January 24 1997, Ninomiya was scheduled to return to Toyota City from Higashifuji to present his progress report the next day. He did not get to give his report because the helicopter in which he was riding crashed, killing six Toyota engineers and two crew members. Ninomiya was only thirty-seven years old. With his death, the Prius project lost a valuable and talented engine designer. In tribute to him and as their show of gratitude for his contribution, all the engineers on the project swore to make the Prius a success.

Emissions Around that time, Yaegashi had confided to his colleague Haruo Watanabe, General Manager of Power Train Engineering Division II which is in charge of engine mass-production, "Nabe-san, you know our Prius. I am wondering if the superior fuel economy is good enough. I feel that a true 21st century car should also have super-low emissions, for example, in NO_X." "I was actually thinking of the same thing. The emissions regulations will eventually become more stringent. We can create more impact if Prius could achieve the highest level in emissions reduction." "The issue then is whether it could be done in time, 175 since we have less than a year before the launch." "Let's have Hirose-kun and others work on that." Member of the Board and General Manager of the Vehicle Development Center II, Kazuo Okamoto, who had succeeded Kubochi when he moved to the Vehicle Development Center I in June 1996, supported their view. A goal was set. "We will reduce the amount of nitrous oxides, hydrocarbons, and carbon monoxide emissions to onetenth of the level allowed under current emissions regulation." That goal was conveyed to Engine Engineering Division II in Higashifuji and BR- VF The Toyota Head Office is in charge of improving the fuel economy, while Higashifuji is in charge of improving emissions. Unless work on the engine system is finished, the Higashifuji group cannot start working on emissions. Since work on emissions tends to take a lot of time, a joint team was created by the two facilities. Because the engine is turned on and off when the hybrid vehicle is in use, the group faced difficulties in stabilizing emissions under those conditions, and also efficiently warming up the catalyst when starting the car. A distinguishing characteristic of a hybrid vehicle is that it also can run on just the electric motor. Hirose's team worked on using this ability to operate only on the electric motor as a way to heat the catalyst. When the ignition key is turned on, the engine starts but immediately shuts off unless it is needed to provide 176 power. In that case, instead of using the engine for power, the hot exhaust from the engine is used to quickly heat up the catalyst. When the engine is used only for heating the catalyst, the car can run using just the electric motor. The group also discussed whether or not the gasoline engine should turn over when the car is started, and decided that it should do so in order to have drivers feel the same sense of familiarity with the Prius that they would with conventional cars they drive. In addition, when the surface temperature of the catalyst exceeds 300 degrees Celsius, the catalyst maintains its temperature by automatically igniting the exhaust. In conventional cars, when the engine is idling, the exhaust temperature drops and the catalyst's temperature also drops, thereby causing the effectiveness of the catalyst also to drop. Prius had the advantage of never having the engine idle because it stopped completely when it was not needed. The exhaust, therefore, did not cool down the catalyst, and the temperature would remain above 400 degrees. Consequently, when the engine was turned on later, the catalyst would work immediately. By U.S. standards, Prius at this point would have been classified as a LEV (low emission vehicle). Simply by moving the catalyst closer to the engine near where the exhaust is emitted, Prius could be classified as ULEV Yaegashi's complex feelings towards America's regulations had in fact
helped propel the development of the engine. The team already has started to study methods to further 177 lower emissions for future export vehicles to the United States and Europe, and has tested a few ideas. The engine group's main goal now is to create a Prius that not only is fuel-efficient but also emits next-to-zero emissions. 178

Chapter 7
A Second Technology Division? Production Technology's Help - Motor

"Toyota has two technology development divisions," says a Toyota engineer with sarcasm, referring to the technology division and the production technology division. The technology division develops and designs a product, and the production technology division develops technology and designs facilities for mass-production. Almost all engineers that come to Toyota want to design cars, and most of them want to work on engines. Even though Toyota is known to let its younger engineers have a certain degree of freedom with their choice of work, that is possible only within their department. If every new employee could do what he/she wanted to do, Toyota would end up with too many engine designers and no finished car. If an engineer ended up in the technology division, he/she is lucky. There are many new engineers with college backgrounds in engine or chassis design that end up in the production technology division. That is why the production technology division is filled with such engineers. And that also is why a strange relationship 179 exists between the technology division and the production technology division that are located opposite from each other on Highway 248 in Toyota City.

Passive position In an effort to solve problems that develop at huge corporations, Toyota adopted new employment policies starting in 1997. They included interim employment for biotechnology and semiconductor specialists, fall employment of graduates of foreign universities, and open employment for engineers that requires no recommendation or reference from university lab professors. Until then, most engineers were employed only if they were recommended by their university lab professors. Every year, even after joining Toyota, many engineers from the production technology division applied for transfer to the technology division. However, most transfer requests would be denied so eventually the engineers would build a career as production technology specialists. When a new model is developed, a technology development center first designs the car, then the production technology division takes over, but the production technology division usually has a subordinate role. With the development of Prius, however, its role was a 180 little different. The technology division had little experience or know-how with inverters and motors, so the production technology division often stepped in to help. Both divisions for the first time acknowledged each other's ability, cooperated on an equal level, and accomplished a great feat. This cooperative relationship was unprecedented. One prime example was the development of the motor, which is the main component of THS (Toyota Hybrid System). THS uses two motors. One is for conveying power from engine and battery to the wheels and converting deceleration energy to electricity (regeneration). The other is for generating electricity from the energy created by the engine. The second motor also acts as the starter when starting the engine, and turns the planetary gear that is directly linked to the engine up to a predetermined RPM. The structure of these two motors is basically the same, and they are both three-phase current-types that use a permanent magnet. The standard voltage is 288 volts, and the power output is about 30 kiloWatts. Electric and Hybrid Vehicle Engineering Division had designed these motors specially for Prius based on the RAV4EV motor developed by Electric Vehicle Division, which was the precursor of Electric and Hybrid Vehicle Engineering Division. 181

Who is familiar with motors? Kaoru Kubo, who designed the motor at Electric and Hybrid Vehicle Engineering Division, had studied mechanical engineering at Yokohama National University. He joined Toyota in 1978, and built a career as a production technology specialist through his experiences at 1st Machines Division, and the Motomachi, Kamigo and Teiho Plants in Toyota City. He was in charge of designing internal production facilities, and moved to the FA System Division at the Teiho Plant in 1991 to work on electric motors for the first time. At that time, internal production of motors was increasing in the facilities division. The motor was specially designed for in-plant use, and was definitely not intended for use in a car. "In the beginning, nobody knew anything about motors. When we ordered a motor from

another company, it arrived with a shaft sticking out. We had to learn quickly about the structure of the motor itself in order to figure out how to use it optimally." Engineers, therefore, began studying motors. Meanwhile, in the early 90s, Higashifuji Technical Center began conducting research on EV and hybrid vehicles. EV development was speeding up in response to future emissions regulations, and hybrid vehicles were a part of the project. As the research for hybrid vehicles began, the 182 technology division began looking for anyone with know-how in motors, and the search reached Teiho Plant. There was almost no one in the entire company who actually built or analyzed motors. Most people only dealt with peripheral technology. No core technology for motors was found within the company, so the hybrid researchers focused their attention on the FA System Division that had studied the structure of motors. The first project at Higashifuji was a groundbreaking EV that used a "wheel motor" that Shiomi liked. In this EV, the motors are directly linked to the tires and are contained within the wheels. Since shafts and couplings to connect the power source to the wheels were unnecessary, the car's design was extremely simple. In addition, large engine space was not necessary. It was a unique 4WD EV that suggested many possibilities. In early 1991, even before the Electric Vehicle Division or BR-VF were established, several people from Higashifuji were called together to form a working group with Shiomi as the leader. Two engineers from Teiho Plant joined this group, and worked on designing the wheel motor. In developing the Prius, production technology engineers who were deeply involved in development helped create a few bridges between the two technology divisions. Several years earlier, however, some production technology engineers already had become involved in product development. This working group, however, was disbanded after 183 coming up with several designs but before building a prototype. The project proceeded no further than theory. Even though Shiomi wanted to develop a car that met the demands of a low-emission vehicle, a car designed with four
motors and four inverters proved to be too costly. Shiomi, therefore, changed his strategy to developing a pure EV that used a motor and a decelerator. Even though the working group had been disbanded after a year, the Electric Vehicle Division was established within the Vehicle Development Center III when the Center System was introduced in September 1992. EV production was carried over, and a design for RAV4EV was finally hammered out. Electric Vehicle Division was organized by engineers from each technology department and the FA System Division, which was a part of the production technology department. Several people were transferred from the earlier working group as well. One of them was Kubo from FA System Division.

A strange order Kubo never volunteered to be in that department. Having written his thesis on combustion analysis of diesel engines, he naturally wanted to go into engine design, but he had been assigned to the production technology division instead. For the first seven or eight 184 years, Kubo had submitted requests to be transferred to a technology department, but his wish was never granted. Thanks, however, to his experience with motors in the FA System Division, he was finally transferred to the technology division after all those years of waiting. Kubo found out about his transfer through a strange series of events. After being hospitalized for two weeks, Kubo returned to his office and was approached by a colleague who asked him, "Will you sell me your house?" A few years earlier, Kubo had bought a new house that stood on a nice location near Teiho Plant. "Ha, ha. Are you kidding me?" Kubo replied, but the colleague was not joking. While he had been in the hospital, a rumor had circulated that an Electric Vehicle Division would be established and that Kubo would be assigned to it. Engineers assumed the department would be located in Higashifuji, so that Kubo would have to sell his house and move. Kubo had no idea that such a rumor existed, but the story proved to be accurate. He soon received an order from his boss. The new department was located in Toyota City, however, so he could keep his house and did not have to move. The Electric Vehicle Division was planning to develop the RAV4EV from scratch. Although the initial plan was to buy motors from another company, Shiomi, who just had been appointed as General Manager of the Vehicle 185 Development Center III, persuaded the team to consider manufacturing the unit within the company. The department was split between the pro-purchase group and the pro-manufacture group. In the end, the department settled on manufacturing the motor. The pro-purchase group recommended an induction motor built by a specialized manufacturer. At the time it was an innovative AC (alternating-current) motor, and its efficiency had been made better than DC (direct-current) motors by eliminating the brush. The pro- manufacture group recommended building a synchronized motor with permanent magnets so that a

more efficient and compact motor could be made. Through extensive testing, the group succeeded in building a satisfactory prototype. Since its efficiency, travel range and size were superior to the other motors, it was selected. EV development was in its early stage at the time, so that the cost of motors was less of an issue because other parts, such as the battery, were so costly. The first objective was to achieve the performance level necessary for a car and then to shrink the size of the motor. Kubo remembered his feelings at the time when Toyota decided to manufacture the motor. "It was the first time that Toyota had succeeded in building a highpower motor, but I was not so excited. I was worried about developing the technology in terms of high-volume production." The power output was 45 kiloWatts. For a permanent magnet-type synchronized motor, it was the 186 most powerful on the market. There were no other comparable motors. In other words, there had been no need for such a motor up to that time. In this class, there were only induction motors specifically designed for use in heavyduty machinery. Toyota's motor was very large, and Kubo could not visualize putting such a large motor in a car. The Electric Vehicle Division launched a 3-door RAV4EV in the fall of 1996, and a 5- door version the following year. The price was more than 5 million yen, and only two of these cars
rolled out of the production line each day. These cars were not much more than prototypes, and were bought largely by utility companies, government agencies, and corporations. The motor was made in Teiho Plant, and the body was built at the Motomachi Plant.

A tiny engine room In early 1995, a little before BR-VF was established, several members of the Electric Vehicle Division studied the hybrid system. Although no one had been assigned to work only on the hybrid system, the project moved ahead on parallel course after the RAV4EV was launched. A microbus Coaster equipped with a series-type hybrid system already had been launched and sold in small numbers. While they worked on the Coaster, the 187 group had discussed whether they should use the series-type or the parallel-type on a passenger car. BR-VF's establishment in February was largely influenced by the Electric Vehicle Division's work. Fujii, General Manager of EV Development, also served as leader of BR-VF, and the BR-VF project team members used a part of the Electric Vehicle Division's room for their work. The two organizations naturally had daily contacts, and were familiar with each other's research. The development of the motor was in fact a joint effort. As mentioned earlier, these two organizations were consolidated in April 1997 into the Electric and Hybrid Vehicle Engineering Division. When the hybrid system was approved in June 1995, the Electric Vehicle Division became responsible for designing the motor because BR-VF did not have design functions.
The request for a motor design was the first in a series involving a hybrid system that BR-VF sent to the Electric Vehicle Division. Kubo of the Electric Vehicle Division began the design process together with Matsui and others from the Drive Train Engineering Division that designed the hybrid transaxle. Matsui, who was also a member of BR-VF, immediately began working on the design requirements. Seeing that, Kubo was reassured but with mixed feelings. RAV4EV, which Kubo had worked on, had only one motor, but the new hybrid system would include an 188 inverter and a transaxle, connected together with the motor, generator, decelerator and power split device. Moreover, the design included an engine that does not exist in the EV. Kubo was instructed to place all of those components into a compact engine space designed by G21. The space for the engine was "unbelievably" smaller than that of RAV4EV. "How can I lay out the components in this space?" Kubo pondered. The EV consisted of a motor, inverter, and decelerator, and had far fewer parts than Prius. Moreover, the battery was installed under the floor so the engine compartment was spacious. Each part, therefore, had been designed larger than those for Prius. Compared to what he now faced, Kubo felt guilty to have had such a simple design task with RAV4EV.

Cut another 5 millimeters Kubo began to work on the design specifics of the motor. Selecting the shape of the motor was important. He discussed that with Matsui and others as if they were solving a puzzle on how to combine the motor with the other components and to create a unit while keeping the whole system confined within the limited space. The shape could be either a long narrow cylinder or a 189 thin donut-shape. With a thinner shape, the space inside the engine compartment opened up to allow more freedom in design. The group pooled their resources to use the space efficiently and to neatly link the power split device to the decelerator. The group took advantage of its experience with

RAV4EV, and selected the permanent magnet-type motor. The motor's structure was exactly the same as that of the generator. A motor produced torque from electric energy, and a generator produced electric energy from torque. When regenerative braking is used, the torque turns the motor which then acts as a generator. The motor's power output was set at 30 kiloWatts; the generator, a little less. The motor's size was determined by the specifications set by BR-VF. The Drive Train Engineering Division drew the design of the whole transaxle based on motor size. Several minor changes were made to facilitate mass-production, and complex parts were simplified. Even when minor changes were made, the motor group met with the decelerator group to discuss size changes. In the beginning, the Electric Vehicle Division designed the motor but negotiated with the Drive Train Engineering Division to set the width at 106 millimeters. When Kubo reviewed the finished design plan, he felt something had been changed. He looked carefully, and found that the motor width was 5 millimeters less than the plan. He checked with Matsui to see if that was a 190 mistake. "You know the motor width, it says 101 millimeters on the plan. Isn't that off by 5 millimeters?" "Oh, we had to cut it down a bit, because it didn't fit." Matsui replied calmly. "Wait a second. That's not what we agreed on." "But we've been working on the plan with that measurement. "What are we to do if you keep on changing our agreement?" Kubo had second thoughts, however, "Too bad. It is no use building something that won't fit. Cutting back 5 millimeters shouldn't be a problem." He managed to convince himself, and agreed to 101 millimeters. The prototype motor that was 5 millimeters smaller than the initial plan was estimated to produce three percent less power. Test proved, however, that the performance would be even worse. Kubo thought,
"This is hopeless." He had to do something, however, since he had agreed to work with 101 millimeters. He nonchalantly told the Drivetrain Technology people, "We knew that the performance would drop this much, since we lost 5 millimeters. It's all right, we'll figure out something." When he quickly ran an analysis of the motor, he found some calculation errors. At that time, since each component was still being developed, each group still had time to run calculations and analyses. 191 While the motor technology was being improved, the car itself was going through four performance reviews. Each time, the width requirement for the motor was changed, and the figure was finally narrowed down to 90 millimeters. Although the width had been reduced by 16 millimeters from the initial plan, Kubo still was able to achieve the planned performance level.

Kubo's experience with the RAV4EV motor helped him develop the motor for the hybrid system. Kubo explained, "Since I knew the basic structure of the motor, I could make a good guess of what the result would be even though the analysis said that the figure could not be achieved." Shiomi's insistence of manufacturing the EV motor in-house now became a valuable asset. However, the structure of the RAV4EV motor made mass-production impractical because it had not been developed with mass-production in mind. The motor for Prius, however, needed to be adapted for massproduction. For example, there are several magnets attached to the rotor located in the center of the motor. For RAV4EV, the magnets were secured to the iron rotor by coils of wire that prevented the magnets from falling off due to centrifugal force. However, this type of construction takes too much work and is not suitable for massproduction. Kubo decided to simplify the structure by planting the magnet inside the iron rotor/shaft. When the magnets are attached to the surface of the 192 shaft,
various phenomena in the magnetic circuit were relatively stable. Now that the magnets were within the shaft structure, Kubo had no idea what would happen. Many basic tests had to be run to determine where and how to locate the magnets, how to shape the magnet for peak performance, and how much the procedure would cost. Development work on all of those factors began after the Prius project was started.

Finding the cost of electromagnetic steel plate The issue came up in October 1996, a year prior to lineoff, when a VE (value-engineering) discussion meeting was held to verify that the performance justified the cost of each part. The engineer in charge of procurement for the motor was called by Uchiyamada to explain the material cost. Uchiyamada asked him, "Why is the electromagnetic steel plate so much more expensive than the rest?" The electromagnetic steel plate is used for manufacturing the rotor inside the motor and the exterior stator. It is a silicon, low-carbon steel plate

that has high electric resistance and magnetic permeability. The quality of the electromagnetic steel plate, how the coil is wound, and the quality as well as the shape of the magnet determine a motor's performance. The quality of the copper wire used on the coil hardly affects the 193 performance. Only the quality of the electromagnetic steel plate greatly affects the motor. After hearing about procurement and the manufacturing problems, Uchiyamada understood the situation, saying, "I guess it could be rather expensive, if it is so important and so difficult to make." At the same time, costs for Prius could never be lowered if he did nothing about them. "We would like the Electric Vehicle Division to cooperate with the purchasing people and the manufacturers, and work on value-engineering by lowering the cost of the electromagnetic steel plate and breaking the stalemate in product development." Uchiyamada thereby created a new assignment. Electromagnetic steel plates were bought from Nippon Steel's Hirohata Works. Kubo discussed the situation with Toyota's purchasing agent, and contacted Manager Koji Tohda of the Electromagnetic Steel Management Division (now Manager of Shanghai Office), who was directly in charge of production, and also Vehicle Technology Division General Manager Shoji Kubota of the Nagoya Office (now Tokai Steel Works Member of the Board), who was the liaison. "We don't have a problem with the quality, but the cost is a little too high. Can you lower the cost by lowering the quality as much as possible?" The two understood the situation and accepted the challenge. "Okay. Since the hybrid vehicle is socially 194 significant, we would like to help out by doing what we can. Let us give it thorough consideration." Thus, the leaders of the two industries began their cooperative efforts to lower costs. On December 20th, 1996, three Toyota representatives (Kubo, Hiroyuki Hattori in charge of electromagnetic design, and Noriaki Murai in charge of purchasing), met in a conference room at the 1st Administration Building in Toyota City with four Nippon Steel representatives (Tohda, his boss General Manager Kenichi Nishiwaki of the Electromagnetic Steel Management Division, Kubota, and Deputy Department General Manager
Yoshinao Tanaka). Tanaka began the discussion. "We can't go into the new year like this. Can you give us the bottom-line performance requirements?" "Okay. This is what we need." Hattori presented the specifications and said the most important need was to minimize "iron loss," which directly affects the motor's performance. A motor with less iron loss can be made more compact, hence cheaper. A motor is subject to two "losses." The first is "copper loss," which is energy lost through heat (Joule heat) when the AC is run through the coil. The second is "iron loss," which occurs in the electromagnetic steel plate. Iron loss is the electricity that is lost when the current passed through a coil alters the magnetic flux so that excess current is released into the iron. The solution is to improve the conductivity of the magnetic line and 195 increase the magnetic flux density. A microelement can be added to the iron to reduce iron loss. Iron crystals are formed as temperature rises during the iron manufacturing process. Addition of certain microelements stop the growth of iron crystals, so that the crystals line up in one direction the moment the temperature reaches a certain point, improving the conductivity of the magnetic line. Adding a microelement to the iron, however, makes the manufacturing process more complex and costly. It was necessary to minimize the addition of microelements while still minimizing power loss. Toyota's aim was to drastically reduce cost while maintaining the same level of performance. The main prerequisite to lowering "iron loss" was to make the stator as thin as possible. **Working through New Year's** Stator, the outside part of the motor wound with wire coil, is made of many layers of thin electromagnetic steel plates. They are layered with the surface of each plate insulated to prevent the current from running in a certain direction. In addition, eddy current cannot be completely prevented in the thin plate. Therefore, a thinner plate means less core loss and higher performance. Nippon Steel came up with three plate types to test with the stator. The first one was 0.3 millimeters thick, 196 the second was 0.25 millimeters thick, and the third one was also 0.25 millimeters thick but with a different annexing agent. Nippon Steel even worked through the New Year's holidays and by the end of January, the three types of plates were ready. By the end of March, prototype motors were made using the three different plates. The 0.25-millimeter plates naturally had less core loss, but the 0.3-millimeter plates performed just as well. The high level of performance was attained by lowering silicon content and using a better manufacturing method. After considering cost, the team decided to
go with the 0.3millimeter plates. Many in-car tests were run and the project seemed to be going smoothly. In mid-April, two problems came up. The first one came from the Power Train & Chassis Components Production Engineering Division in charge of manufacturing the motor. It complained:

"The 0.3-millimeter plates are too thin, and the stator rigidity is too low. Thus they will cause manufacturing problems." The project stopped. Kubo ran to Chief Engineer Uchiyamada. Even though the 0.3-millimeter plates were expected to be significantly cheaper, Kubo asked to change the plan. "Okay. It will be meaningless if we can't manufacture the unit. Think of a method to improve the efficiency using 0. 35-millimeter plates. We'll do something with the cost." Uchiyamada accepted the inevitable. 197 As Kubo was returning to his office, he thought to himself, "We can't give up here." He immediately called Nippon Steel's Kubota. "The production technology people say they can't manufacture a safe product. Let's start again. Let's work on 0.35-millimeter plates for the stator and run the same tests." "Other companies actually use those thin plates. Is there any way for Toyota to work with them?" "Unfortunately, our production technology people really can't do anything about it." Since the Nippon Steel engineers had developed the plates within a short period of time by even working through the holidays at New Year's, they would not easily give in. Nevertheless, as long as there was a problem, Toyota could not use the product. After Kubo's second request to try 0.35-millimeter plates, Kubota finally decided to develop new ones - again within a short period of time. The second problem was that the fuel economy was dropping. While many test motors were being produced with various materials after New Year's, Kubo realized that motor efficiency had started to drop steadily after a certain point. He had no idea why. As he was looking for the reason, the car testing group notified Kubo that fuel efficiency had dropped by two to three percent due to lowered efficiency of the motor. Prius was designed to be twice as fuel-efficient as other 198 cars of its class so it could not afford to be in such a situation.

Should we install a machine? Meanwhile, the Power Train & Chassis Components Production Engineering Division in charge of the motor manufacturing machine, was also troubled by the fact the motor's performance suddenly began dropping. Until just recently, the team had been winding the copper wire coils manually. Ten thin copper wires were wound by hand around the stator several times, and each coil was placed into an extremely narrow space one by one. There were tens of these coils evenly spaced. It would be extremely difficult for a manufacturing robot to pick up a number of such coils to place them in the narrow space. The team tried to build an automated facility in which a robot would be able to insert a few of them at a time but in several tiers. The team suspected that this facility could be affecting the motor's performance considering the timing of the facility's installment. In fact, even though the number of coils used was the same as that indicated in the design, there was a slight aberration in the electromagnetic circuit between the manual placement and machine-assisted placement. When electric current is applied, a circular current forms 199 within the coil. If the coil is in a thin bunch, nothing would go wrong. However, when the coils were placed in tiers, a parallel circuit formed a block. While investigating the cause of this problem, two Chief Engineers, Ken Tanoue of Power Train & Chassis Components Production Engineering Division and Takaaki Ikeda of Machine & Tools Engineering Division, were contemplating whether they should install this machine or not. They had already placed an order to a machinery manufacturer for the coil winding machine to install in the Honsha Plant at the beginning of 1997. The machine was supposed to be installed between April and June. If they decided to reconsider installing the machine and began design changes and improvements, they would never finish in time for line-off. Throughout the Golden Week holidays, Tagami wondered if the machinery should be installed as scheduled or if it should be cancelled. In any case, the machine's manufacturer would be working on the order throughout the holidays. "It is too late to cancel the order now." Tagami discussed the idea with Ikeda but decided to install the machine after the holidays as planned. His solution was to somehow find out the cause and to reconstruct the new machine. For the time being, the machine was installed. However, if they were unable to produce appropriate motors, other departments would have major problems in 200 their vehicle tests. The team used the old coil winding machine from Teiho Plant to make the prototype motors, and tried to devise remedial measures. No matter how the machine was adjusted, it was unable to wind tens of wires at
the same time. So, the design of the motor itself was changed. The copper wire was changed from 0.7-millimeter to 0.9-millimeter, and the number of times the coil was wound was reduced by 33%. The method of connecting the coils also was changed. After these changes, the team was finally able to achieve the motor efficiency as initially planned. The three machines were reconfigured one by one. Testing for mass production was conducted as scheduled while the new winding method was tested on

another machine. The machine manufacturer supported the project on a 24- hour basis. As a result, despite the additional cost, the machine was ready in time for mass production.

Unprecedented mass production of motors Meanwhile, Nippon Steel was working on the steel for the 0.35-millimeter stator. It was inevitable that the metal quality would be slightly lower. The question was whether the performance loss would be acceptable. Motors were actually test-produced using the new metal. Various coil winding were tried and evaluated. 201 Eventually the group concluded that the quality of the plates was within the acceptable range. With the 0.35- millimeter thickness, there would not be any manufacturing problems. Performance loss was contained within the performance variance of the motor. Only one type of electromagnetic steel plate was used to test the 0.35-millimeter stator. The best steel for this thickness and the most reliable steel was used since the project could not be delayed any further. With the new electromagnetic plates, the cost of producing the motor was reduced by 30%. The motor manufacturing industry is completely different from the auto industry. The large-size motors used in manufacturing operations and in railroads are almost all manually constructed. Monthly production of 1,000 units would be considered somewhere between small and medium production volume for Toyota, but that same amount would be enormous in the motor manufacturing industry. Manual production has much leeway but is not cost-effective. Since automation of motor production was unprecedented, Toyota's Production Technology departments encountered many difficulties. If monthly production were to eventually increase to several thousand or even tens of thousands, a breakthrough in production method would be needed. If in the future, EVs, hybrid vehicles and FCEVs were to replace gasolineor diesel-engine cars, electric motors 202 would replace internal combustion engines. Auto makers cannot afford to purchase electric motors from outside sources because motors would be a core item for cars. Stable, mass production of motors, therefore, would be the key to a successful eco-friendly car strategy.

Emergency situation arises By the end of 1996 when the motor group was having difficulty selecting the stator, a major problem in the transaxle developed during an official test. One evening, Drive Train Engineering Division's Matsui was meeting with his staff in his office, when the phone rang. One of his staffers answered for Matsui who was occupied at the time. His expression grew tense as he listened and spoke a few words on the phone. "What's wrong?" "There's a huge problem. They are saying the THS won't assemble properly. They say there is a misfit between the case and the gear on the power split device or something." "What? Someone bring me the plan!" Suddenly the office was in a rush of activity like inside an agitated beehive. A moment later, a staff member brought a printout of a CAD plan. 203 "Here it is. There is an error." At that point, Matsui felt overcome by a sense of hopelessness.

It was during the official testing of THS, which formed the core of the project, when the unthinkable happened with the gear system. THS consists of engine, motor, generator, and decelerator, and energy is distributed according to commands from the hybrid computer. THS is the heart of the operating mechanism for Prius. However, it was not working because a gear wheel was stuck against the wall of the case for the power split device. The year was coming to an end, and the vehicle testing schedule was supposed to begin after the New Year's. It was a simple design error. The dimensions were wrong for a side of the case, and the error was rudimentary and inexcusable. It was simply due to careless negligence. The casing wall was to have been carved 10 millimeters deeper so as not to bind the gear wheel but that surface variation had not been indicated clearly on the plans. How did this rudimentary error happen? It was because of CAD. CAD becomes more useful as the task gets more complicated. At the time, three-dimensional CAD was starting to replace the existing two-dimensional CAD in the divisions that design the body. Many drivetrain designers, however, were still using the two-dimensional CAD. Since many drive train parts revolve, the designers would draw a two-dimensional plan and 204 then simply turn the plan around to make a three-- dimensional form. Since they designed in this fashion, they forgot to indicate the hollow shape on one surface. Since the case is a solid body, every surface needs to be drawn correctly for the design to work. The designers were so used to using the easier two-dimensional CAD that they failed to realize the pitfalls of their practice.

Emergency manual procedure For building the prototype THS unit, Drive Train Engineering Division handled the design, Foundry Engineering Division's Meichi Plant did the casting, and Power Train & Chassis Components Production Engineering Division handled machine processing. The parts were then shipped to the Prototype Department which assembled them. The design error was discovered while Power Train & Chassis Components Production Engineering Division was test assembling a unit. Accompanied by an experienced engineer, Matsui ran to see Power Train & Chassis Components Production Engineering Division's Tagami. He discussed with a Power Train & Chassis Components Production Engineering Division engineer the extent of the problem and how much thinner the case wall was to be. Matsui, who had expected to be grilled for making a highly unprofessional error, began apologizing. 205 Tagami immediately stopped him and said, "Don't worry about that. Let's think of how to correct the situation instead." "We've already cast tens of them, but we stopped the rest. Matsui-san, can you redraw the plan for the mold right away? Meanwhile, we will fix what we can." Matsui felt completely indebted to Tagami. Before casting could continue, the mold needed to be changed. Modifying a mold usually takes one to two months. The date for building the prototype was set, and there would be no time to rebuild every case, starting with the mold. At least seven cases had to be finished within the year so that they would be ready for testing after New Year's. So even without a detailed drawing, Tagami and Matsui decided to machine down some of the cases. There were about ten casings. Some of the technicians came to work on weekends immediately before the winter break and manually modified the cases. The day after the problem surfaced, Matsui brought the new plan to Design Management Department for approval and delivered it to the Power Train & Chassis Components Production Engineering Division's Honsha prototype plant. Meanwhile, the Foundry Engineering Division finished the mold change in a week instead of the usual four, and began manufacturing new cast parts. They placed the project on top priority and put their maximum efforts into it. 206 In the end, the ten cases manually repaired by the Power Train & Chassis Components Production Engineering Division were used for bench testing, except for one that was actually used in a test vehicle. The cases cast in the new molds were used on all test vehicles after that. The impact of the error was minimized, thanks to cooperation among the departments, the human network, and the efforts of individuals who worked through nights and weekends. "Phew, now we are prepared to build prototypes after New Year's. At one time, I truly feared the outcome. I felt so sorry that we were holding back the schedule when everyone else was focused on building the prototype. It is such a shame for us to cause the delay with such a careless error." After all had been done and the work completed, Matsui felt much relieved.

Concurrent Engineering Tagami's view was a little different. "Everyone is working hard, and design errors can happen. The fact that we actually proceeded to make the faulty part is a matter of concern." Toyota had been in the process of introducing the concurrent engineering (simultaneous engineering) method. It aims at shortening the development period and reducing cost through the participation of production 207 technology and production preparation divisions in design and development. Two types of concurrent engineering had been introduced. The first was called "horizontal consolidation" in which departments develop parts simultaneously as they monitor the developmental progress of other parts. The second was called "vertical consolidation" in which the development division and the production division jointly discuss for optimal completion. The prototype division also had adopted these methods. If this simultaneous development policy functioned properly in this case, the engineers should have noticed that the figures conflicted when they programmed the numerical control (NC) computer for processing cast parts. The purpose of concurrent engineering is to allow these engineers to notice design errors and to promptly take measures to fix them. The design error, however, was finally discovered at the final assembly phase. Tagami thought, "Needless to say, the design group is responsible. However, the processing group also could have found the errors. It is pointless to blame one person for this. The concurrent engineering system is still far from fully functioning." Executive Vice President Takahashi admonished the group saying, "It is not Toyota's style to simply build goods out of a design plan. Mutual feedback between the manufacturing processes from design to production is 208 indispensable to achieve short-term development." After the series of problems was solved, Tagami summarized his lesson. "Frankly, this is not working. It needs to work more systematically. One of the major tasks given to the Prius project was to standardize the development process. We must change the nature of manufacturing through Prius. Fortunately, we came out of this problem through the cooperation of everyone. However, if we don't reflect on the actual nature of the problem, we may not be so lucky next time. How effective is our concurrent engineering practice? We can pass on our accomplishments only by standardizing the process taken to achieve them. How could it have been made more efficient, simple, quick, and secure? The production technology group must think this through thoroughly." In many ways, as Tagami had noted, this problem was solved quickly thanks to the importance of the Prius project itself and through the good relationship between the engineers at Higashifuji Technical Center and those at Head Office technology division. This problem brought out both the good and the bad of Toyota's manufacturing capability. Despite it all, Tagami said, "I guess we are much better now than five years ago when we started advocating the concurrent engineering policy." 209

Chapter 8 Hirose Plant's First Major Challenge - IGBT

Hirose Plant was built exclusively for the production of electronic parts and it is the first of its kind owned by a domestic auto maker. It is located in an industrial complex outside of Toyota City, about 30 minutes from Toyota's Head Office. It is fairly close to Korankei, the most famous place in the Tokai region for viewing the fall colors of Japanese maple trees. The landscape of this region resembles that of Germany or Switzerland. Toyota began its own production of the Electronic Control Unit (ECU) for cars in 1985, and built Hirose Plant in 1989. In 1990, Toyota also began developing and producing its own Integrated Circuit (IC), or semiconductors, for the ECU. Toyota could have outsourced its electronic parts. For instance, among Toyota's affiliated companies are Denso, which had formerly been Toyota's electronic accessory division but had become one the largest parts manufacturers in the world, and other large electronic and electric manufacturers, such as Aisin and Fujitsu Ten. Toyota also could have bought parts from Toshiba or 210 Matsushita Electric Corporation. Toyota's management thought, however, "The competitiveness of auto makers eventually will be determined by its electronic parts. If we cannot produce them ourselves, we would become a mere assembly manufacturer." In 1985, therefore, Toyota's three Executive Vice Presidents, who were at the time Gentaro Tsuji, Kanetaka Kusunoki, and Kiyoshi Matsumoto together with then Members of the Board Akio Numazawa and Akira Takahashi (now Executive Vice President) boldly decided to venture into the construction of the Hirose Plant. Even at that time, auto makers were expected to develop their capabilities in electronics, but no one expected them to manufacture semiconductors. Shoichiro Toyoda, who was president at the time, approved the 15 billion-yen investment with no hesitation. There were three reasons for building the Hirose Plant: 1. To prevent auto manufacturing technology from "hollowing out." 2. To stay ahead of parts manufacturers by taking responsibility for both development and production. 3. To establish an electronics plant exclusively for autos. In fact, there was one other, and major, reason as President Okuda explains, "We were more afraid of not knowing what was inside the black box rather than of our 211 technology becoming a black box. Without that knowledge, we could not accurately calculate cost, and we would have to buy them from our suppliers at the seller's price. Toyota's electronics division is roughly divided into the Electronic Technology Department in each of the I through IV Vehicle Development Centers, the Electronics Production Engineering Division at Hirose Plant, and the Electronic Parts Manufacturing Department. Electronics Engineering Division I develops air bags, car navigation, and audio. Electronics Engineering Division II develops electronic parts for chassis, drivetrain, and powertrain. Electronics Engineering Division III is located at Higashifuji Technical Center, and is responsible for predevelopment. Electronics Engineering Division IV is at Hirose Plant, and conducts research and development for in-vehicle-use semiconductors. Electronics Production Engineering Division and Electronic Parts Manufacturing Department are both within Hirose Plant which is responsible for every aspect of semiconductor production - from base development to mass production. Because it is located with electronics, the development of Prius provided the perfect opportunity for Hirose Plant to display its true worth and was given two tasks. The first task was to develop the motherboard for the Prius ECU which would become the control center of the hybrid system, and would act as the brain for Prius. The decision to create the design within Toyota was 212 made at an early stage because the control system could be based on the hybrid system constructed by BR-VF using simulators. Since Hirose Plant had ten years of experience, as ECU production had begun in 1985, there were no manufacturing problems.

Production or purchase? The other task was to manufacture the "inverter" unit for switching the battery's DC into three-phase current and electronically controlling it. The device was indispensable for using an AC motor. The project team decided to use a semiconductor called the Insulated Gate Bipolar Transistor (IGBT) for the core of the inverter unit. Hirose Plant was assigned to develop the IGBT. A type of semiconductor called Thyristor is often used as the switching element for "inverters." However, IGBT is capable of switching and controlling strong currents of several hundred amperes at a much faster speed with a voltage signal. With Prius, a Thyristor's switching speed would not be fast enough. IGBT already had been used in the *Shinkansen* (Bullet Train), but its full capacity and performance limits were still unknown. Toyota had no experience making them, and it also needed to do basic research to determine if an IGBT suitable for Prius existed in the world. The only thing Toyota knew for sure was that Prius could not be completed without this device. 213 The question of whether to manufacture the IGBT at Toyota or to purchase it from an outside source was discussed at length. Senior Managing Director Takahashi, Managing Directors Shiomi and Tadaaki Jagawa (now Senior Managing Director), and Member of the Board Nobuo Fukuma (now Taiho President) insisted on manufacturing in-house. "This component eventually will become the heart of the car. It is definitely as important as an engine or a transmission. As an auto maker, we must develop it ourselves. Hybrid vehicles will spread and penetrate the market in time. We should manufacture this component so that we don't end up with just one hybrid vehicle," Takahashi argued. The Electric Vehicle Division, however, disagreed with the idea of manufacturing the component in-house and argued back, "We can't compare our young, ten-year-old semiconductor division to electronics companies that have long histories of success and progress. Our ultimate goal is to make cars. We should not get into manufacturing operations for components simply out of our old fashioned sense of duty." Engineers in the department were afraid of venturing into something with which they had no experience, so they wanted to purchase the part from the most reliable manufacturer available. No agreement was reached, however, so for the early tests, the team bought the IGBTs from Mitsubishi, a 214 reputable manufacturer. No one at Toyota seemed to be eager to work on its development at that time. Some, in fact, suggested that a Toyota Group parts supplier should take care of it. Board Members Shiomi and Fukuma who were in charge of development, put an end to the argument. Fukuma, who was responsible for electronics, told his staff; "There is no way of telling until we try. Just give it a shot. After that, we can decide." Shiomi was the one who made the final decision, however. He was in charge of development, and would have supported the idea of purchasing from an electronics manufacturer, but he said, "We should try to do it even if we suffer a little. This is the kind of situation for which we built the semiconductor plant ten years ago. It is not too early for the plant to start producing results. We should bet on making a great breakthrough by trying to make the part at Hirose Plant."

Making it the global standard Shiomi had boldly ambitious plans. His analysis of the situation went something like this: "The market for high-capacity IGBT is less than 50,000 units per month. Moreover, most are for production facilities, and massproduction technology has yet to be developed. Even if we commissioned the development of IGBT to outside 215 manufacturers, there would be no way for them to drastically reduce cost, as they would probably be stuck in their own ways. It is certain that future autos will be powered by electricity. If we produce our own IGBT, we can control the market. There is no point in developing parts that are already mass-produced. We should inject our resources into developing parts that have more potential." Shiomi also strongly believed: "The automobile should evolve into the FCEV that is powered by reacting hydrogen and oxygen together and harnessing electricity. The era of hydrogen will arrive, not just in autos but also in other industries." Shiomi strongly endorsed Toyota's development of next-generation power sources so that the development of IGBT was just a milestone on a long road of research and development. Furthermore, he felt: "There is probably nobody in the company that truly understands the nature of this situation. Nobody, therefore, can disagree with me." Even though he would be responsible for the difficult task of supervising the development work, he took a long-range view of the automotive industry and decided that the development work must be done. The project was initiated by Managing Director Shiomi who was in charge of vehicles. Member of the Board Fukuma who was in charge of electronics agreed with him, and Senior Managing Director Takahashi, who was in charge of production technology, endorsed the idea. 216 As a result, there was no way out for the Hirose Plant staff. In previous cases, the staff of Hirose Plant, which handles everything from development to production of semiconductors, had requested the Board to allow it to develop various other devices, but always had been told not to ask for too much. This time, however, the opposite was true. The Board ordered the plant to develop the IGBT, and so the project was launched. General Manager Naoki Noda of the Electronics Production Engineering Division (now Member of the Board) heard of the decision and was surprised as well as concerned about the sudden increase in the work load. At the same time he also was excited at the opportunity. IGBT takes up a lot of space on a semiconductor wafer. Its production would drastically increase the plant's work load but the production lines would be used more efficiently so that the plant's operation would be improved. "We can finally show off all the technology we have built up. Let's show everyone that Hirose is finally stepping into center stage," Noda told his staff. "Every hybrid vehicle will use at least one of these semiconductors, and the use of hybrid vehicles will spread worldwide. What if Toyota is the first to successfully develop this device?" Noda asked himself as he created a picture of the future in his mind. Indeed, Toyota may be in the position to perfect a technology that could become a global standard, just as Okuda had said. At the same 217 time, despite his enthusiasm about future prospects, Noda was not sure if the device could be developed before the year 2000. In May 1995, after hearing about the decision, General Manager Isao Yoshikawa, Tomoyoshi Kushida, and other staff members of Electronics Engineering Division IV in charge of developing semiconductors hastily began their research into IGBT. Semiconductors are used in many parts of a car. One of the most powerful semiconductors is used inside a small motor that handles current of several tens of amperes and voltage of several tens of volts. IGBT was different. The engineers saw immediately that the required performance would be about fifty times greater. They were stunned, because they could not find a point from which to start making such a powerful device. Yoshikawa suggested, "Since they are all semiconductors, the basic theory must be similar. Can't we somehow base it on the conventional Power MOS (Metal-Oxide- Semiconductor) Transistor?" As a result, the group started the project by first increasing the current pressure resistance of existing semiconductors. Hirose Plant already had experience in developing 100- volt 20-ampere Power MOS. Instead of developing a brand new concept, the group tried to develop the new device based on an already existing design. However, there was no example to study and the group was unable to set target specifications. By studying existing examples 218 such as home air conditioning inverters and train inverters, the group managed to come up with a ballpark figure. One of the largest in existence at the time was the 1,200-volt IGBT that had just been introduced in the *Shinkansen* (Bullet Train). The group was also able to find a 600- volt device on the market. If the group were to buy the IGBT, the ones that were available would be at the 600-volt 600-ampere level. The group finally had a rough idea of where to begin. That fall, a parts exhibition for the hybrid vehicle was held at Toyota, and the components to be produced inside the company were officially selected and approved. For IGBT, the Electronics Engineering Division IV would develop the chip, the Electronics Engineering Division II would develop the IGBT module, and the Electronics Production Engineering Division would coordinate mass-production.

A bitter experience On October 1995, Electronics Engineering Division II Staff Leader Shoji Abou was summoned by Design Department No.23 General Manager Shoji Ikawa. "We are now assigned to develop the IGBT module. It is for Prius. Electronics Engineering Division IV is currently developing the core element, so we would like you to lead the development for the module." 219 Yasuho had not started his career at Toyota. He joined Toshiba in 1981 and worked on designing ICs for five years. When he began thinking that he wanted to work on the consumer products rather than developing parts for them, he found out that Toyota was hiring people for the newly established electronic auto parts production division. He moved to Toyota in 1986. Since that time, Yasuho had worked at Electronics Engineering Division II designing hybrid ICs (not for hybrid vehicle use), which is a complex, multi-part circuited ceramic board. The hybrid IC was typically used in very harsh conditions, such as in the engine "igniter." Yasuho later developed the computer for Electronic Fuel Injection (EFI). He knew nothing about such devices but was finally able to design one after studying Denso products. Yasuho had no idea what the IGBT was like, and there were no experts in the company to turn to for help. As Electronics Engineering Division IV's Kushida had done several months before, Yasuho began reading books and technical papers. As he studied, he realized that he would be dealing with very powerful electric current. Prius' motor was designed to be around 30 to 40 kiloWatts. Since the home air-conditioning inverter was usually 1 kiloWatt, this new device he was to design would be handling enough electric power for several tens of airconditioners. Yasuho quickly realized that the IGBTs available in the market would not be powerful enough for 220 use on the Prius. He could easily see based on his experience that the heat generated by the device would destroy the semiconductor. The "igniter" designed earlier by Yasuho was a device that ignited the gasoline inside the cylinder by accurately controlling the duration and amount of the electric current passed into the primary side and creating high voltage on the secondary side. The IGBTs available in the open market had the same structure as his igniter but used far smaller amounts of electricity. In fact, Electronics Engineering Division II had bitter experiences more than ten years ago from an igniter causing heat cycle problems. Yasuho thought that he should not try it in a car, but he could not dismiss the idea until he tested it. Even though he knew it would not work, Yasuho bought an IGBT and tested the life of the temperature cycle. The result was as he had expected. Its life was only one-tenth of the required duration. Toyota had actually developed a car (RAV4EV) using the same IGBT. The IGBT worked in that car because in an EV no heat is produced by an engine. There was no heat damage, so its life was longer. In the Prius, however, it would be damaged by heat because in a hybrid vehicle there is a motor and an engine. Furthermore, the motor's power output was quite large, so the IGBT itself would emit a lot of heat. Those were the two major problems for IGBT because it is susceptible to heat. 221 Yasuho pondered. "I'll have to design something much more advanced than the `igniter' so that it can work. Now, how can I do that?" What he needed was the world's best IGBT module that would withstand the heat cycle, but there was no such thing in the world at the time.

Looking for the material Meanwhile, Electronics Production Engineering Division's Staff Leader Yoichiro Baba had also noticed the heat cycle problem. The IGBT chip was on top of a large ceramic board, which was bonded to a copper plate. Copper was at the bottom, the ceramic board was soldered on it, and the IGBT chip was soldered again on the ceramic, forming a three-layer construction. Ceramic worked as the insulator. The problem here was that the expansion rate of the copper was four times greater than that of the ceramic. The expansion rate of the aluminum nitride used for the ceramic was 4.5 PPM / degree C. The copper's expansion rate was 16.5 PPM / degree C. The chip was 4 PPM / degree C. In other words, the expansion rates of the ceramic and the chip were roughly the same, whereas the copper expanded four times as much. If the copper should expand by itself as the temperature increased, the solder 222 would come part. The heat would not be transmitted, and the module would overheat and break. As Baba had thought, the module broke during tests. Baba needed an assembly that could withstand use in a car, so he tried to come up with improvements. Yasuho' s Electronics Engineering Division II and Baba's Electronics Production Engineering Division worked together with him. In the end, Baba's basic construction design was selected after determining that the module would resist heat cycle and that it would be easy to manufacture. Yasuho then made additional improvements. A typical IGBT of that time was a module constructed of a large ceramic board whose side measurements were between four and six centimeters, with the chip on top of it. The ceramic base was first redesigned so that the sides were 17 millimeters by 32 millimeters. With the larger size, the effect of the shrinkage would be less. The expansion rate of the copper part needed to be reduced so the copper needed to be replaced by some other material. "Yasuho-san, we can't come up with a good material just by sitting here and thinking. Why don't we each take some time to go look for it?" "That's a good idea. Let's see who can find it first." Yasuho sought out the suppliers that he had used when he was working on the igniter. He eventually found a promising material mentioned in a research paper. His Electronics Engineering Division II was located in the 223 Head Office district, and was about 16 kilometers (10 miles) or 30 minutes by car away from Baba's Electronics Production Engineering Division in the Hirose Plant. He immediately called Baba by phone. "Baba-kun, I found the perfect material. I'll drive over and show it to

you." Baba had been searching for the material by visiting exhibitions and technology shows. He also had found a promising replacement candidate at about the same time. "Good timing. I've just discovered something that might work." The two had brought exactly the same material. Moreover, they later found out that there was only one company that mass-produced that particular material. That material was a compound of silicon carbide sponge soaked in aluminum. Through this process, the expansion rate could be kept at 7.5 PPM / degree C. This material could lessen the expansion rate by
a half compared to using copper. However, using this material had two drawbacks. First, the heat conductivity was only one third that of copper. Lower heat conductivity meant that the material would overheat more easily when strong electric current was passed through it. Even though the expansion rate was low, the material would be useless if it produced too much heat. The two men had no idea how much heat it would produce. The second problem was supply. The one company 224 that produced this material was a venture business in the United States. It would be too risky to depend solely on this one company. They had to resort to this material, however, since there was no other alternative. This material was chosen, but their anxiety also proved to be justified. Immediately after Prius was launched in December 1997, the electronics division was overcome by panic. There was a rumor that the material supplier might go bankrupt. The staff immediately held a meeting with the procurement division, but they were unable to get reliable information. Prius had just been launched with much fanfare. Just when the anxiety level of the staff reached its peak, fearing that the supply of the much needed material might stop, an investment company bought out the supplier and put it back on track. Prius was saved. "We can't continue to depend on a company like that forever." The Prius team took the situation so seriously that it immediately decided to begin production of the material. **Prototype completed** The story now returns to the end of 1995 when the two men discovered the new material. Relieved to have found it, Yasuho visited Uchiyamada, who had been concerned. 225
After Toyota decided to develop its own IGBT, Uchiyamada's views changed: "It would be okay to use the ones in the market, but if we are developing our own, we must make a product that can dominate the world market." Yasuho told him, however, "I'm afraid that is wrong. If we use what's available on the market, it would not even last three years. We'll have serious problems later." He explained his views in detail by showing photographs and actual remnants from tests in which the boards were burned or had blown up into pieces. "I see. Yasuho-kun, please do your best to make a good reliable product. But make sure you keep it inexpensive, too. "Don't worry, sir. I've been converted into a Toyota-man. I am always thinking of ways to cut cost," Yasuho replied with a smile. With such a man as his trusty helper, Uchiyamada felt that it would not be so bad trying to manufacture the part. Having decided on the basic construction and the materials, Yasuho and Baba also went to Shiomi to report on the progress. "Really, you've found it? Now you just have to build it. Show me the finished module by the time cherry blossoms are out." However, as this was their first try, they were not able to finish the module as quickly as that. After repeated trial and error, the hand-assembled prototype was finally 226 completed by the end of April when cherry blossoms already had faded. This prototype was a module with exposed wires on top that connected to a control board the size of a letter-size notebook. The two confirmed that the prototype met the expected maximum power requirements. However, when it was run at maximum power, the wire (as thick as an adult finger) that connected the module to the power
source vibrated. It seemed to be caused by the pushing and pulling of the strong magnetic field created by the electric current. Then the wire began to buzz. When the electricity was turned off, the wire was hot. This would be a perfectly normal phenomenon for electronic experts, but the two men were shocked. They could not imagine that the wire could get so hot. In fact, the incident help to remind
them that that their project was could be quite dangerous. The two went to report on their progress to Shiomi, just before the *Golden Week* holidays. "Sorry to have made you worry about the project for so long, but we now have a prototype that works somewhat. And, the cherry blossoms are probably still blooming in Hokkaido," Yasuho said confidently. Shiomi, who often is sarcastic, was unusually pleased, and said, "Good job. Keep up the good work." As things turned out, the real worries were to come later.
227

Explosion The blossoms were gone and the cherry trees were now completely covered by green foliage. Somehow, the prototype IGBT worked. The next task was to determine what level of current would cause a burnout and also to determine the critical value. The critical value was confirmed by gradually raising the current, so that the weaknesses could be overcome. Electronics Engineering Division II and Electronics Production Engineering Division worked together to build test modules, and tests were run on a workbench at the Hirose Plant. The project progressed smoothly until that point. Most modules broke at the estimated critical value. The critical value was raised by modifying the design little by little. By September, the first official prototype was completed. It was in final form, neatly contained in a case. Unfortunately, the situation drastically changed after this point. A loud explosion shook Hirose Plant. "Oh my God! The IGBT exploded!" Even line workers came to see what had happened. Although the same tests had been repeated after September, for some reason starting in October, the IGBT started breaking apart before the estimated critical value or rated output was reached. The critical value suddenly had started to get lower. IGBT bench tests were held on the third floor of the 228 electronic parts building at Hirose Plant in the EV testing facility with large power source devices and load devices. Adjustments and modifications were done in the daytime, and tests were done at night. They found that a little increase in power caused a sudden explosion, and a
moment of light followed by darkness. Electric power in the building would momentarily drop and cause the fluorescent lights to turn off. Tests were run every day until midnight. Every time they thought that they finally had the problem figured out, the module would break and explode like a firework, with light bright enough for a photo shoot. For a while, every staff member was dumbfounded as similar failures occurred more than ten times in a row. When they took the module apart, they found the inside to be black with soot. The aluminum wires connecting to the chip and the electrodes were melted and splattered everywhere. The loud noise seemed to be coming from the evaporation of aluminum. "Gosh, this is hopeless." Yasuho and Baba were frustrated as the IGBT continued to blow up over and over again. Although the module was supposed to be ready for the official prototype in the fall, it was constantly breaking and far from ready. When a decent module was finally installed in the prototype, it was already a month late. As more modules broke, the manufacturing group became busier. In the beginning the group needed a 229 month to finish a module, but eventually became experienced enough to finish one in just a few days. Yasuho was always feeling extremely guilty that the finished module always would be destroyed in testing. One midnight when the group was thoroughly disillusioned after a series of miserable failures, Baba began telling a story at an employee lounge.
"Have you all heard this story? It goes like this. There were these monkeys that lived on an island. They all ate their potatoes without washing them. One day, something caused a monkey to wash the potato before eating it, and the monkey discovered that the potato tasted better. After that, other monkeys began to imitate, and the number grew. When the total number exceeded a certain point, that meant virtually every monkey on the island was washing potatoes." "If everyone tries hard to improve and continues to make many units, one day we will stumble across something that's good, and will continue to make good things after that. Let's just keep on making the units for a little while longer." The staff felt encouraged, and was inspired by Baba who had the comforting presence of an elder brother.

230 **Suspicion** As the engineers continued every day to test the modules with the goal of finding the performance ranges, they also tried to find the cause of the breakdown. When the staff inspected and compared the destroyed samples, they noticed one thing. The semiconductor chip itself looked different from the original design. "Hey, everyone, this is it. This is suspicious," a staffer shouted. As mentioned earlier, management had decided to manufacture the semiconductors although there had been proposals in the beginning to buy them from chip manufacturers. Electronics Engineering Division IV started doing research around May of 1995, and in fact, Kushida's group in the department succeeded in developing one of the world's best IGBT chips. This was the chip that was used for the tests. The most important performance index of an IGBT chip is the "on-resistance." A semiconductor has far stronger electric resistance than a conductor even when it is "on" or when the electric current is flowing. The current multiplied by the resistance created by the current becomes the loss. This

resistance is called the "onresistance," and the most important performance goal is to lower this "on-resistance." While running the current in the chip, the resistance consumed in the chip is better if it is lower. Kushida and his group succeeded in 231 developing an IGBT chip with the lowest "on-resistance" level in the world. However, there was a trap. Another performance index of a chip is "breakdown resistance." It is technically called "avalanche-ruggedness," and is an index that shows how much abnormal current or resistance the chip can withstand. Since the chip was going to be used in a car, an unexpected amount of electricity might be required at times when climbing up steep hills and so on. There also might be changes in the battery voltage. The breakdown resistance indicates the critical point that a chip will break at abnormal conditions. Making the matter even more difficult, when "onresistance" is reduced, the "breakdown resistance" also drops. The two indexes were at a "trade - off" relationship. There also was another matter of "switching responsiveness." Switching response time is the time from the moment the electricity is turned off until the time the current actually turns off inside the chip. When electricity is turned off, the electrons remaining in the semiconductor and "holes" somehow bond and become zero, thus turning off the current. Just as a faucet still has residual water even after the water is turned off, it takes some time for all accumulated electrons and "holes" to bond. When the time needed to bonding again is longer, the loss is greater. It is necessary to intricately balance these three linked factors to achieve low on-resistance and high breakdown resistance. 232
Naturally, the engineers at Electronics Engineering Division IV were aware of these three factors during development, but they did not have the know-how to achieve the optimal balance. They had simply worked from the premise: "Let's develop the world's best IGBT chip for the world's first mass-produced hybrid vehicle." It is possible that the eagerness of Electronics Engineering Division IV propelled the group towards thinking that their goal was to develop semiconductors with low on-resistance and smaller loss. Through many design changes and improvements, the on-resistance steadily dropped. In the end, the group succeeded in developing an IGBT with the lowest on-resistance in the world for planertype semiconductors. Ironically, the breakdown resistance that they had assumed to be safe had also dropped much below their original estimate.

Deserting under fire During the time modules were breaking apart at every test, the electronic parts plant that tested the IGBT and the microelectronics plant across the street from it that made chips were becoming skeptical of each other's capabilities. The module group blamed the breakdown on the chip group, and a silent resentment toward each other was building up. "The breakdown resistance is too low, 233 because they are not designing the chip right." Meanwhile, General Manager Yoshikawa of Electronics Engineering Division IV was proud that they had developed the best chip in the world and argued, "There must be problems with the way you people are running the tests. The chip is probably being overloaded because of all the mistakes in the tests." Baba at Electronics Production Engineering Division was also thinking, "Maybe the cause of the explosion is to be found somewhere else. Is it really our problem? Or, is it another problem? I don't know...." The most important element - basic trust among the working groups - was being undermined. The situation did not improve in December. Section General Manager Ken Kawahashi, Kushida's boss, became increasingly worried. One day, Yasuho, the one in charge of module design, called Baba and said, "Baba-san, maybe we should give up developing our own module. Do you suppose we should get at least the semiconductor from some another company?" Baba, who was passionate about the idea of producing the module within the company, felt powerless and replied, "Maybe we really should give up something. Shall we call up Fuji Electric or some other company one of these days?" Noda lost his temper when he found out that such a conversation actually took place. "You people, are you thinking of deserting the group 234 under fire? What was the point of your work until now? We have a responsibility to complete the car. To fulfill our duty at Hirose Plant to carry our work all the way through to the end, to do what we can do here. If we give up now, Hirose will never have another opportunity." Noda's energetic reaction made even Baba speechless.

Overcoming the misunderstanding In reality, mutual trust among the departments was reaching a low point and wearing thin. Relationships were steadily growing hostile. Staff morale was dropping.

Without a firm sense of trust in technical development, even what is possible can become impossible. Noda, however, came up with an idea. Until then, the roles of the chip group and the module group were clearly separated as the "early" process group and the "later" process group. Noda decided to place them on equal footing. He appointed Toru Tamano as the leader for both groups. Tamano was the Development Department No. 4, General Manager at Electronics Production Engineering Division. He had been involved in electronic parts production from the beginning, and had gained the trust of both design and production divisions. He understood the feelings of the people in both groups. In addition, he had a mild temperament and was able to make judgments patiently. 235 Noda also started the "IGBT Mailing List" on the Intranet. It was based on BR-VF's Intranet mailing list for exchanging information. By looking at this mail, a staff person could immediately see what was happening at or within each group and see what kinds of problems each group was having. By sharing information, Noda felt that trust might be restored. Noda's ideas produced results. By appointing Tamano leader
and by consolidating the efforts of several groups, the developmental process was streamlined. Thanks to E-mail, asking fundamental questions became easier, even though they had been difficult to address before. Making exchanges of opinion exchanges and asking of questions available to everyone helped solve misunderstandings and grudges. Department General Managers, such as Noda, were able to instantly grasp the ongoing situation by browsing each day through their staffs correspondence on the Intranet. Because information and opinions were exchanged, the teams began to suspect that the cause for the module's malfunction was the chip's design change. Since there were no more grudges between the departments, the work went swiftly. Kushida of Electronics Engineering Division IV immediately began work on redesigning the chip. "Okay, let's change what seems to be causing the problem. We'll first raise breakdown resistance." Improving switching speed and breakdown resistance
236 in a chip by slightly changing the design usually takes one to two months, and completing the IGBT module with the chip takes another month. However, by the end of 1996, all other departments were continuously submitting complaints that they were unable to properly evaluate the car because the IGBT kept breaking down. By this time, the second-generation prototype had been built, and the Prius team was at an important evaluation period for perfecting the car. They simply could not spend several months making the new chip and the new module. Fortunately, the semiconductor facility was run on a twoshift system. The period from late night to dawn, which would be the time for a third shift at other facilities, and weekends were completely open. Kushida used an open production line during these hours to start making the chip. Kushida got help from several technicians with whom he was familiar so that the chip was completed as quickly as possible and brought by hand to the Electronics Production Engineering Division. There Baba and his staff quickly made the module, assembled it into an inverter, and brought it to the vehicle facility. It usually took three months to make the IGBT module, but Kushida and Baba completed the module in as little as two weeks. During the three month period from December 1996 to February 1997, the whole Hirose Plant was working extremely hard. 237 Yasuho at Electronics Engineering Division II in the Head Office and Arai who had moved from Electronics Engineering Division III to Electronics Engineering Division II came to Hirose Plant almost every day. They checked the condition of the chips each day and coordinated with the module group. Then, the new module was finally complete. "Okay, we got it." It was mid-February when Noda finally felt reassured. Hot-blooded but sarcastic Baba was thrilled and said, "This is the first time that Electronics Engineering Division IV really did something. They finally showed us that they could achieve
something. They've been napping all this time since the plant opened eight years ago, but they are now awake and on their feet." Noda replied cheekily, "Baba-kun, you Electronics Production Engineering Division guys were lucky that you had a lot of energy stored from the nap, too." Hirose Plant was gaining back its atmosphere. Now they could have the module in time for the first Prius prototype. **Complaints**

The IGBT on the prototype worked well. Yasuho, Baba, and Kushida felt that they

were finally relieved. However, their job was not over yet. "Hello, electronics people, the car keeps stopping." 238 Many departments were complaining that the inverter would stop immediately after it was put to tests inside the hot tunnel. Since it was in winter, the car had no problem running outside. In the hot environment, the IGBT itself became hot, and the sensor to protect the IGBT from overheating kicked in and stopped the car. This was Yasuho's first concern when he started designing the IGBT. The cause seemed to be the heat sink. Its heat conductivity was half what it should be and the loss was 20% more than the estimate. In addition, Yasuho did not have enough time to tune it. This time, his group had to work on heat and loss. It was another case of double torture. At the start, copper was used for the heat sink because of its high heat conductivity. Since copper has low heat resistance, it cools quite effectively but it also deteriorates quickly. Yasuho estimated, based on his past research and experience, that copper would deteriorate and fail to deliver the initial performance level in just two to three years. After receiving approval from Uchiyamada to make a change, he had used a new material for the heat sink. This material could maintain cooling capability but had low initial cooling capacity. It would not cool quickly so that the IGBT continually became hot. "The copper won't last, and there are no alternatives. There is no time, either." After thinking through the problem, Yasuho revisited 239 Uchiyamada at the end of March. "Mr. Chief Engineer, since we can do nothing about the initial lack of cooling capability, can you put in an external cooling device?" "Copper won't work at all? Okay, then, we can't use it. I'll ask the cooling people. We'll figure something out here. But, you still have to work on the loss, though." "Yes sir, we'll do it for sure." A radiator for cooling the inverter was now added to the design of Prius. Now, back to the issue of loss. The Electronics Engineering Division II took the issue relatively lightly and thought that it could be solved by simple adjustment. In due time, deep doubts arose. "The loss in this IGBT is twice as high as Mitsubishi Electric's general-use IGBT that we used in the pre-preprototype," said the evaluation group. "No way. That's impossible." Yasuho turned pale and dispatched Arai to Higashifuji Technical Center to borrow a high-precision measuring device. When they measured again, the loss was only 20% higher than Mitsubishi's IGBT, instead of the 200% that they had been accused. "Oh, it's not 200; it's just 20." Yasuho felt relieved, and said to Arai, "Arai-kun, we can probably work something out with our IGBT." 240

Let's do whatever we can The chip finally made by the Electronics Engineering Division IV had been designed to have the highestpossible breakdown resistance, not only because the group learned a lesson from the series of breakages in the beginning, but also because the chip simply should not break while the vehicle was in operation. Their chip's final breakdown resistance was far higher than the general use chips made by Mitsubishi Electric, Toshiba or Hitachi. It was almost twice as high as the chip with the highest breakdown resistance. However, when a chip's breakdown resistance is high, the on-resistance also is proportionately higher, the loss increases, and performance falls. The situation was now just the opposite of the time when the group was troubled by constant explosions. As they were determined not to have any more explosions, they came up with a way to improve the switching speed and to lower loss while maintaining overall performance. In order to do that, Kushida and his group decided to modify the semiconductor wafer. Generally, an IGBT chip has something called lattice defects inside for increasing switching speed from on to off and vice versa. These defects have been created within the crystal lattice. A semiconductor controls current and resistance by the volume of electrons and holes (carriers). When it is 241 in the off position, the carrier completely disappears in the semiconductor. However, it takes some time for the carrier to completely disappear.
A semiconductor with high breakdown resistance in particular has many thick layers within its structure that have relatively low density, and the carriers accumulate in these layers. The thickness of such layers causes the switching speed to slow down. Lattice defects are created within these layers for the carriers to disappear into. By letting the lattice defects absorb carriers quicker, the switching speed can be increased. By cleverly manipulating these characteristics, a chip with fast switching and low on-resistance can be made. Lattice defects are created randomly by radiating electrons at once on the wafer and letting the electrons penetrate various parts of the wafer. Since this method creates many defects, it becomes difficult for the electric current to pass through, thus creating more resistance. The Electronics Engineering Division IV decided to create lattice defects strategically by accelerating the ions with cyclotron and depositing them into the wafer. By doing that, the on-resistance was kept low while switching speed was increased. For a 1,200-volt IGBT that has much higher breakdown resistance, better performance can be obtained by creating partial lattice defect rather than randomly all over, because the layer with breakdown resistance is thicker in such an IGBT A Cyclotron is sometimes used for that 242 purpose. However, the layer with breakdown resistance is thinner in a 600-volt IGBT, and it was thought to be ineffective to create partial lattice defects. However, the group decided to do whatever they could, and had some expectations of favorable results. The performance consequently improved much more than expected. After making test units repeatedly, they found a

point with good balance between the on-resistance, the switching speed, and the breakdown resistance. By then, the group had completed a chip that had more breakdown resistance and slightly less loss than chips made by the world's other electronics manufacturers.

Fearless Meanwhile, Electronics Engineering Division II was concerned about the on-chip temperature sensors. These sensors protect the IGBT from becoming too hot. The group broke all conventional rules and set up a system that measured the temperature directly on the chip. Until then, it was common to measure heat by installing a thermister on top of the ceramic board where the chip sat. An engineer who knows everything about semiconductors would have dismissed the idea from the beginning, saying, "There is no way that a sensor like this would work on such a place with so much noise." However, the group decided to install the sensor directly 243 on the chip. Even if the thermister were placed on the ceramic board as close as possible to the chip, the temperature reading would be off by as much as 30 degrees C. If a thermister were to be used, the output level had to be controlled rather conservatively because the actual temperature would be somewhat different. On the other hand, an on-chip sensor can measure accurately, so the chip can operate at the maximum power until the temperature limit, which was set at 125 degrees Celsius. The temperature of the water for cooling was 60 degrees. When the actual estimated temperature would be 30 degrees off when the temperature difference between the chip and the coolant was only 60 degrees, the power output may end up being less than a half of what it actually could have been. Although the on-chip sensor was an idea of a fearless amateur, it made it possible to let the IGBT operate at its maximum potential. However, in the spring of 1997 when this was under development at the Electronics Engineering Division II, Fuji Electric announced that it had developed the same method. "Damn, they got it before us," said Yasuho in vexation. However, the experts at Fuji Electric had worked on its ideas for years, while the group of amateurs came up with it in just several months. Meanwhile, Baba was busy trying to increase the level of quality and reliability. Soldered parts could not 244 conduct heat when there were air bubbles in the solder. He worked hard to find a way to minimize such bubbles. The IGBT module consisted of six rows of three parallel ceramic boards each with an IGBT and a diode. One thousand 0.3-millimeter
aluminum wires had been ultrasonically wire-bonded to each IGBT. If one wire was not properly bonded, the module was defective. Baba purchased ultrasonic wire-bonding equipment from Orthodyne Electronics, a U.S. company, and improved on it at Teiho Plant. Each module was inspected before assembly, and was again inspected after it was assembled into an inverter. Baba had a difficult time coming up with an assembly method that had no failures. Since the facility was for general use, it was difficult to find the optimal manufacturing condition. No Japanese-made wirebonding equipment of that time could be modified and it was a long time before Baba finally discovered Orthodyne's equipment that allowed the greatest amount of customizing and adaptation. However, the worst problem was that Baba and his group had to find everything from materials to additives to facilities by themselves. They were often asked what the purpose was or what Toyota was trying to make, but they could not give away any information. It would have been easier to find the right tools if they could tell potential suppliers what they were doing. While responding vaguely to all questions, they collected as 245 much information as possible so they could make the final decisions themselves. They were at least able to seek advice from electronics experts at Toyota's group companies Denso and Toyoda Automatic Loom Works, and were able to collaborate with them on some issues. Today, now that Prius is on the market, many suppliers have disassembled and studied Prius and are offering their products to Toyota for future consideration. Most of the products now being offered to them were exactly what they had been looking for when development was under way. Although the engineers had looked for such products, they ended up manufacturing them inhouse in the end. By doing so, they developed ways to economically mass produce small runs, such as just
2,000 parts per month, and found ways to even further reduce costs in the future. These parts developed at Toyota undoubtedly will become core parts for the 21st century auto industry in the production of EV and hybrid vehicles. That is why the ability to manufacture them is extremely

significant. Chief Engineer Uchiyamada heard from a colleague after the completion of Prius, "Uchiyamada-san, do you know when they started using inverters on trains? It was in the 80s. Since they have an IGBT inverter for every other coach, the train is not affected even if one fails. However, they seem to be having quite a few problems with those inverters. Considering that, the reliability of 246 Prius' inverter is totally amazing." Even if the battery fails, Prius can run on the gasoline engine and the generator. However, if the computer and the inverter fail, the car will immediately stop in the middle of the street. To prevent serious accidents, these two items were designed and developed with great care. Uchiyamada was amazed by the story about the trains, and said, "If I had known about that story earlier, I would not have had the guts to develop it ourselves." 247

Chapter 9 Cooling the THS - Radiator

Under the hood of a car, there is a radiator up front to cool the engine, and next to it is a condenser of a similar shape for cooling the air conditioning coolant. These two off-stage helpers function, prevent the car from overheating and help the air conditioning system. Prius has one more item needing cooling. It is the special radiator to cool electric components, such as the motor and the inverter. At Electronics Engineering Division IV, which provided the IGBT, engineers decided to solve the heat problem with an exterior-cooling device because they were unable to find any other way.

An expert in cooling

Staff Leader Shunkichi Suzaki who handled the cooling system had worked in the same testing department as Chief Engineer Uchiyamada. After joining the company in 1968, he worked on engine cooling for 23 years until 1991, becoming an expert test engineer in the field. After moving to Electric Vehicle Division in July 1993, he was in charge of cooling energy and heat collection for RAV4EV. He then moved to Vehicle Development 248 Center IV Vehicle Engineering Division I in 1994, and took charge of engine room cooling. He was the cooling expert who had worked on engine cooling for almost all Toyota models. In January 1996 when G21 was starting up, Uchiyamada invited experts from various departments to give technical lectures. He had naturally gone to Suzaki for the lecture on engine room cooling. After that, Suzaki was gradually "coerced" into the G21 project. One year earlier in January 1995, Hideki Nakajima was dispatched under Suzaki from Vehicle Evaluation & Engineering Division No.22, Vehicle Development Center It. Since Vehicle Development Center II was expected to handle Prius if the project was elevated to the vehicle development level, Nakajima had been placed in position in advance. A few more people were placed under Suzaki from Vehicle Development Center II. There were three main tasks to cooling the hybrid system. The first task was to cool the engine; the second was to cool the EV motor. The third task was to deal with the unique situation that arose from combining the engine and the motor in the hybrid system. It was about making the whole system work The first two tasks were familiar to Suzaki. He and his staff were confident that they could solve any problem related to those two. The third task, however, troubled the group until the end. 249

Two rows or three rows?

The third and most difficult task was to figure out how to place the three heat exchangers or radiators. The third radiator was requested by Uchiyamada for cooling the IGBT. Placing the engine radiator, the air conditioning condenser, and the inverter radiator together in tandem one after the other at first appeared to be the easy and obvious solution but in practice that turned out to be extremely tricky. It would have been easy if the three could be placed in the front part of the engine compartment but there was no room for them. The inverter radiator had the greatest need for cooling, then the air conditioner condenser, and finally the radiator for the engine. Placing the inverter radiator immediately against the nose of the car would have been the ideal solution since it needed the most cooling to prevent the IGBT from overheating. The air conditioning condenser could be placed behind it, and then the engine radiator. The ideal solution was to place all three in a row in the front. There were, however, several disadvantages to doing that. First, the cooling devices would end up taking up a large portion of the already tiny engine compartment. Since the Prius was designed by G21 as a 21st century car with new packaging, the apparent idea solution would be wrong if the body package had to be altered for the sake of the cooling system. The team also did not know how 250

compact the Electric Vehicle Division could design the actual hybrid system consisting of engine, motor, and inverter. The "off-stage" cooling devices were better off being as compact as possible. Another problem was the use of air conditioning in the summer. If the three radiators or heat exchangers are placed next to each other, air warmed by the heat from the inverter radiator would flow directly to the air conditioning condenser. The condenser would not work as efficiently as if it had been placed up front, so the compressor would overwork to lower the temperature when the air conditioning is turned on, creating a heavy burden on the engine and fuel economy would suffer. If air conditioning were not used, there would be no problem. But its use in summer would result in poor fuel economy so that the reputation of Prius as a fuelefficient car would be fatally undermined. If the condenser were to be placed in the middle and still achieve the same performance as if it were placed in front, it would need to be much larger in size. Its cost would rise and the space requirement would be greater. A third, problem involved the pride and confidence that Suzaki and his staff had as cooling professionals.
When they held discussions, Suzaki often urged his staff to do better by saying, "Anyone can come up with the method of placing the three radiators next to each other. Our job is to use our knowledge to solve a unique problem. If we 251 settled on that simple method, the rest of the development people would look down on us." There were three prototype models for Prius. The pre-pre-prototype was made at the end of 1995. The pre-prototype was made in April 1996, and the official prototype was built in February 1997. For the pre-pre-prototype, or the first test vehicle, the group used the simplest three- radiator method. Suzaki had decided that "the most important issue right now is to work on reliability. We have to make sure that this neverbefore- attempted hybrid system is properly cooled." The
objective of the first prototype was to first verify that everything worked together. Evaluation of the first prototype would provide the baseline data for future development and improvement. If the cooling group took risks at this point and caused a malfunction of the engine and the motor, an accurate evaluation would be impossible. Suzaki, therefore, decided that "We can be patient now so that we can try new things later." At this point, the group was not yet being rushed or pushed.... Evaluation of the prototype cooling system came out better than they had expected. The group now had the confidence to try another method, which was to place the air conditioning condenser in the front and to place the two other radiators in the second row on top of each other. Suzaki said it was "the ideal system with the best balance" because his group had confidence in it and it was 252 the perfect layout by which to show off the group's capability. This new configuration could be at least several tens of millimeters thinner than the three-row method. The concept of the new vehicle required the distance from the front tires to the nose (overhang) to be short so that the car would be more nimble and maneuverable. Having a asthin-as-possible sandwich of the cooling devices placed ahead of the front wheels agreed with this concept. Computer simulation showed that the total weight of the two-row design might be 15 to 20% less than that of the three-row design because the condenser was smaller. Naturally, material costs would be reduced as well.

Safety considerations There was another advantage to the two-row design. Vehicle occupant safety in the case of a collision would be improved because the extra space in the front end could be designed to absorb the energy of a head-on or an offset collision. With the introduction of the subcompact car Starlet in December 1995, Toyota had set a voluntary passive safety standard that is higher than the existing standard in Japan or overseas. Toyota had been promoting cars that met this voluntary standard as featuring its new "GOA" passive safety body. A Toyota vehicle with GOA design has an engine 253 compartment that is collapsible while the passenger compartment is rigid. In a collision, the engine compartment absorbs the crash forces to protect the occupants in the passenger compartment, which helps secure the occupant space. Most Toyota cars today, including uni-body station wagons, feature GOA bodies. Since the new package concept for the 21st century car was a small car with a large passenger compartment, the engine compartment would be smaller than in other cars of the same class so that components, such as the engine, motor and inverter would have to be placed ingeniously within the small space. If extra space could be created, even if only by the depth of a radiator, passive safety would be improved. The group also thoroughly discussed functionality. Since the condenser was placed up front, air conditioning would function efficiently in summer. As it would be exposed to plenty of air in the front row position, the surface area of the condenser could be minimized. Designing the engine radiator (which would be placed in the upper second row) for cooling the small

1,500cc engine was easy because the group had sufficient know-how from developing much larger radiators for 3000 to 4000cc-class engines. Their major concern was the inverter radiator with which they did not have experience. They were worried that the radiator might not cool sufficiently because of the warm air flowing to it from the condenser. 254 The group tried dealing with this issue by looking at the overall performance. To achieve a balance, the frontrow condenser was designed as small as possible, and was placed a little higher to leave some room below. The inverter condenser was placed in the second row so as to take advantage of the unused front row space where it would not be fully exposed to warm air emitted by the condenser. The group thought the radiator could be safely placed in the second row this time since it would be exposed mostly to air that was at a temperature close to the outside air. Suzaki and his staff submitted this two-row layout for the second prototype with a lot of confidence since they felt the system provided better cooling capability, compact design, improved safety and adherence to the original design with optimal balance.

Too hot by five degrees Despite all that, a test engineer from Electric Vehicle Division implored the cooling group at Vehicle Engineering Division I. "Can you lower the inverter temperature a little more? We can't run any tests like this." "Oh, sorry about that. We'll fix it right away." Such conversations were occurring more frequently in June 1996 when the pre-prototype tests were conducted. 255 The second prototype was completed in April of that year, and various departments were running evaluations on the test track at the Head Office technology division. There was, however, something wrong as the various cooling components were not working appropriately. The performances were much worse than in the previous prototype which had the three-row layout. Suzaki contacted Nakajima and asked: "How much higher is the inverter's temperature than it should be?"
"Let's see ... about five degrees." "Five degrees, that much? That's a little tough." The development of every component, such as the engine and inverter, was based on test data from the last prototype. For example, the temperature of the cooling system was expected, therefore, to be the same as or lower than the temperature in the last prototype. Engineers in each department had continued with their development work based on that assumption. To the engineers in other groups, it was outrageous that the current inverter's temperature would be five degrees higher than the previous one. Suzaki, however, had expected some problems to come up because key systems, such as the inverter, were continuously redesigned and renewed. For example, increased engine or motor performance meant more heat would be created. In another example, the battery department was able to make a better battery after it had 256 experienced considerable difficulty in achieving the voltage target. Although Suzaki had been kept informed of progress being made in other departments, he did not have specific details about them until he actually saw the finished product. Moreover, the last prototype had been tested in winter when the outside temperature was 10 to 15 degrees Celsius, which is a favorable setting for cooling devices. The current prototype, however, was tested in June when the daytime temperature sometimes reached 30 degrees Celsius and the heat from the test track pavement constantly affected the car's temperature. Suzaki and his staff were aware of those disadvantages. In real life, however, the car would be exposed to more adverse conditions, such as midsummer rush hours. Suzaki, therefore, felt his group needed to take some risks in order to make it across the finish line.

Decision In theory, a few risks were fine but in reality satisfactory results were tough to achieve, no matter how much they tried. After a month, Nakajima told Suzaki. "Suzaki-san, it's not looking very good. Maybe it's better to go back to the three-row design." "No. I believe we've finally discovered the optimal method. Please give us a few more tries until we get it to 257 work." Suzaki encouraged his staff to try harder. In the meantime, he discussed the matter with Uchiyamada to prepare him for a worst-case scenario. "As a supplementary group, we can't hold up the others. We are thinking of going back to the three-row design if worse comes to worst." "Suzaki-san, don't give up yet. It is still too early. Please stay with it until we really run out of time." As Uchiyamada was trying to change the development system through the Prius project, he thought, "If we give up here, we'll come out of this with no results. If we keep falling back on backup plans and fearing risks, we will never progress. The new concept of Prius makes it worthwhile to try new things. Unlike model-changing the Crown, delaying the launch of Prius by one month because of this should not be so damaging." However, no breakthroughs in development followed. Around this time, representatives from each department involved in the development for Prius started to meet every two to three weeks to present progress reports. Every six weeks, a meeting was held to report on the progress to the executives in charge of development and production technology. The cooling group came under a lot of criticism at the report meetings. At a meeting held in early winter, Deputy General Manager Takahide Kawamura of the Electric Vehicle Division in charge of the inverter, 258 generator and motor, stood up and said harshly, "Suzaki-san, your cooling system has to meet the required temperature." Electric Vehicle Division was Suzaki's old home before joining Vehicle Engineering Division I. "I'm sorry. We will, but we would like to work on this a little longer. We want to stay with it until we really run out of time." Suzaki and Nakajima wanted to go back to the threerow configuration but they did not want to let down the staff members that were still working hard on the two-row system. At the end of fall, Suzaki visited Uchiyamada again. "We've done all we can. We believe that our direction is good. However, if we carry it through, we may run out of time. We should be prepared to switch back to the three-row system." "Okay. We should probably consider that." The group began reconsidering the three-row format while still continuing to work on the two-row system. Going back to the three-row configuration meant the cooling group had to redesign the three radiators and they also had to change the routing of the pipes and hoses that connect them together. Suzaki visited other groups working on cooling devices, and explained the situation he was facing. One person he visited was the engineer who designed the pipe and hose layout at the Electric Vehicle Division. 259 "I'm sorry to have to ask you this, but can you redesign the system for three radiators?" "Why can't we stay with the two-row design?" He too had preferred the two-row system which was lighter and more cost-effective. Reality, however, was against them. He finally agreed with Suzaki but predicted that the two-row design would be redeemed the next time around so that everyone would be rewarded for his efforts. The year was coming to an end. Suzaki was enjoying a rare opportunity to relax at home, and was reflecting on his experiences. "I've worked non- stop and only on cooling after joining the company. Today, I am working on the most challenging project of building a hybrid vehicle for the 21st century. Just one year ago, management decided to launch Prius one year earlier than initially planned. That means we'll be seeing Prius on the streets by this time next year. For someone that just looks at the car or even for someone who owns the car, whether the cooling system is in two rows or three rows is probably not important. Nevertheless, designing a good two-row cooling system would be a major step in the development of cooling technology. The time left on the development schedule is ticking away...." New Year's Day came. Suzaki flipped through the 1997 calendar. It reminded him that very little time remained. "The utmost priority is to complete Prius. For that, we have to cool the inverter effectively. Then, it's the air conditioning. Okay, we'll go back to the 260 three-row system. There will be another time to try again. This is an honorable retreat." At last he had made up his mind to go back to the three-row system. After the decision was made, work went swiftly. In fact, it was imperative that they quickly redesign for the next prototype from the two-row to the three-row system. In May 1997, the hybrid system was installed in a Corona Premio for a Test Drive Event for automotive journalists and news reporters at Higashifuji Technical Center. Two of the hybrid systems used for the event were still equipped with the tworow cooling system, but were driven despite temperature concerns. The cooling group was busy redesigning the layout of pipes and hoses for the final Prius prototype so had no time to fix the ones for the event. By the time the layout arrangement for the pipes and hoses was finished and the whole cooling system was finally complete, it was almost summer and just before the official prototype would be built on an actual production line. The cooling system was ready in time for the final tests in the summer. The inverter was cooled properly, and the air conditioning worked. The targeted summertime fuel economy also was achieved. 261

Chapter 10 Merging Two Different Cultures - Battery

"Fujii-san, you're making the battery carrier again?" A colleague teased him. Fujii smiled back, and said, "I'm afraid I am for the time being. But you'll see it one of these days." Despite his words Yuichi Fujii, General Manager of Electric Vehicle Division and Prius battery development supervisor, had no confidence. Batteries caused the largest number of problems for Prius, and the biggest concern among the development personnel was whether they would be ready for line-off or not. Fujii studied applied mathematics at Kyoto University

School of Engineering, and joined Toyota in 1966. After working on engine vibration and noise at Testing and Engine Departments, he moved to Higashifuji Technical Center and work on research involving maneuverability and stability. In 1993, Shiomi asked him to head the new Electric Vehicle Division. Since then, he had been involved in batteries. The battery for the RAV4EV, an EV that the Electric Vehicle Division had been working on, is a huge 400-liter box that weighs 450 kilograms. Some people jokingly called the car a "battery carrier." Prius needed a 262 drastically smaller battery to be taken seriously as a car. BRVF's simulation produced a development target based on the requirements to build a car as to how powerful the battery was needed to achieve double fuel efficiency. The requested battery performance was 288 volts and power output of 20 kiloWatts, at 75-liter volume and 75 kilograms in weight. This, however, included the control and cooling units. The battery itself had to be 50 liters and 45 kilograms. This was one-tenth the size of the battery for RAV4EV. BR-VF ruled that the output had to be achieved at the given weight for the car to function.

Working with Matsushita again At the time, the Electric Vehicle Division had codeveloped with Matsushita Electric Corporation and marketed a nickel-metal hydride battery for the RAV4EV. The nickel-metal hydride battery produces twice as much energy as a lead battery, and the energy per volume is also greater. It can be designed as a sealed unit, and needs no maintenance, such as adding water. In the spring of 1995, Electric Vehicle Division General Manager Fujii requested co-development of the main battery for Prius to Tetsunari Kawase, Member of the Board at Matsushita Battery Industrial Co., Ltd. "The nickel-metal hydride for RAV4EV is extremely good. Can we develop together a battery for the hybrid 263 system based on that model?" "Sure. Let's give it a try." Thus, two giants of Japan's manufacturing industry were teaming up once again. "Kawase-san, we need something that will work by the end of the year (1995)." "That should be enough time." BR-VF prepared an extremely crude design by roughly outlining the components, and determined the size of the battery based on its placement under the floor. The strategy at the time was to place the battery there. Its location beneath the floor was considered to be the most appropriate place since it did not affect the size of the passenger compartment. Matsushita had a round-shaped nickel-metal hydride battery for general public-use, and decided to base the battery for Prius on this. The first battery was completed in the summer of 1995, but had only half the output at 10 kiloWatts and twice the volume. Since it was far from being ready for use, two sets of previously used nickel-cadmium batteries were installed and prepared at 288 volts. This battery was so huge that it took up the whole trunk. "We'll put the nickel- cadmium in the trunk for the time being. When the nickel-metal hydride is ready, we'll put it under the floor." Nobody was worried about the battery at the time. In the end, ironically, the placement of the battery became a major problem. Although Fujii was acting as the Section General 264 Manager of BR-VF at the time, he never imagined that the management technology for charging and discharging electricity (charging while driving or the battery control technology to switch back and forth between the engine and the motor) would be so difficult. Instead, he was worried about the unit itself and whether the THS using the motor and the planetary gear would be compatible with the battery or not. However, the worst problem that he experienced later was controlling the battery. He had an especially difficult time dealing with the problem of heat, which he had never anticipated. Matsushita said it could complete the battery within the year, but it was a major commitment. It was because the expected power output per volume was twice as high as conventional batteries. Moreover, the hybrid vehicle required a type of power that had to be available instantaneously, at peak level. This type of battery performance hardly existed in the world at the time. The nickel-cadmium battery for electric tools came somewhat close, but the power output was several times lower. "If we connect the dry cell nickel-metal hydride battery in series, we can meet the volume requirement. The next issue is to instantaneously charge and discharge power. That is the key." Kawase repeated to himself. The year was coming to the end, but the nickel-metal hydride battery's performance showed no sign of a sudden breakthrough. The prototype vehicle was still using the temporary double nickelcadmium battery. "We'll have 265 the prototype team use the nickel-cadmium for the tests, and we'll concentrate on developing the nickel- metal hydride. We'll have to adjust the battery to the prototype's data." Dark clouds were appearing on the horizon for the battery group.

Because battery output is determined by the volume of the active materials, the pole plates were rolled out as thinly and widely as possible to achieve higher power. In order to fit a pole plate inside the same case as a size A battery, it is rolled up. Batteries were made over and over again, and tests were run every time. The group tried to achieve higher power output with this method. In order to achieve the other target of instantaneously charging and discharging power, the group tried to figure out how to lower the resistance on the connection terminal from which electric current is withdrawn. When this terminal has high resistance, heat is produced, and electric energy is lost in the form of heat. When draining water from a tank, it takes a long time to empty the tank if the faucet is small. It was the same idea as trying not to let this faucet clog up. Matsushita's know-how was used for the welding method.
By focusing on improving these two things, performance began to improve by the next spring. 266

A difficult heat problem

The improved prototype battery was installed under the floor of the vehicle, and tests were run. Daytime temperature began to rise in May, and some days were as hot as midsummer days. Due to the outside temperature, the battery started to produce more heat because the cooling system was not yet complete. Perhaps due to the heat, the battery's output only reached 10 to 15 kiloWatts. When the car was forced to continue running, the indicator for battery malfunction lit up, and the car stopped. There were two issues to the heat problem. The first was whether the battery should be designed to be more heatresistant to prevent power loss. The second was how the battery could be cooled from the outside. There were many possible causes of heat, but the group could not make sense out of all the possibilities and could not find a solution. A hybrid vehicle switches through various driving modes very frequently. It can run on the engine alone, the electric motor can assist the engine, or the electric motor alone can move the car. It is necessary to estimate and control how much electricity is discharged from the battery for every mode and how much electricity is left in the battery.
In real life, the car must go up a long uphill in the middle of summer, or go through snow or ice. It is 267 necessary to determine how long the battery can last in every condition. It is possible to move the car with the engine alone when the battery is drained, but the performance drops drastically. For these reasons, engineers in charge of THS were waiting anxiously to test the "real" nickel-metal hydride battery instead of the temporary nickel-cadmium. Ogiso, who was in charge of hardware at G21, was getting worried. Although other unit groups, such as motor and THS, were constantly going through trial and error, they were improving steadily. The battery was far behind the others. Ogiso checked up on Fujii every now and then. "We'd like to start testing with the battery. How is it going?" "It's pretty good, but we need just a little more time for installation." "If we keep on working with the nickel-cadmium, we cannot get accurate data. We don't care if it's ready or not. We would like to install the actual nickel- metal hydride in our test vehicle."

Reluctantly, Fujii called his staff Kazuo Tojima in charge of the actual development work, and told him, "Let's submit one that comes closest to the necessary specifications for the time being. We can test our own batteries and get the car to match the battery in the end." Although the best-performing battery was given to 268 Ogiso, it was far from what had been requested. Furthermore, the engineer from Matsushita said to cool the battery to 25 degrees and to never exceed 45 degrees. In actual on-board testing, it was simply impossible to meet those conditions. A car is used outside, and the scorching sun naturally heats up the battery. The cooling system also was not yet performing at its best. Therefore, none of the testing engineers would accept the fact that the battery would overheat quickly.

When the test vehicles equipped with the nickel-metal hydride batteries finally arrived, engineers from every department immediately set up the battery's usage pattern for every driving condition, and decided to run an endurance test. Several driving patterns, such as that of Mount Rokko of Kobe City, Shibetsu in Hokkaido, and Highway 153 in the mountains of Mikawa (Aichi Prefecture) were selected.

Each route was harsh on the battery. When the car made it to the top of Mount Rokko, the hybrid system's assist-energy ran out, and the car became incapable of recharging. The battery condition was monitored using these driving patterns. At the same time, several test-driving sessions were setup for executives. The battery group faced a series of problems on these occasions. In the hybrid vehicle, a staff member monitored the battery temperature with a laptop computer and sat in the passenger seat. 269 "Hey, the President's going to be testing this car. Is it okay?" "At this temperature, it's impossible." "Ask him to drive another car first." A few minutes later, the battery was ready to go. "Now, it's ready." "Okay ... President Okuda, the car is ready for you." Since the cooling system was not working properly and the overheating of the battery was not yet controlled, the battery was placed in shade and cooled with fans and portable coolers until the last moment. Even after these efforts, the temperature would sometimes suddenly rise just before an executive was ready to test drive the car. "You shouldn't drive the car in this condition." "How can I tell him that? Just let him take it." "No way. At this temperature, it is too dangerous. It might catch fire during the drive." In such cases, the executive had to be quickly escorted to another car. Observing these flurries, technical executives, such as Wada and Shiomi knew that the goal was still far off. The President and Chairman had decided at the end of 1995 to launch Prius a year earlier then scheduled, and the new launch date was the end of 1997. However, the project was still at the pre-development stage, at least from the viewpoint of a normal engineer. Although everyone thought that it would be difficult to get the car ready in 270 time, nobody would actually say so. It was Okuda who most eagerly checked up on the development progress of low- emission vehicles, such as Prius, through these test-drive sessions. Okuda himself once sat behind the steering wheel of Prius at one of these sessions, and told Fujii in the passenger seat, "Fujii-kun, one day everyone will be driving a car like this. You people are working on a great mission. It's probably the most amazing work at Toyota. One day, these cars will be needed outside of Japan, especially in India and China." Later, Okuda drove another EV and mentioned, "I guess people might think it's more fashionable to drive cars like this in the future." In fact, these cars were still in the development stage, and were far from being marketable. Fujii felt deeply moved and encouraged by Okuda who was willing to try such a car and say that they would be sold in developing nations in the future.

Reliability as a mass-produced vehicle Soon it was the middle of summer in 1996. Although power output was improving, the group could find no way to solve the heat problem. When the car stopped at a traffic light in August, the temperature of the battery under the floor immediately exceeded 50 degrees. 271 Performance rapidly declined, and there was no way of telling how long the battery would last under such adverse conditions. They tried to cool the battery by creating an air passage in the battery case. The air, however, already had been heated by the engine, and served no purpose in cooling the battery. Development was at a standstill. One day, Wada visited the group. "Hey guys, are you still having problems with heat? If it's so difficult, why don't you put the whole thing into the trunk? It's probably much easier to deal with heat if you put it there." In the RAV4EV, the battery had been installed under the floor, and BR-VF had drawn a design that placed the unit under the floor. The whole project team adhered to the idea of placing the battery under the floor. Wada's comment freed everyone's mind, and the battery was placed in the trunk instead of underneath the floor. The battery was placed in the trunk immediately behind the rear seats. It was the most favorable place for the battery It was away from direct sunlight or heat reflected from the pavement, and was always in the shade. In addition, the cool air from the air conditioning could be drawn towards the battery. The air also could be drawn out of the car from side vents. The heat problem was finally being resolved. Fujii, who had acted as both Electric Vehicle Division General Manager and BR-VF General Manager, had 272 handed the BR-VF leader position to engine-expert Yaegashi in March 1996, and began focusing on the delayed development of the battery. Fujii brought up safety as another issue besides improving the basic performance. Dry cell batteries for general public use are not required to receive approvals for risks that involve human lives. Even if they short-circuited, the consequences are not life threatening. Malfunctions of batteries in an automobile, however, can cause severe injuries. Devising measures to prevent electrocution in the case of an accident is imperative. Moreover, the engine must start at extremely low temperatures like negative 30 degrees Celsius. Inability to do so also can be life-threatening. A personal computer battery needs to work only within the range from zero to 40 degrees Celsius. However, a car battery needs to function from negative 30 to positive 60 degrees Celsius.

Since it was an entirely new design, the group had to consider how to test it at extremely low temperatures. Since the battery group alone could not solve this problem, engineers from the engine and the hybrid system joined to find a solution. There were still many more issues to resolve. The annual sales volume of Toyota's RAV4EV already in the market was 400 units. Power companies and governments agencies were the only buyers, and silently agreed to use them in moderation. They would not scrutinize the ability of the car. 273 In contrast, the annual sales volume of Prius was projected at 12,000 units. This figure had a totally different significance. It would be impossible to keep track of how it would be driven by whom. At this figure, Toyota would be unable to track each car. Based on that reality, the battery needed to clear every test in any situation under any climate condition. The car, therefore, was driven at 140 kilometers per hour for 1,000 kilometers.

Another concern for the battery group was that there were some batteries that failed immediately after they were put to use. The evaluation team called the battery group and complained that the car stopped and would not move. They immediately blamed the problems on the battery. When they went to check on the vehicle, the battery was apparently dead. However, another battery built in the same way would be working fine. Engineers were thoroughly confused. Later, when Fujii was assigned as an Executive Vice President of Panasonic EV Energy, a joint venture between Toyota and Matsushita, he thoroughly checked the battery production site. To his surprise, he found out that the defective rate in the manufacturing process was unexpectedly high, and that the production was unstable. That was why there were so many variances in quality. 274

Establishing a joint venture company In December 1996, when the group was still unable to produce a satisfactory battery, Panasonic EV Energy (EV Energy) was established. It was a joint venture company involving Matsushita Electric Corporation (24%), Matsushita Battery (36%), and Toyota (40%). Matsushita Electric's Kawase was appointed President, and Toyota's Fujii was appointed Executive Vice President. Uchiyamada told Fujii, "Perhaps you should reconsider setting up the company at such a busy time." He was unable, however, to change the decision of the three companies. EV Energy is a joint venture project between Matsushita and Toyota that anticipates the future EV and hybrid vehicle market. Toyota was already in touch with Matsushita from the days of former President Tatsuro Toyoda, and the joint venture was established under Okuda. Since Okuda assumed, "the era of EVs and hybrid vehicles would not arrive for another several years," the company was given the role of conducting R&D for three years. This meant that the company should start making a profit in the fourth year, and also that the battery for Prius had to be completed for production as soon as possible. On February 20th of the following year, a large reception was held at Tokyo Prince Hotel to mark the 275 creation of EV Energy. Toyota's President Okuda and Matsushita Electric's President Yoichi Morishita shook hands on stage, and the media extensively covered the occasion. GM's Member of the Board in charge of EVs and executives of most auto makers in the world attended the reception. The whole world was keenly watching this battery manufacturer that was aiming at the
21st century. "We have to succeed with the battery for Prius by all means. If we fail, God knows what will happen." Fujii whispered to Kawase, the President.

Not one speck of lint Immediately after coming to EV Energy, Fujii walked throughout the company, observing everything. It was one surprise after another. For example, there is a unique process called "aging" in the production of dry cell batteries. The finished batteries are left sitting for two to three weeks. Batteries that have even the smallest lint or metal dust trapped between the plus and the minus ports will "leak" after the component materials are activated. Needless to say, such a battery would run out of energy and cannot be used. This aging process is used to find and remove these useless batteries. Another surprise was that a very slight percentage of regular dry cell batteries for general use would become 276 defective on the store shelf even though they were shipped after the aging process. "Sometimes you forget that you've had these batteries. You try to use them one day and find out that they don't work. You think to yourself, `I thought these were brand new. Or, was I wrong?' You know

what I mean?" General Manager Munehisa Ikoma of Engineering Division I explained to Fujii nonchalantly. "Wait a minute. We are connecting 240 of the 1.2volt batteries in series for Prius. What happens if there is just one defective battery? The car won't start." Fujii stood aghast and was speechless. "We'll have to improve reliability by at least 240 times. The lint and metal dust end up in the battery because they are there in the first place. We'll start by removing them." Fujii decided to thoroughly review process and quality management from top to bottom. The batteries assembled at EV Energy were preprocessed at Matsushita Electric's Tsujido Plant (Chigasaki City, Kanagawa Prefecture). Tsujido Plant was run by EV Energy's parent company, but there was no time to be intimidated by that. Fujii immediately visited Tsujido Plant and explained the situation to the people there. Fujii actually walked into the production line, where there could be lint that blew in or from cleaning cloth. He was not trying to establish a clean room, but he lined the machines with acrylic sheets to prevent lint from entering. He felt he had to at least remove all visible lint. 277 He targeted processes that would be subject to lint exposure, and tried to improve them. However, the line workers who were used to the production method for general use batteries were confused. Fujii took his time to explain and tried to change the practices of the workers, who still failed to understand why this procedure was necessary. Matsushita had been manufacturing only car batteries, dry cell batteries, and general use batteries for PCs and electric tools. For such uses, the aging process was enough to remove the defective ones. A company that made batteries for decades would not think of reducing the defective rate to zero in the manufacturing process. Some time later, test production for batteries began, and Tsujido Plant began producing them. As expected, a battery problem came up. All of the
240 cells were returned to the plant, and the workers measured each cell with a tester. They found one defective cell. When they disassembled it, there was a small piece of lint inside. As these instances were reported frequently, each worker began to realize the significance of one cell causing the car to fail. "This is a serious issue. We can't meet the stringent requirements if we don't do what we should." Workers were now voluntarily cleaning and improving the production line. The difficulty of connecting
240 cells in series and Toyota-style quality control concept were literally a "culture shock" to the workers at Matsushita 278 Battery. Since Tsujido Plant was manufacturing nickel-cadmium batteries for electric tools, Fujii decided to use the facility to make the Prius battery. However, that was not enough. In order to meet the high reliability and required performance level in the method of connecting the cells and welding for an automotive part, the development, design, and every aspect of production needed to be improved. Quality control also needed to be implemented. For example, the 240 cells should never come loose even after driving on an extremely bumpy road. With the existing standard, this requirement could not be met. This was a totally new experience for Matsushita Battery. However, Matsushita had not displayed its exceptional ability just yet. Matsushita built on-site all the machines used for making batteries, because it had all the necessary manufacturing know-how. It made machines that were much better in quality than the existing ones for welding and assembling. Ikoma later looked back and said, "It was a tremendous lesson. No other battery manufacturer would have been able to do something like this." The method of producing lead batteries is the same around the world, but the quality is not. By establishing EV Energy and combining the advantages of both Toyota and Matsushita in manufacturing, Matsushita Battery's capability improved by several levels. 279

Matsushita style? Now the story goes back to February 1997, after the opening-establishment reception. After the celebration had faded, EV Energy received the final specifications for Prius. The battery's evaluation still had not been made at this time, and Fujii was becoming quite impatient. He did not believe that the people at EV Energy were very concerned about it. In other words, they were too relaxed. He felt that was more true with engineers from Matsushita. Feeling agitated, Fujii asked Kawase. "I have a feeling that there is a difference between an auto maker and an electric appliance maker in the way they feel the sense of crisis against lead time. A Toyota engineer has it in his bones to be fully aware that preparing for production development should occur at a particular point in time. On the other hand, I feel that the Matsushita engineers are a little too relaxed." "Fujii-san, what can I do? Everyone at (EV Energy) Mechanical Technology Center is working hard without sleep. You have to trust them." He understood that fully, but was not comfortable with the lack of tenseness and the relaxed atmosphere. "At Toyota, everyone would be worried about time at this point. But here, I can even feel that President Kawase is still relaxed. Is this the difference in corporate culture between

Toyota and Matsushita? Or is it the 280 difference between an auto maker and a general-use battery maker?" Fujii pondered. "It is true that the Matsushita guys are confident that they have worked day and night on Prius. However, the quality level required on general goods is much lower than that on autos. We might end up with a huge problem in the end." Fujii had a hunch.

Matsushita's engineers finally realized the difference in quality control between Toyota and Matsushita during the endurance tests held from spring to summer of 1997. The battery was installed in a test vehicle, and various data were recorded. Until that point, the Toyota team was working separately from the Matsushita team. After the joint venture was established, the two groups attended the tests on the test course. Matsushita's engineers realized that the amount of data to be taken and the required quality level were all at least one digit higher than what they were used to. They immediately sped up the development process. The other departments were requesting the battery to be improved every day. EV Energy was overcome by a sense of crisis. As was mentioned earlier, THS already had been shown to the public, and the launch date and the estimated price of the hybrid vehicle had been reported in the media. "What on earth would happen if a car receiving so 281 much attention cannot be launched as scheduled due to battery problems?" Fujii was scared to even think about it. His concerns quickly spread throughout EV Energy. The company burst into a concerted effort towards the end. "Fujii-san, look, he looks like he's fainting." One evening, Fujii found a young engineer looking pale. "How late did you work yesterday?" " Till four in the morning." "Gosh, you should go home and rest now." Fujii told him, then walked around the plant for inspection. When he came back after an hour, the young engineer was still working. "What are you doing here?" "Urn, I had to make sure of just one thing. Let me finish this today." During the last stretch, Matsushita engineers' concentration on work proved to be absolutely amazing. In the end they produced what they had promised. "So this is Matsushita style...." Fujii felt that he finally understood Kawase's composure and trust towards his staff. 282

Selling to the world Another difference in corporate culture was the way they considered cost. Without doubt both companies were extremely hard on cost. However, the degree of concern was a little different. Since very few batteries are used for general consumer goods, consumers accept the additional cost of batteries to some extent. With a PC for example, the battery costs only several thousand yen, compared to 200,000 yen for the PC. However, Prius uses 240 batteries, and their cost as a percentage of the price of the car and their actual price are both quite high. At first, Fujii focused on developing a reliable battery to mass-produce the first hybrid vehicle in the world, and had no extra time to think about cost. However, once product development was complete, the next issue was cost. In order to mass-produce and truly spread the technology, the balance between performance and cost was important. Establishment of EV Energy was advantageous in that sense, because Fujii experienced hell immediately after setting up the company, and understood the hardship of both production and cost. For EV Energy to succeed as a company with the success of Prius as a product, its product must produce profit and should be sold at a fair price to the public. "The public won't approve of the company if you only 283 sold the goods to Toyota. You must develop goods that would appeal to every auto maker of the world," President Okuda told Fujii when EV Energy was established.
The basic philosophy of the company is to first create social value in Prius and then to openly make the acquired technology available to society. Today, Honda has decided to use EV Energy's battery in its hybrid vehicle to be launched in 1999. Many other foreign auto makers are trying to sign deals as well. The combination of Matsushita Electric's philosophy to "produce good things inexpensively in large volume" and Toyota's idea of perfecting the products helped to bring about the world's top EV battery, which is slowly becoming the global standard. At the end of October when the presentation of Prius was over, an appreciation party was held at a pub near EV Energy. It started at seven in the evening. When the party was at its peak, the pub's hostess asked a regular customer. "You are all here so early today. What's the occasion?" Until that day, single engineers had always rushed into the pub a little before the 11:00 p.m. closing just in time for a very late dinner. 284

Chapter 11 The Two Product Planners - Commercialization

Toyota's highest decision-making body is the "Executive Vice President Committee" comprised of Board members whose positions are Executive Vice President or higher. The plan to launch Prius in December 1997 was officially decided at the Executive Vice President Committee held in December 1995. A concrete development schedule for G21, the organization that plans the 21st century car, was also started in January 1996 and was given the product planning code "Zi" under the Vehicle Development Center II. The project had shifted from the development phase to the commercialization phase. At this point, merchandising experts were needed. Toshihiro Oi of the Vehicle Development Center II was nominated. Oi had commercialized the sub-compact passenger-cars Tercel in 1994 and Starlet in 1995. Oi had a lot of experience in this subcompact class. 285

A sudden nomination

At the end of 1995, Oi was being interviewed by an automotive magazine which was doing a special report on the new Starlet at a Toyota facility outside of Toyota City. In the middle of the interview, his boss Isao Tsuzuki called him. "Oi-kun, I shouldn't be telling you over the phone, but you are wanted at Prius starting next year. Sorry it's such short notice." "Oh, you mean that Prius. Okay, I'll be there." Although Oi accepted the order, he actually had almost no knowledge of the hybrid system at this point. The G21 (Zi) members who had worked in the red carpet room since January 1994 as a part of Planning Division II, were to move to Planning Division II following the product planning lift-off. Oi was now joining the three G21 members who had worked together for almost two years. Oi's first task as a new G21 member was to help the three to move. When he stepped into the red carpet room for the first time, he was overcome by its solemn atmosphere. "This is where the secret project was carried out." As he removed the lifesize design sketch from the wall, he felt, "It seems easier to work here. I would have preferred this room over the other one." The product planning team now had four people. Uchiyamada explained the reason why Oi was added to 286 the group. "We three members have finally become experts in the hybrid system, but have absolutely no experience in product planning. If we want to start a production line to launch a new car, we need an experienced member. That is why we invited Oi-kun. He is an expert in completing a product. He will prepare production jointly with the plants and coordinate with the sales department. Also, building a prototype prior to mass-production is completely different from building a couple for a Motor Show. We will ask him to supervise in that area. After all, he would probably not have enough time to catch up on the hybrid system." Uchiyamada tried to put everyone at ease with a little joke. Immediately after joining the group, Oi noticed something different about the group. The three others seemed to be constantly sharing the same new information even if they never discussed about it. Oi thought that it was because the three had worked closely for two years, but later noticed that that was not the case. In fact, the three had been exchanging the newest information through E-mail. Back then, the Intranet had not yet been established within Toyota, and many engineers used only specialized computers and were still unfamiliar with personal computers. "How impressive. These guys are developing a car for the 21st century, and are so ahead of us. They each 287 had a PC in the red carpet room. Look at me. I only work with a phone and a fax, still deeply stuck in the 20th century." Oi, who had never used a PC, was impressed and decided to start learning how to use a PC before learning more about the hybrid system. He caught up before the summer came. Conversations at the G21 office were full of specialized terminology. Oi began by studying what they meant.

I want to work on safety

Oi was born in Hokkaido, and studied fluid dynamics at Tohoku University School of Engineering. His purpose in joining Toyota was a little unique. First, he wanted to work on safety, and he selected an auto maker. He grew up in Fukagawa City in the center of the prefecture, but was living in a dormitory to go to high school in Hakodate City in the prefecture's south. There, from his dorm room he became a witness to the crash of a Toa Domestic Airlines (now Japan Air System) YS-11-type aircraft "Bandai-go." He did not see the actual crash but heard it. He had heard an unusually loud jet noise. Investigators were trying to determine whether it was due to pilot's error or

to a mistake by the control tower. Later when he entered college, he attended the court hearings for this case. Through this experience, he began 288 to feel that he wanted to work on aviation safety technology in the future. However, there were no aircraft manufacturers in Japan. He decided to work for an auto maker instead. Oi had no affiliation with western Japan, so his choice was Nissan. Nissan was hiring three people from his university, and there were five candidates. "Okay, let's decide by *janken* (the child's hand game commonly known as "stone, paper, scissors") just to be fair." The five agreed. Oi was the first one that lost. Meanwhile, there were two openings with Toyota. He contemplated a little and made his decision. "It's okay if I have to go beyond Hakone, as long as I can work on cars." Thus he came to Toyota. He requested to be placed in a safety-related division, and worked on seatbelt design for a long time. After working mostly on seatbelts for passenger cars, he moved to product planning. He took charge of concepts for new models, prototype evaluation, and development supervision. Due to his background, he was especially hard on safety issues. One of the tasks in product planning is to run test cars to the ground to expose their weaknesses. Those involved in the development tend to make the tests easy, but product planners give no mercy. They try to check the cars from the standpoint of a consumer. Oi was excited to learn all about the hybrid vehicle. He
test-drove a pre-pre-prototype for the first time, and 289 was shocked. "Is this really a car?" The pre- pre-prototype was a car that finally had been put together, and was a huge step forward as far as the development people were concerned. However, for an engineer in charge of completing a marketable product, the car was a piece of junk. The vibration from starting and stopping of the engine was particularly bad. Safety was not even an issue at this point. The main problem was how to set it up as a car. The launch date was set to be the end of 1997, and Oi was skeptical whether or not it could be commercialized. "Where should I start? We have less than two years." He calmed down, and thought of what to do. Even though he was a product-planning expert, he had never been given such a premature product to merchandise. After a few days, he made up his mind. "Okay, we should quickly select our suppliers. Since there are so many new parts, we will not make it to production on time if we don't quickly decide how to get those parts, whether by manufacturing them ourselves or by buying from another company, and who we should buy them from. We can't continue to focus on development alone." In March, with the engineers in charge of production management and procurement Oi began selecting parts suppliers. 290

Let's share information Oi explained everything about the project to the representatives of each department. Questions were asked, such as "What is G21 (Zi)?" and "What car is the product planning division trying to build?" Oi realized, "Fewer people knew about the project than I thought. We will have a major problem if we don't speed up." Since the parts for a hybrid vehicle are highly specialized, Oi contacted companies that had worked on EVs. However, he and the management we re unable to reach a decision on whether the parts should be manufactured in the company or be ordered from suppliers. "The hybrid parts based on brand-new technologies will be manufactured in-house. The ability to understand, evaluate, and produce the basic technology should by all means be retained within the company." This conclusion was finally reached one or two months later. Toyota is known to be extremely keen on reducing cost, but finishing the product in time received higher priority than controlling cost in the case of the hybrid vehicle. Every member had a feeling that this car would not be as profitable as an ordinary car. Toyota's cost reduction method was not about demanding unreasonable discounts from its suppliers. It 291 was about continuously removing waste, because waste begins to appear with time even after improvements are made. Oi established the
"Development-Production-Sales Correspondence Committee" in June to encourage each department to understand the project's progress and to prepare for production in advance. This was a common method at Toyota. At the correspondence meeting, discussion begins by determining what each department should decide in order to bring the car into production. The plant should be selected before determining distribution. Although the Machine & Tools Engineering Division was about to choose the plants to manufacture each of the components, the assembly plant was not yet selected. If the production volume is not set, the production process cannot be determined as all these issues are interdependent. "We should make all information related to the hybrid vehicle as open as possible. We should first explain the hybrid structure to everyone, and disclose all new pieces of information as they become firm." Disclosing so much information at this stage was unconventional. A competitor might get

access to this information. However, almost everyone was unfamiliar with the hybrid vehicle. "If we don't share the information and have everybody understand the system, this project will fail," felt Oi, and 292 decided to trust all workers who were involved in Prius. Production Management Department sponsored the correspondence committee. It started out with 10 people from Product Planning Department representing the development division, Production Management Department representing the production division, and Domestic Planning Department representing the sales division. As the committee developed and various problems and questions arose, departments involved with those issues were called to join in finding the best answers. The committee functioned as a place for each division to verify overall progress. Members frankly shared opinions and requests to the other divisions, and discussed every issue until everyone was satisfied.

Selecting the plant The biggest problem was deciding where the car would be manufactured. Although this is officially decided at the production division meeting, the committee agreed to do the necessary preparatory work. Toyota's cars are assembled at Motomachi, Takaoka, and Tsutsumi Plants in Toyota City, Tahara Plant at the eastern edge of Aichi Prefecture, Kyushu Plant in Fukuoka Prefecture (Toyota Motors Kyushu), and by several affiliated companies such as Toyota Auto Body and Araco (Toyota City). Affiliated companies, geographically 293 disadvantageous Tahara Plant and Kyushu Plant were ruled out. Of the three local plants, the committee decided on Takaoka Plant based on its experience with sub-compact cars, the timing of switching to the production of a new model, and the plant's capacity. Takaoka Plant, which had produced the Starlet and Tercel, was Oi's home ground. The whole company also was inclining towards settling on Takaoka Plant. After the plant was selected, the committee had to decide whether Prius was to be produced on an exclusive line or with other models on the same line. Preparation differs between the two formats. If the line workers do not understand the process completely, the line will not function properly. Upon receiving the committee's recommendation, the development division verified whether each procedure was operative by actually assembling a test vehicle. The test results showed that parts and procedures were completely different from conventional cars, and the division ruled that sharing the line with other cars would be extremely difficult. The committee began preparation for an exclusive line. In June 1996, based on the assumption that it would be selected, Takaoka Plant dispatched a group of "Reverse Resident Engineers" (RE) to work with Oi at product planning. Resident engineers are development engineers stationed at the mass-production plant for a period of time to make improvements by looking for design problems 294 and others issues. These resident engineers sometimes make as many as three thousand adjustments in one to two months. This is Toyota's unique method called *"tsukurikomi,"* and is reputed to be a major factor in Toyota's ability to produce cars of the highest quality in the world. The "reverse RE" group was a group of production technology engineers sent from the plant to join the development division before the production line was installed to improve and perfect the hybrid vehicle with which they had no experience. Before Takaoka Plant was officially selected, the plant's Quality Management Department sent Fukuo Mayumi and Koji Matsumoto to product planning. The two were not officially transferred, but came on their own. The plant also was eager to make this unprecedented project succeed. The first job for the two was reconnaissance by attending the weekly meeting and gathering information. When Takaoka Plant was officially selected at the production division conference after the Prius Design Review in September 1996, the two were officially placed at Vehicle Development Center II Product Planning Division. Then, they began working on details, such as plant layout. 295

Building the sales structure Meanwhile, the sales division was engaged in a heated discussion trying to decide which sales channel should sell the Prius. Toyota's auto sales were divided among five sales channels: Toyota Channel, Toyopet Channel, Corolla Channel, Auto Channel (Netz Channel starting August 1998), and Vista Channel. In 1946, when dealerships that had sold Toyota cars from the pre-war period reached nationwide, the Toyota Channel was founded. Since then, as new models were introduced and the number increased, more dealerships opened. Toyopet Channel followed in 1956; Publica Channel, the predecessor to Corolla Channel, in 1961; Auto Channel in 1967; and Vista

Channel in 1980. Toyota's sales structure encompassing 309 dealerships and 5,000 outlets was established. This strong sales structure, which gave birth to the phrase, "Nissan of technology; Toyota of sales," was vital to support Toyota's strong sales division. During the era of rapid growth, quantity was an advantage, and Toyota's market share grew. However, in 1996, immediately before the launch of Prius, the traditional structure was suffering from many forms of fatigue. Toyota's sibling models were competing against each other and resulted in discount wars. Dealerships were no longer paying attention to services, such as compulsory auto inspection, which is another 296 source of income. Antiquated sales practices, such as homevisit sales were making business inefficient. In 1996, one year after Okuda was appointed President, Toyota's annual market share fell below 40%. This was the first experience in falling sales since Toyota Motor Corporation and Toyota Motor Sales merged in 1982. Okuda expressed his sense of crisis in this emergency situation, "Maintaining a 40% market share is our last line of defense." When a very large corporation begins to crumble, the rate of deterioration accelerates due to its sheer size. For Toyota, 40% market share was the slogan that united 70,000 domestic employees and kept up their morale. It was also what assured the domestic annual production of more than 3 million units and, therefore, the employment of all Toyota Group companies.

Characteristics of the five channels In January of 1997, Toyota reorganized its sales division into a five sales office system that worked in keeping with the channel system, and defined the characteristics of each channel. Toyota Channel handled largeclass cars, Toyopet Channel carried medium-class cars, Corolla Channel handled compact cars, Auto Channel catered to women and young people, and Vista Channel handled unique cars that followed trends. In principle, all 297 channels were to carry exclusive models. They were expected to hammer out sales promotion plans to emphasize their individuality and to operate without depending on sales incentive payments from the manufacturer that came to subsidize dealers' profit. The discussion to decide the sales channel for Prius took place at the height of the sales division reform efforts. Since Prius was the first hybrid vehicle in the world, the channel selected to sell Prius would receive a lot of attention from the public. On the other hand, service mechanics at dealerships would face significant difficulty from having to service unprecedented high-voltage electric systems. From the standard point of vehicle size, Corolla Channel or Auto Channel would be suitable. From its uniqueness, Vista Channel would be a good choice. However, these channels seemed to lack sufficient service and sales structure. Through overall evaluation, Toyota Channel was selected due to its seniority and superior experience in service and sales. If Toyota Channel received such an exclusive privilege, the other four channels would be unsatisfied.
Each of the four insisted on joint sales by two or more channels. Each had its point. However, supply of Prius would be limited, since monthly production was estimated to be 1,000 units. Toyota Channel alone had more than 1,000 stores. After several discussions, all agreed to settle on Toyota Channel's exclusive sales. 298 Toyota Channel did not carry compact cars, and had never sold cars produced at Takaoka Plant. It was necessary therefore, to establish the route for distributing cars from Takaoka Plant to Toyota Channel stores. After the sales channel was selected, it was the service division's turn. The division collected technical information from various departments, and implemented service personnel education programs in several phases. With conventional cars, Toyota's Service Department learns the new technology two months prior to launch, and dealer service personnel education takes place one month prior to launch. With Prius, Toyota's Service Department began learning the new technology almost a year before launch, and service personnel education began immediately after the long vacation weekend in August, four months prior to launch. Product Planning Department cooperated, and planned a one-on-one education program for each dealer service personnel.
However, Service Department people were often having difficult times themselves. "We will run out of time," thought the Service Department executives. Universal education of dealer service personnel was cancelled, and was switched to leader education. Service Department asked each of the 50 Toyota Channel dealerships to select a specialized Prius service person and a salesperson to be educated exclusively. This education method was totally new at Toyota. The education began by having each leader identify 299 the actual parts to see what they were like. The education also emphasized "soft" as well as "hard" in terms of thinking. However, it would be impossible to completely absorb the technology that was completely different from that of conventional cars. So, for the meantime,

dealerships were instructed to contact the manufacturer whenever main units, such as the battery, needed to be serviced.

A car that "moves" instead of "running" Toyota has several divisions that do not exist at other auto makers. Product Audit Department is one of them. This section that is placed within the planning departments of each of the three Development Centers to inspect each car under development from a consumer's point of view. This section also considers how to make the development more efficient. These are the section's two tasks. This is a new section established in the early 90s, and Vehicle Testing Department used to be in charge of this function in the past. After becoming an independent body, the function began to focus more on "soft" issues rather than on "hard" alone. The section inspects a car from a consumer's point of view, and regularly feeds the information to the development team. As a result, the section has helped to create products with higher customer 300 satisfaction. It was Motoyasu Muramatsu of Planning Division II who was responsible for Prius in this Product Audit Department. He was an expert who had worked on several compact cars, such as Tercel and Starlet. The Vehicle Development Center II Product Audit Department has four groups according to car size. This organization includes staff, local technicians, test drivers, and personnel to run evaluation tests. At the beginning of 1996, Muramatsu saw Prius for the first time. The body was not yet complete at the time, so it had the body from the 1995 Motor Show. He test-drove a model equipped with a THS prototype on the Higashifuji Technical Center test course. At that time, Muramatsu was not yet in charge of the car. "If G21's hybrid vehicle goes into mass production, one of our four groups will be in charge of it. Okay, let's give it a try, since it seems pretty different." Out of curiosity as an engineer, he visited Higashifuji with his staff assistant Motoo Kamiya. His first surprise came as he sat in the driver's seat. There was a hand-made computer the size of a barbecue grill in the back seat. When he opened the trunk, it was filled with batteries. He started the engine. "Hum, Kamiya-kun, this thing moves rather than runs. 301 It did not run very smoothly. Still, when he slowed down, the engine stopped while the car still moved. When he stepped on the gas pedal, the engine started again. "Oh, that's the hybrid system. I guess it's okay." The two were impressed and unimpressed at the same time. In any case, they both agreed that the car was not fit for merchandising, and left that day. Back at Toyota Honsha the next day, Muramatsu and Kamiya talked about Prius. "The engine stopped as we continued to move. That was pretty interesting." "That's right. I was impressed. But I wonder if it can run in the middle of summer or middle of winter." "I thought of the same thing." "Let's see, Kamiya-kun. Would you try it out at Shibetsu (test course)?" Concerned with whether Prius would start in the middle of winter or not, Muramatsu promptly sent Kamiya and a test-driver to the test course in Shibetsu, Hokkaido, in the middle of winter. The test-vehicle had no amenities such as a heater at the time, and the two worked wrapped in many layers of overcoats. The temperature was negative 10 to 15 degrees Celsius. When the car stopped in the middle of a test, they called for help on a radio. "Somebody,
come help us quick! We're freezing...." As expected, the car did not run very well. 302 Kamiya's honest opinion was that the car would not be commercialized for quite a while. He was relieved to have come out of the test in one piece.

The same car as that car? A while later, rumors of mass production of Prius began to circulate. This time, the rumor seemed to be real. The Planning Division II's Product Audit Department was officially selected to be in charge. "Good, we'll give it our best." Muramatsu began dissecting Prius with the eyes of a professional. Since it was a brand-new car, he had no idea where to start. First, he opened the hood and tried to figure out how to disassemble and rearrange the engine components. There was, however, direct current of 288 volts under the hood. The Prius sold today is furnished with plenty of safety devices, but the test vehicle back then was not. With ordinary cars, nobody can be electrocuted if the engine is off, but this was the first high-voltage device car for Toyota. Muramatsu called a designer from Electric Vehicle Division to draw a work chart, and started by studying it to avoid
electrocution. When he finished his work, he was sweating profusely. Muramatsu then spent March and April trying to learn the safety procedures for all parts. 303 Later, each department began test-driving for operational stability, noise, and vibration. The work chart was eventually handed over to every

technician of the departments that was actually studying the car. The motor is started like all conventional cars - by turning the key. However, the engine did not start on early test vehicles; only the ready-light glowed. The engine did not have to start since the motor was used for acceleration. Nevertheless, nobody was ever sure whether the car would actually move or not. After a number of test drives, problems popped up everywhere. "It's not going. It's not moving. Something's broken." The test course was turning into a field hospital for Prius. "Hey, do you have your cell phone?" This was how people greeted each other on the test course. When the car stopped in the middle of the course, the test-driver would have to walk all the way back. It was no joke in summer or winter. It was the first time that such a trouble-ridden car arrived on the test course at this stage of development. However, technicians who were 50 years old and near retirement remembered the old days. "A long time ago, we used to have these problems all the time. This car is like the cars back then." However, technicians under 40 had only worked on 304 cars that would run without problems. Everyone was witnessing an interesting generation gap in an unexpected setting.

Muramatsu felt that controlling the battery was the most difficult problem to solve. The batteries continued to die. He knew engines thoroughly, and was familiar with the motor through his experience with RAV4EV. However, the hybrid vehicle's battery was entirely new to him. Prius charges and releases electricity while in motion. Even the engineers at Electric Vehicle Division did not have the know-how to control the battery properly. "What do we need to do to make the driving of Prius closer to an ordinary car?" When he asked himself that question, he immediately thought of the battery problems. Whenever he changed the driving conditions and test drove the car, the battery would die. No matter how much he hoped it would keep going, the battery drained after only two to three trips around the test track. According to calculations at the time, the car should have gone 20 times around the test course at full throttle. The battery group worked furiously, but was unable to achieve half or even a third of the expected performance level. No matter how much the group tried, they simply could not get the battery to last. Getting the battery ready was a gamble until the very end. 305 "Let's just assume that the battery will meet the scheduled specification in the end, and lets continue with each of our tasks." Chief Engineer Uchiyamada made that decision and the project continued. The Product Audit Department put emphasis on testing for driving performance. Prius was an eco-friendly, car that was supposed to be twice as fuel efficient as other cars of its class. Logically, the highest priority should have been on fuel economy, but Muramatsu had a different view. "A hybrid vehicle should be naturally fuel-efficient. However, no matter how good the fuel economy is, a consumer would immediately dismiss a car that runs poorly. It should drive at least as well as ordinary cars. If consumers had to give up the fun of driving in an eco-friendly car, they would never buy one." Muramatsu put an especially difficult demand on the development team. He told them he did not want to sacrifice performance for fuel economy, just because the Prius was the first hybrid vehicle in the world.

One test vehicle after another

Testing for high-speed driving, stability, and handling are conducted at the Higashifuji Technical Center test course. The number of test vehicles reached 100,
306 and the driving distance on the test course was almost five times longer than other new models. Since the development period for Prius was extremely limited, R&D and product development advanced almost simultaneously. With the development of ordinary cars, test vehicles of different phases share many parts. With Prius, however, experiences and/or manuals from previous test vehicles could not be used for the new test vehicle because each test car and every computer changed with every test. For every test breakthrough, a new test vehicle was prepared to evaluate the new idea. The first task of the Product Audit Department was not to evaluate the car but to get it running. A new test vehicle would almost never work at first because of a computer bug or an error in specifications. Since nobody had particularly difficult experiences in the past, no one was comfortable with the situation. "I'm sorry but this car is not working," a young Product Audit Department staff member complained when he went to pick up a test vehicle at the test office on the fifth floor of 8th Technology Plant. He had received a call to get the first prototype. He had assumed that a car would be working from the very beginning. "We assembled it as we were told, using the unit from the Power Train &

Chassis Components Production Engineering Division. If it doesn't work, maybe there's something wrong with the design." The test plant staff 307 member replied. The car would not move. If the car does not move, the staff cannot evaluate it and get their work done. Normally, he would just turn the ignition and start his test, but a sitting "piece of iron" is useless. All the staffers of Product Audit Department came and pushed the car from the test plant to the Product Audit Department room on the first floor of the same building. People from the test plant and design engineers from the Electric Vehicle Division were called to examine the car, and the car finally started to run after a week of additional work and adjustments. Since Prius was the top priority project of the company, the testing department also considered it first priority. The department received orders to build six or seven test cars in a week, and completed them one after another. However, none of the cars would start running as delivered. Since those that would not start were rolled into a room at the Product Audit Department the place was soon filled with inoperable test cars. The room was turning into a repair shop. The section could not figure out why the test cars would not start. There were many possibilities. Kamiya, who was in charge of summoning engineers, had no idea whom to call. Engineers working on the hybrid vehicle never had time. When he began to doubt that engineers were not responsible for the problems, he became rather reluctant to call individual engineers. Instead, he summoned every 308 member of the group that might have been responsible for a problem. At first, most people did not show up immediately because they did not think the problem was urgent. Kamiya went around the building and tried to get people to come. He thought, "This is not at all fun work" There were many
reasons why the car might not start. There might be a mistake in the computer or the electrical harness, or the nine computers. Since the cause of the problem was usually the responsibility of several departments, it was a good idea to get people from each of those departments. By early 1997, test vehicles were finally becoming operational from the beginning.

Make it drive like a Corolla One of the characteristics of a hybrid vehicle is that the gas pedal pressure can be freely adjusted. In an ordinary car, the pressure against the gas pedal opens or closes the fuel throttle valve. The feel is almost the same whether it is electronically controlled or mechanically controlled. With Prius, the gas pedal itself was a type of electronic throttle. It was possible, therefore, to set the level of engine power by adjusting pedal pressure and travel. The "feel," therefore, could be set to be just like that of a conventional car or completely different and new to 309 characterize a hybrid vehicle. Muramatsu could not decide, and asked Uchiyamada. "Uchiyamada-san, what shall we do with the gas pedal feel?" "Let's not make it too strange so that a driver won't feel uncomfortable switching from a conventional car. We would like to give it some character within that framework." "When turbo cars were first introduced, people were intrigued by the sudden thrust of acceleration. It had that powerful turbo character. I wonder if we can create something that can leave an impression like that."
"Turbo, huh? That shocked me, too, but I never felt comfortable with it. I guess young people liked it, but the turbo was eventually adjusted to accelerate less abruptly." "Well, we should at least let it have the same feeling of acceleration as the Corolla. We can't let Prius get a reputation for being slow or sluggish." "Hmm. Okay, let's aim at creating the same feeling of acceleration as a 1,500cc Corolla. If we do that on a hybrid vehicle, people will find it sensational." Thus, Muramatsu set the "drive feel" of a 1,500cc AT Corolla as the target. After that, the decisions were more subjective and answers could not be calculated. How a person feels about something is completely subjective and reactions are diverse. Muramatsu ran one test after another while slightly changing the resistance of the pedal 310 and the speed at which the pedal lifted back up. He also tried to match the degree of applied pressure on the pedal to the actual speed. The goal was to achieve a paradoxical target that would allow the driver to operate the car smoothly like an ordinary vehicle while maintaining a distinctive hybrid vehicle-like feel.

Using the media What Uchiyamada and Muramatsu really wanted was the response of the general public. Raum, developed by the Vehicle Development Center II at the same time as Prius, was designed so that older people could ride and operate it easily. The project team asked a nursing home for cooperation, and asked for opinions by having older people drive and ride the test vehicles during the development stage. Prius would have benefited from a similar test method, but that was impossible

since Prius was a top-secret project even within the company. Muramatsu came up with the idea to invite people from the media to test-drive the car. A large-scale test-drive event was held for the media in May 1997 at Higashifuji test course, and also in Hakuba Village, Nagano Prefecture, after a press release on the Prius was issued in October. Certain journalists also were to be invited to a test-drive at the test course in Shibetsu. 311 The media encompass a wide range of people from fastidious motor journalists to business journalists with no technical knowledge. Muramatsu could count on the unprejudiced business journalists to have opinions similar to that of an average person in regard to the hybrid vehicle. Muramatsu wanted to find out what they felt as an ordinary driver so that the opinions could be used towards improving the feel of the gas and brake pedals. At the same time, Muramatsu took advantage of the "car-freak" journalists at the test-drive event who were excited to have the privilege of driving the car before launch. The May event in Higashifuji was named "Hybrid System Test Drive Event," and the journalists drove a car with the body of Corona Premio equipped with THS. Toyota could n ot release the name Prius prior to the launch press release, and certainly could not show the body design. Uchiyamada, Yaegashi, and Hiroaki Kato General Manager of the Product & Technology Information Department, Public Affairs Division, attended the event, and gave technical explanations of the hybrid system and talked about Toyota's efforts in building low-emission cars. After that, the guests went to the test course. "We have three cars ready for you. We would like you to drive around the test course twice. Since there are many participants, please switch after two laps so that everyone gets a chance," an event organizer told the journalists. Each participant was limited to two rounds not only 312 because there were many people but also because of the battery problem. At this time, the performance of the nickelhydrogen battery was poor. Even though the batteries hopefully would last until the end of the event, they could have given out if somebody drove too roughly. If the car performed poorly in front of the media, a negative report could result, such as "Toyota's hybrid vehicle - technically incomplete; prospects for production still afar." Such a negative report prior to launch is fatal to a car. The event had to go smoothly and successfully. Ogiso, who had worked on the technical parts of the car, was very concerned. The test drive began. Everything had been going smoothly for a while until a TV crew began making requests. "Excuse me. Can we please drive one more lap? We would
like to get a better shot." "Park there, and step on the gas." "We would like to tape the interior while driving." Many TV reporters were attending the event from Tokyo and Nagoya. Since they wanted to air the footage in the evening news programs, they were all working hard to get a better picture. Meanwhile, newspaper reporters became impatient and began complaining that the TV people were holding up the test drivers. While dealing with the selfish people, Ogiso was praying that nothing would fail. "These people have no idea.... In any case, I hope the battery lasts through the day." 313 The event ended without any major problems. The following day, a recap meeting was held at Toyota Honsha. An engineer accompanied each driver, and asked for the driver's detailed impression about driving the car. Many of the opinions coincided with those of the engineers in charge of development. Although they were not unexpected, some of those opinions had still been dismissed within the company as unimportant issues. When an engineer said, "A journalist appraised this feature at the test- drive," that feature would receive more attention. Otherwise, a feature would be removed only by a comment, such as "Since technically knowledgeable Mr. Soand- so pointed out this about that feature, it is probably no good." The opinions of 10 to 20 captious journalists were compiled in one place. Some engineers felt, "Nobody has complained about my work. Good. I can keep it the same." Regarding the feel of the gas pedal, some said, "It runs better than I thought," while others said, "It is annoying because acceleration is slow." The opinions were widely varied. In fact, two cars with different acceleration feels were used for the test drive. The first one would accelerate at once when the driver stepped sli ghtly on the gas pedal. The second one would not accelerate much when the usual amount of pressure was used on the gas pedal, but eventually would move from a build-up of torque. The 314 car with better performance received more motor assistance for acceleration. On the other hand, battery output was the key factor and was prioritized in the car with poor performance. Since the motor was controlled to restrain battery output, the power would not go to the wheels for a while but the car would move forward suddenly. In order to find the optimal point between the two different performance types, the group agreed to work on altering the computer program. Another important issue that was pointed out regarding acceleration was that the gas pedal did not have enough resistance. In an ordinary car, the gas pedal is connected to a mechanism and because of its nature, the downward gas pedal resistance is different from when it is lifting up. A driver takes advantages of this difference to

stop acceleration to maintain a certain level of speed. With Prius, however, the gas pedal only has a sensor and a spring, so the resistance is the same in both directions. Therefore, even if the car accelerated at once, the car would decelerate immediately when the foot is lifted off the pedal. It was difficult to keep the pedal down at a certain point using the weight of the foot. These complaints also were pointed out. This was the inevitable problem not only for Prius but also for all cars that use an electronic throttle. If the electronic throttle sensor is placed all the way up by the engine and the pedal is connected to it by a wire, the feel would be the same as an ordinary car. However, it would 315 be costly. In order to achieve the feel of a mechanical wire connection, the control system was adjusted so that pedal resistance would differ between the two directions up or down. The issue was never perfected, and remains a point of needed improvement.

Make it quieter Another concern at the test drive event was vibration. Vibration during the starting and stopping phase of the engine was almost unnoticeable at this point, thanks to Variable Valve Timing with intelligence (VVT-i), electronic engine control, and the rubber buffers used for mounting the engine. Muramatsu, however, was asking for a higher level of performance. Engine, body, and other parts have particular resonance frequencies, which are usually between 300 and 400 revolutions per minute (RPM). When the engine rotates in this range, vibration increases by resonating with the chassis and body. When the engine is turned off its RPM always passes through this range. Resonance can be prevented by letting the engine RPM pass through this range as quickly as possible. If the engine stops while the car is moving, this resonance is usually unnoticeable. It is more noticeable when the engine starts. When the Prius engine is started by rotating the 316 crankshaft, resonance vibration occurs just like when an ordinary car starts its engine. Resonance can be minimized if engine rotation is increased quickly. Instead of using combustion inside the cylinders to start, the electric motor can be used. When the engine RPM reaches a certain level, the electronically controlled fuel injection system (EFI) injects fuel and the engine is started. Vibration is most strongly felt while the car is stopped and idling at a traffic light, for example. By completely stopping the engine when the car is stopped, Prius can best show off its characteristic quality. By designing the engine to stop when the car is not moving, unless the air conditioning is being used and by starting the engine only after the RPM reaches above the resonance frequency range, vibration was made less noticeable. However, stopping the engine during idling phases created a new problem. While noise in an ordinary car is not noticeable due to constant idling and acceleration noise, it becomes a noticeable problem in the case of Prius. This small amount of noise due to relay switch operations was minimized through increased use of insulation material. When noise is measured inside Prius, it is far less than in Corolla, but many, people are mislead into thinking that Prius is just as noisy as Corolla because of preconceived impressions. 317

Finishing with the brakes Final checks were done on the brakes. Brakes are a part of the special features of Prius. They are regenerative brakes that convert heat energy produced from the friction of braking into electric energy which is stored. Although Toyota had already used these brakes in RAV4EV, new units were developed for Prius. A regenerative brake works by combining a conventional hydraulic brake and an electric brake, which uses the motor as a generator while braking and stores the produced electricity in the battery. Making the whole process work smoothly was particularly difficult. The story goes back a little. Ogiso, who is in charge of hardware at G21, visited the Electric Vehicle Division to ask whether regenerative brakes could be used for the Prius. "Do you think we can use EV regenerative braking on the Prius?" "For RAV4EV, the battery cell is 450 kiloWatts. For Prius, it is maximum of 20 kiloWatts. An EV can suck up energy, but a hybrid vehicle cannot because it has to intricately control a small battery and efficiently use the regenerated energy." After several discussions, Ogiso decided to develop a new brake. The hybrid vehicle is different from an EV in the following fashion. With the hybrid vehicle, the 318 hydraulic brake starts to work as soon as the brake pedal is depressed, and the electric brake then kicks in. Since only the energy generated during the use of electric brakes can be regenerated as electric energy, the electric brake needs to be efficient. When a hybrid vehicle decelerates from 100 kilometers per hour, the hydraulic brake initially helps the deceleration, but the electric brake takes over as the speed drops. On the other hand, when braking at

30 kilometers per hour, the brake for Prius was designed so that the electric brake would operate immediately so as to increase regeneration. With a conventional EV, regeneration can occur only at the same level regardless of speed. Chassis Components Engineering Division II handled its development. In May 1995 when the management decided to develop Prius as a hybrid vehicle, Electric Vehicle Division was the only organization that worked on Prius. Electric Vehicle Division and Chassis Components Engineering Division II discussed together to establish a project team inside Chassis Components Engineering Division II consisting of engineers from both organizations. Since the monthly production volume of Prius was to be 1, 000 units, development of control computers and units needed a different structure from EVs whose production is low-scale. The Electric Vehicle Divisions joined Section General Manager Fujii and Staff Leader Harumi Ohori. Engineer 319 Shingo Urababa also joined the project. Chassis Components Engineering Division II sent Department General Manager Tatsuhiko Yoshimura, Section General Manager Yoichi Kato, and engineers Masahiko Kato and Akira Sakai. Young Sakai was named to supervise the group as the working leader. Electric Vehicle Division members mainly worked on RAV4EV, while Chassis Components Engineering Division II took charge of Prius. Through information exchange, parts and specifications were commonized to a high extent. In
1996, development of the brake for Prius was almost finished, but coordinating the operation of the electric and hydraulic brakes was a challenge. It was difficult to take into account and adjust to the driver's feel. To help the situation, Satoru Niwa of Chassis Components Engineering Division II moved to Electric Vehicle Division to study the control system, and supported the work of finishing the brake designs.

Evaluating the jolt When the work on the brake system was almost complete, Vehicle Development Center II General Manager Kubochi test-drove the car. Being a speed freak himself, Kubochi was happy with the strong brake, saying, "This brake works very well. It has a good feel." 320 However, the initial braking power is much stronger than on most Toyota cars. The brake worked abruptly with a jolt immediately after the pedal was pushed down. At this point, it would have been difficult to pump the brakes to achieve a more even operation. The group wanted to improve the feel while maintaining the performance. It was difficult, however, to perfect it due to the limitations of the regenerative brake. The same problem was noted at the media test drive event held in May 1997. To further evaluate the brake, women and young people from the company who seldom drove cars were also asked to test-drive. Eventually, all of them said it was not as annoying as they expected. The group judged that the brake was not too uncomfortable once they got used to it. There are two types of brakes in general: those that are operated by stroke (stepping length) and others that are operated by stepping force. Japanese cars are generally stroketype, while European cars are generally force-type. To be different, brakes for the Prius were designed to be similar to the force-type brakes. In addition, this style helped facilitate control between the hydraulic brakes and the regenerative brake. The brake was adjusted so as to release the increased braking power before coming to a full stop. Even during the test-drive event at Hakuba in Nagano Prefecture held after the presentation of Prius on October
321 14th 1997, the brakes received both good and bad comments. Uchiyamada ruled that nothing would be changed with the initial brakes. Uchiyamada instructed the production plant to minimize any extra fine tuning saying, "Don't do anything special to these test vehicles. Some of the journalists are probably going to buy Prius as family cars. Make sure that the performance of these cars is identical, so that potential buyers don't notice any difference." The regenerative braking is manufactured in the company, the oil pressure booster is supplied by Aisin, and the actuator unit is produced at the Hirose Plant. The brake feel was made a little less sensitive by intricate tuning. It was literally a final touch. In November, test drive events for the "RJC New Car of the Year" and "Japan Car of the Year" competitions were coming up. The production division did its best to provide the best car so that no complaints would be heard.

Preparing for every situation The car was significantly improved after the Product Audit Department criticized it harshly. However, it was still not a finished product, because anything can happen to cars when they are actually sold to the public. Solutions were prepared for every

contingency. Many situations that are easily resolved in 322 conventional cars would become interesting problems for Prius. For example, what might happen if a driver removes the key from the ignition while driving? With a manual transmission (MT) car, the driver would stop the car and restart the engine. With an automatic transmission (AT) car, the driver would shift to neutral and restart the engine. What then should be done with a hybrid vehicle? Anything was possible, since it was a matter of programming the computer control system. Considering safety and convenience, the group decided to program the control system so that the driver should do as he would do in an AT car. On an AT car, when the gear is in drive, the car continues to creep forward even when there is no pressure the gas pedal, as long as the brake is released. Although the THS structurally does not let the car creep forward, the group added that feature by letting the motor provide enough power to cause the car to creep forward, so that a driver would not feel uncomfortable when switching from an AT car. Opinions varied when it came to operating in reverse gear. Since Prius moves backwards very slowly, it uses the motor. The engine, naturally, would not kick in, so people around the car might not notice that the car is backing up. "What if the car has an alarm to sound like trucks do?" Someone suggested, but the idea was rejected. 323 One of the valuable characteristics of Prius is that it can run on its motor when
driving at low speed. If the driver drops the speed, Prius can enter a residential area at midnight without waking up the neighbors. However, if Prius were in reverse the "alarm" feature would sound when backing into a parking space, and thereby annoying the neighbors. "Since Prius is so new and different, the driver and the people around the car would probably use extra caution in the beginning. However, as the number and the variety of hybrid vehicles increase in the future, we will have to introduce some warning measures. That will require an understanding of society." Uchiyamada concluded. Prius now had a new topic to consider in the future: the spread of hybrid vehicles and its social impact.

Disarmed The final stage before commercialization is strenuous endurance testing. A 24-hour endurance drive was conducted at Higashifuji. Other cars are usually placed on a roller mill for testing endurance, but the group wanted to see if the driver felt anything different after driving many hours in the Prius. Drive performance deteriorates in winter when battery performance drops. Battery performance also drops in summer due to overheating. Those conditions 324 needed to be looked at closely. Cold-resistance tests were conducted in winter in 1996 and 1997 in Shibetsu and in Canada. In the summer of 1997, the car was shipped to New Zealand for another cold-resistance test on a farm. At the same time, another group installed the THS in a Corona and drove 4,000 kilometers from California to Nevada. Five engineers, including an engine expert, a THS expert, and mechanics, participated in the excursion, and rode in one car. The hardest experience of all was the five-day journey, travelling
3,000 kilometers in the 45degree (Celsius) weather. Fortunately, there were no problems. While the five members felt confident with the car, they also felt disarmed, because they had expected some problems to come up. The battery, the cause of great concem just a few months ago, was finally complete, and Muramatsu was overcome with emotion. More than 100 batteries had been used on test vehicles. Once they were installed in the Prius, the rear seats had to be removed to set the batteries out every time it discharged or had other problems. The batteries, then would be sent back to Panasonic EV Energy for inspection.

When Prius is driven for a long time in conditions that causes stress on the battery, a turtle- shaped indicator lights up in the Center Meter gauge that shows battery charge volume. It means that the driver must 325 drive as slowly as a turtle, because the battery is empty and the car is powered by the engine. Muramatsu suggested a silly idea. "Why don't we first have the whole turtle as a warning, and then have a turtle without hands or feet to show that the battery is empty, that the turtle is finished and can't do anything about it?" "Muramatsu-san, this turtle indicator is not a joke. It is the uniform standard for our eco-friendly car. I'm sorry, but we can't do that." The idea was flatly rejected. This time, it was Muramatsu that was finished. 326

Chapter 12 Human Network - Production

After mass production was approved at the September 1996 Design Review, the company suddenly became busy. The production division started to prepare in full scale. The Power Train & Chassis Components Production Engineering Division that test-produces components such as transmission, began discussing who would be building which part. In particular, the Toyota Hybrid System (THS), which is the heart of Prius, was to be mass-produced for the first time. Selecting the plant was an important task. Six months prior, in March 1996, the company was expecting the monthly production volume to be at most around 200 units. Due to the relatively low quantity, the department members somehow agreed that the prototype plant at Toyota Honsha would be suitable. The department had also begun working on how to increase the output based on the manufacturing method at the prototype plant. However, when the members contacted the Member of the Board in charge of production with this method, the situation turned out to be different. "The monthly production will be 1,000 units instead of 200." This was a request of the sales division, not the 327 production division. The sales people said that monthly sales of 200 would be suitable only for specialized products, and would not produce enough impact as a mass-production model. The production division now had to change their plans. At
1,000 units per month, the production could no longer be based on the same method for prototype building. The task had to be transferred from the Power Train & Chassis Components Production Engineering Division, which specializes in prototype building, to the Machine & Tools Engineering Division, which is the actual production team. The two Power Train & Chassis Components Production Engineering Division engineers, who had been doing advance work for production, were transferred to Machine & Tools Engineering Division, and the production preparation was restarted. It was impossible for this volume to be manufactured in a plant as small as the prototype plant, so the two visited the General Manager of the Machines Division at Honsha Plant to ask for production facilities. However, the two failed to get a favorable response. An idea to reestablish the Honsha Plant, the oldest plant at Toyota, was just being considered at the time. The plant was built in the pre-WWII period, and was producing chassis and drivetrains for small trucks. The idea was to scrap this plant and rebuild it into a two-story structure. 328 If the plant were to be taken down to start building a new structure, the company would lose its capability to build small truck chassis and suspension. The plan, therefore, was to continue production while building the new plant. The process of moving production equipment during construction was as complicated as a puzzle. Since the complicated scenario had been laid out already, the supervisor was reluctant to build the component for Prius.

Restoring Honsha Plant The engineers on duty from the Power Train & Chassis Components Production Engineering Division and the Machine & Tools Engineering Division met again. They looked to see which plants were open to build components. Kinuura (Hekinan City, Aichi Prefecture) and Tahara Plants were mentioned, but both were more than one hour away from the head office. "We stopped building new components at the Honsha Plant a long time ago. In the past, many functional parts such as Landcruiser engines were produced here, but the plant today only makes simple parts such as differentials and frames. Crucial functional parts are all built at Kamigo, Tahara, or Kinuura. Is this right for our plant?" It was Chief Engineer Tagami of Power Train & Chassis Components Production Engineering Division that posed 329 the question. Tagami wanted to produce the parts at the Honsha Plant for two reasons. First, he could not stand the fact that his home plant had not been producing any significant functional parts in the past several years. The production capability of the Honsha Plant would be lost if this continued. He felt the Motomachi Plant, which is nicknamed
"Motomachi of *Takumi* (artisans)," needed a little competition with the Tahara Plant, whose slogan is "Number One in Manufacturing." Second, as the Honsha Plant was located only a short distance from the design and production technology divisions, he wanted to set up a production line close enough so that design engineers could come to supervise as necessary. In the Head Office district, technology division sits on the East Side of Highway 248 and the Honsha Plant sits on the West Side. The Electric Vehicle Division and BRVF are situated in a building along Highway 248, so that the engineers can reach the production line, which is two buildings away, by exiting the gate and walking through an underground pass. The short distance helps problems to be solved promptly. Of all Toyota's plants, the Honsha Plant was the only place that the design engineers could get to quickly. "We should try to put

the line at the Honsha Plant." Production engineers such as Tagami continued to feel the same way, so they visited Director Yasuhito Yamauchi, 330 General Manager of Honsha Plant, to make a direct request. "Honsha is the best location to make good parts. We implore you to let us produce the new motor for the 21st century at the Honsha Plant," Tagami explained. "We understand. You have a good point. The unit should be manufactured at a location close to the production technology and design divisions. Considering the future, we would also like to manufacture components at the Honsha Plant. However, since we are very busy right now, I will tell the people to work carefully." Yamauchi agreed with Tagami and his staff in principle. Now, Tagami had to negotiate with the Honsha Plant Machines Division. Tagami visited the Machines Division General Manager again, discussed the issue, and asked him to redraw the production line plan. Tagami could get only a very small space, so the production line for his department's parts had to be separated onto the two floors, but a line for producing 1,000 units was somehow secured. The Machine & Tools Engineering Division handled the actual work. In addition, the production technology team acquired a room in the plant for production preparation so that the engineers on duty could be stationed there. This helped facilitate communication and prepare for production within a short time. If it had not been for the Honsha Plant, many problems could have come up. Production 331 technology division made the right decision by insisting on the Honsha Plant.

Engine production was assigned to Kamigo Plant. This plant has a mid-size, medium-scale production line that is capable of monthly cross-manufacturing 1,000 to 3,000 units of several types of engines, such as the V12 engine for Toyota's top luxury car, the Century. This line was naturally selected for manufacturing 1,000 to 2,000 engines for the Prius. The cylinder block was made on an exclusive line, but the cam, crankshaft, and cylinder head were made on a general production line. The Prius engine was to be assembled on the same line as the V12 engine.

Nightmare after nightmare New Year's of 1997 was the beginning of a series of troubles for Toyota. Since December of the previous year President Masaru Tomita of Toyota Peru, the local sales arm, was still being held hostage with many others at the Japanese Embassy in Peru. Consequently while the hostage situation remained unresolved (the hostages were released near the end of April), affiliated departments had no time to enjoy their New Year holidays. Then, on the evening of January 24th, Toyota's corporate helicopter that left Higashifuji Technical Center 332 for Motomachi Plant in Toyota City lost radio contact and by midnight accurate information on the helicopter's status was still hard to come by. At the end of a strenuous search effort, concluded the next morning, the helicopter was found. It had crashed in the mountains of Okazaki City, Aichi Prefecture. Six engineers were victims of the crash: Vehicle Evaluation & Engineering Division III General Manager Hisao Hara, staff Ken Iwashita, Starlet Chief Engineer at Vehicle Development Center II Masaji Sakamoto, Planning Division II staff Aya Yanase, Power Train Engineering Division III Koji Oshima, and Masahito Ninomiya in charge of THS cold start fell victim to this crash. There was a third nightmare. Just one week later, in the early morning of February 1st, a fire broke out at the Kariya 1st Plant (Kariya City, Aichi Prefecture) of Aisin, a key parts manufacturer of the Toyota Group. Fortunately there were no victims, but the plant was completely destroyed. As a result, Toyota's production lines almost completely stopped for five days. The fire affected the production of 80,000 cars over the next three months. The Kariya 1st Plant mainly produced a brake part called a proportioning valve (P-valve). The valve, which partitions oil pressure to both front and rear brakes, was supplied to most Toyota models, save Starlet and Celsior, as well as to some Mitsubishi models. 333 By principle, Toyota minimizes risk by purchasing parts from at least two suppliers or at least two plants of a supplier. Every time there are accidents or natural disasters such as the Nihonzaka Tunnel fire on Tomei Expressway and the Hanshin Earthquake, Toyota thoroughly reviews its risk management in parts purchasing. Although Toyota's risk management was adequate, as is the practice, parts manufacturing is diversified, so rather than relying on a single supplier, Toyota relied on many. By doing so, parts are extremely cost effective, as some manufacturers have specialized in their production for many years and have succeeded in reducing cost by mass production using proprietary machinery. Since other companies cannot join the market and earn profits successfully, certain companies have made such parts exclusively. The P-valve was one such part, because tolerance and processing precision to thousandths of a millimeter is required. Aisin had streamlined, and consolidated its production to the Kariya 1st Plant. Toyota immediately set up a countermeasure committee led by the production technology division, and began an investigation. The P-valve requires intricate processing using special machinery. In order to process the same part using general-use machinery, Toyota needed high-precision machinery and talented personnel. Toyota looked for alternative production facilities at various departments within the company and other group 334 companies, but soon decided that that was not enough. Toyota further contacted suppliers of other auto makers, independent parts suppliers, and non-auto metal processing companies. At the same time, another group was dispatched to Aisin's Handa Plant (Handa City, Aichi Prefecture) to quickly set up an emergency line using general machinery, and to refurbish the special machinery that had been partially damaged by the fire. Toyota unsparingly injected manpower and supported Aisin's effort to restore 80% of the necessary production of P-valves in just a few weeks. Quickly after the fire, Toyota took note of every plant that might be capable of manufacturing the P-valves. Frontline base teams were established in Machine & Tools Engineering Division and the Machines Division of Teiho Plant. For the first several days, the teams worked on preparing to produce P-valves. When the P-valve supply was reestablished, the teams took charge of keeping track of the production volume every day. The Power Train & Chassis Components Production Engineering Division that builds prototype parts units also owns many general-use manufacturing machinery. This department was mobilized to use all its machinery for producing P-valves, and the production of prototypes was temporarily stopped. Since Power Train & Chassis Components Production Engineering Division had to stop building prototype parts temporarily, test cars and test units could not be 335 manufactured during that time, and the development schedule was directly affected. However, most new cars ran on engines alone, and the project group had enough knowhow from past experiences. Also, every engineer thought that a little delay in prototype building could be overcome thanks to Toyota's development skills. However, the situation was different for development code "890T," or the hybrid vehicle Prius, which had been selected as a toppriority project.

Combination of machine and people Ever since the Power Train & Chassis Components Production Engineering Division had begun trial production of the P-valves, Chief Engineer Tagami realized that a machine was left unused in the department. A P-valve has an extremely small opening which needs to be polished on the inside. The process requires extremely high precision (onethousandths of a millimeter). Since only a few machines can handle the difficult task, not all machines in the plant are in use all the time. Tagami, who was concerned that the prototype parts for Prius would be delayed, looked around the plant and decided that some prototypes for Prius could be made using the machines that were idle. Although Prius was given top priority in the company, there was very little time. Just one delay could wreck the 336 whole schedule. When a prototype part is delayed, it cannot be included in a test vehicle. Naturally, no evaluation can be made, and the delay in prototype building affects the whole development schedule. That is why Tagami was anxious to do as much as he could despite the emergency situation. His superiors instructed him to put priority on making the P-valves, but he found some available machines. Finding the people to operate the machines would be more difficult. The P-valve processing was conducted in two shifts with the first shift going from early morning to the evening and the second shift spanning from the evening to 1:00 a.m., with third shifters coming in as needed. The three-shift schedule was not a typical schedule of three equal shifts over the course of the 24-hour period. This department had a little over 400 technicians, with half of them taking the first shift, and the other half taking the second shift. In more favorable circumstances, Tagami wanted to have 100 people on P-valves and another 100 on regular tasks. However, the machines were run with priority on production of the P-valves, some people would have nothing to do at times. By efficiently combining free people and open machines, it would be possible to build prototype units for Prius. "Okay, the rest is up to our human network." After observing the department for a few days, Tagami noticed 337 that the work was becoming a little more comfortable. Tagami made a suggestion to the department. "If we use the open machines with some free people, we should be able to start making the 890T prototypes. What do you all think?" "You mean the Prius parts? Actually, we were a little worried about that also. We'd be happy to do it." Tagami was deeply moved by the young technician's reply. Nobody disagreed. The next day, Tagami checked for the necessary machines for building the prototypes and for the occupation rate of the machines used for the P-valves. Tagami contacted Yoshihito Kato, Member of the Board in charge of Power Train & Chassis Components Production Engineering. Kato was also acting as the Machine & Tools Engineering Division General Manager that supervises machine processing, and had been stationed at Aisin with the Machine & Tools Engineering Division staff since the fire. He had been directing operations on the frontline team. Kato, who has a demeanor of an academic, listened to Tagami's story and said, "Okay, I will take responsibility. However, make sure that you don't take things too far." Thus, unit prototype building for Prius was restarted. While all other projects were delayed at least by one month, Prius managed to stay on schedule. 338

The decision to double production Production preparation for parts and body continued, with plans to produce 1,000 units per month. In November 1997, immediately before launch, the idea to double the production of Prius came up. As information on Prius reached the media, expectations began to run high. Automotive magazines reported test-drive events in detail, and dealerships received many questions. Based on all that information, the monthly production rate of 1,000 units did not seem to be enough. However, the sales division was cautious. Naturally, people would be interested in a car with a brand-new system, but would that mean more sales? Prius would inevitably be more expensive than conventional cars. If early buyers start saying after the introduction that the hybrid vehicle did not perform as well as expected, consumers would be swayed by such comments. Despite the pressure, the sales division did not request the production division to increase output. Executive Vice President Takahashi in charge of production thought about it. Takahashi was responsible for ultimately deciding the production capacity. If there is a request to increase production to 2,000 units after the launch of Prius in December, increased production would be possible only after the summer vacation in 1998. After the orders are placed to obtain additional facilities for the increased production line, production preparation 339 takes six months. Moreover, long vacations such as the New Year's, *Golden Week,* and *Bon* holidays are the only times that the production lines could be modified for additional capacity. Therefore, production could not be increased promptly enough if the request was made after launch. The Production Technology Division calculated the necessary lead time for construction during the holidays in May, and collected as much information as possible. At the end of November 1997, Takahashi finally made the decision to increase production. Although the sales division still had not made the request, the production technology division assumed the liability for facility investment. "If we do not invest now, customers might suffer from having to wait months for Prius to arrive. Moreover, we may involuntarily ruin the opportunity for the arrival of the new hybrid era." Takahashi made his resolution. Prius was the brainchild of Honorary Chairman Eiji Toyoda, and it was propelled forward by Chairman Shoichiro Toyoda. Later President Hiroshi Okuda made the decision to move up the introduction date earlier. The success of the project would determine Toyota's future. Takahashi affirmed everything positively. Tagami of the Power Train & Chassis Components Production Engineering Division was impressed with Takahashi's determination and guts. Regarding other key components, Miyoshi Plant 340 (Miyoshi-cho, Aichi Prefecture) was selected to produce the newly developed electric power steering, because the Miyoshi Plant had experience in producing the oil pressure-type power steering. Motor production was assigned to the Honsha Plant. As for the inverter, the Hirose Plant was put in charge of assembling the inverter, including the IGBT unit, and shipping it
to the Takaoka Plant. Panasonic EV Energy was put exclusively in charge of producing the battery. Each plant was preparing for production. The initial production of Prius would be 1,000 units, and would be doubled by May 1998, six months later. Each plant needed to establish an organization that anticipated the production increase. If one plant failed to produce on time, the car could not be finished. In reality, each plant was having a difficult time preparing to meet the monthly production volume of
1,000 units, and had no time to think six months ahead. "If we fail, we will ruin our reputation forever. We can't afford to fall behind." After New Year's, each division furiously began preparing for increased production. 341

Chapter 13 Superb Technical Presentation - ECO Project At the end of 1996, Toyota launched the "Toyota ECO Project," an environmental project led by the Public Affairs Division. With this project, Toyota proudly announced its views on the environment, past environmental actions and measures, and its position in social enlightenment activities. Toyota has been known to be an extremely cautious company, and has held on to the principle of "action before words" on environmental issues. For example, when auto scrapping first received attention as a pollution issue in the 70s in Europe, Toyota in 1970 had already established Toyota Metal Scrap (also called Toyota Metal), a company involved in recycling scrapped autos and had begun working on this problem as a corporate effort. Also in 1970 the United States established a series of regulations under the Air Pollution Prevention Law, more commonly known as the "Muskie Act" in response to severe air pollution in the Los Angeles area and greater southern California. At about the same time, Japan also introduced similar emissions regulations. Toyota made a consolidated effort in research for a low- emissions system, 342 and was manufacturing units at the newly constructed Shimoyama Plant
(Miyoshi-cho, Aichi Prefecture). By improving all models to meet the new U.S. regulations, Toyota managed to get ahead of American auto makers in the critical field of emissions control. Eiji Toyoda however, who was President at the time, constantly took a low key, reserved approach by saying "Our emission technology is still under testing and has durability problems; there will be a few more years before it can be sent to the market." As a result, the public felt that Toyota was out of step with society's concern over the environment. As an engineer, Eiji Toyoda felt that something technologically incomplete should not be presented. The company's position of respecting "action before words" was seriously misunderstood at the time. In the United States, when a car's fuel economy fails to meet a certain level, the car is levied a gas-guzzler tax. Toyota had been making steady efforts in improving
the fuel economy of cars. As Executive Vice President Wada boasts, "Toyota cars have never been the subject of gasguzzler taxes, because even the larger-size models have exceptional fuel economy." The "Toyota Earth Charter" was founded in 1992. This was a specific acti on index of Toyota's social contribution and environmental preservation efforts in every stage of business from design, production, and sales to disposal. These efforts were purely internal, however, and beyond what was absolutely necessary, Toyota never 343 informed others of its environmental efforts. As global auto makers entered an era of megacompetition just before the 21st century, President Okuda decided to actively project Toyota's environmental efforts and position to the public. Today, the auto industry is starting to develop into new areas, such as environment, safety, and communications (ITS). Competition has just begun. The company that succeeds in establishing the standard technology before others will secure its position in the future. On the contrary, if other companies control the core technology even a large auto maker may weaken and become just a huge assembler. "Rather than just discussing the
environment, we must present an ideal model that is sustainable into the future. It is important to clearly spell out efforts and specify needed actions for the environment even if Toyota alone cannot achieve it." Okuda set the direction and actively promoted the ECO Project. In the past, Toyota manufactured superior goods but did so quietly. Now, Toyota's attitude has become more open. It presents to the public what it can and must do as a corporation, and it communicates with consumers and regular citizens in order to consider and do what is necessary for society's welfare. The ECO Project that started with the slogan - "Act Today For Tomorrow" - is different from Toyota's environmental efforts of the past. Efforts are carried out more visibly through development of low-emission 344 vehicles, renovation of manufacturing plants, and construction of recycling plants. Toyota selected the reduction of carbon dioxide (CO_2), a greenhouse gas, as its most important issue. Toyota announced not only that the fuel economy of existing gasoline engines would be improved, but also that it would take a multifaceted approach by elevating the technology of various power sources used in EV, natural gas vehicles, and diesel engines. The hybrid scenario created for the development of Prius was the very answer to these issues.

Declaring war At the end of December 1996 when the first advertisement was run in newspapers, presenting the concept of the ECO Project, Okuda summoned Wada. "Wada-kun, as the flagship of our ECO Project, I would like to announce the hybrid technology of Prius before the car's launch. Does

March sound good to you?" "Mr. Okuda, we will end up doi ng more than just announcing the technology. The media would naturally ask when it would hit the market. Would we be able to tell them when it would be launched?" "We'll just have to tell them it would be by the end of the year." 345 "But if it should ever be later than that, our reputation would be seriously damaged." Wada carefully selected his words to persuade Okuda to reconsider. However, Okuda was determined to announce the technology in March. Nobody could object. Okuda had the confidence and the calculation that the project needed the extra boost to create the final a momentum to rush across the goal line. He was betting on Toyota's signature ability of mobilizing exceptional concentration of effort. "If we announce the hybrid system now, we will attract the attention of people all over the world. Other auto makers of the world will be curious if we can really mass produce it, sell it in an affordable price range, and achieve extraordinary fuel efficiency. If we set the stage and introduce the cars at once in December, we can without a doubt set the global standard for hybrid vehicles." For Okuda, who believed that environment, safety and information technology would determine the auto industry in the 21st century and that an auto maker without environmental technology would eventually be taken over, presentation of the THS was declaration of a major challenge to the world. Okuda felt that way because he was a manager who had experienced many adverse situations. Even if all the technology executives had objected, Okuda would have stuck to his idea. In contrast, if Okuda had been an 346 engineer, he would not have made the same decision. As mentioned earlier, the launch date for Prius was moved up a year from the end of 1998 to the end of 1997, due to the strong beliefs of Okuda and Shoichiro Toyoda. However, this decision was kept confidential within the company. Although Wada had agreed to the new policy to launch a year earlier, he was not totally confident that it could be done after witnessing the actual development progress and particularly the delay in the development of battery
and inverter (IGBT). BR-VF's Yaegashi had also asked Wada, "If there ever should be problems at line-off, we would like you to delay the launch date." Wada had agreed to it by saying, "Since it is an entirely new car, there will not be a problem in terms of sales if the launch is delayed. If you really can't do it, we won't force it." However, the situation would completely change if THS were to be announced in March. The launch date of the end of 1997 had only been an internal decision. If the launch date were publicly announced, it would become a social responsibility to make that happen. Wada called Uchiyamada and Yaegashi the following day, and told them that the THS would be announced in March. The two objected by saying, "We don't think it's possible yet. We don't even have the actual fuel economy figure." However, there was no way of reversing Okuda's decision. 347

On January 7th 1997, the President gave the annual New Year's address. Okuda first referred to the fact that Toyota failed to achieve the domestic market share target of 40% in the preceding year, and appealed to the workers. "Let's find out why we failed to achieve the target, and try again this year." He continued, "We have announced that we are at our second founding. We are standing at a major crossroads of whether we can succeed in the 21st century or not. This is our sixtieth year. Sixty years ago, we were a venture business that courageously entered the automotive sector. We continued to overcome one obstacle after another. By learning from the youthful zeal and executive ability of our forerunners, we must achieve structural reform in various fields." The President's official decision already had been made, and there was no way of turning back. Uchiyamada, Yaegashi, and everyone involved in Prius made their resolution. While continuing the development in a hurry with the target to launch within the year, the group also began working on documentation for the technical presentation. "Uchiyamada-san, do we have to have the fuel economy in figures?" "Even if we didn't, we would be asked. In that case, we can tell them that it is twice as efficient (28 kilometers per liter), since it has been the initial target for Prius." The development team was reluctant to have an actual 348 figure, because it would be final. They had not yet succeeded in meeting the target. The figure was based on completing all units according to design. However, a figure any lower, such as 25 kilometers or 26 kilometers, would have less impact and undermine the fuelefficient image of the car. Some European auto makers already have diesel engines with a similar fuel economy. The two discussed the matter with engine specialists Shinichi Abe and Shoichi Sasaki, and settled on 28 kilometers.

Persistence and confidence On March 25th, the technical presentation for the Toyota Hybrid System was held at Capital Tokyo Hotel in Akasaka, Tokyo. It is rare for Toyota to make a grand presentation of technology alone. Since the fall of the previous year, some keen-eared reporters in charge of covering Toyota had acquired information that Toyota was developing a hybrid vehicle and began to keep watch on executives in charge of development at night by their homes. This had been reported in some newspapers, but every reporter was surprised that Toyota would announce only the technology. The rule of the auto industry is to keep information on new products confidential until the launch day. Even a slight leakage of the price to a competing company can 349 cause serious damage. Moreover, Toyota was announcing the core structure of the hybrid system. When informed of the THS presentation, some seasoned reporters saw it as an embodiment of Toyota's persistence and confidence towards this technology.

Okuda began with a speech. "Toyota has developed a hybrid system that is an answer to the environmental problems of the 21st century. It achieves a fuel economy that is twice that of conventional cars of the same class, emitting half as much CO_2. It also achieves reduction of CO (carbon monoxide), HC (hydrocarbons), and NO_X, (nitrous oxides) included in the other emissions to one-tenth of the current legal requirement. We would like to launch this car within this year." Drawings showing the THS model design under development at the time and its theory were exhibited in the hall. G21 members, BR-VF members, THS design engineers, and Yaegashi gave explanations. Some reporters were hearing the word "hybrid" for the first time, and were asking questions that were off the point. As they answered each question thoroughly, development team members who had participated as lecturers could sense the deep interest of the reporters. Reporters at the presentation hall surrounded Wada.
The questions were what he had already expected. "How much will these hybrid vehicles cost consumers?" 350 "Well, it will depend on how many vehicles we produce. It is hard to say." "You must have a ballpark figure." "Well, let's say about 20% higher than others of the same class, so that people will find the price acceptable." "Then, it would be 500,000 yen higher than others." "Something like that." The next day, newspapers reported the THS on the front page or at the top of the business page. Every newspaper reported, "The price will be around 500,000 yen higher than Corolla that is of the same class." Wada smiled in glee. In fact, he had thought that the upper price limit for consumers would be 300,000 yen above other cars, and had thought of launching Prius at that price. The media assumed that it would be 500,000 yen higher at 2.4 to 2.5 million yen, but the actual price might be more than 200,000 lower. The impact at launch would be even greater with the price advantage. Wada was chuckling to himself. "If that reporter had asked me again, I was planning to give him the actual figure." Meanwhile, the development team was shocked to see the newspaper coverage. They had expected it, but there now was truly no way to back out. Fuel economy, price, launch date - they were all in the article. Launching Prius within the year suddenly became a public commitment. Okuda and Wada had shoved them into 351 the attic, and had removed the escape ladder. They were on their own. Shinichi Abe, who had joked, "For us to actually do that would be an accident," was trembling in fear at the gravity of the commitment. Yaegashi was surprised at the amount of impact on the foreign media. The American media, in particular, reported the event in greater detail than the Japanese media. The United States has been hard on emissions but easy on fuel economy and CO_2. That had not changed from the first days of the Muskie Act, with which Yaegashi was involved. With their attention on THS that emphasizes fuel economy, Yaegashi felt as if it was another challenge from the United States.

On July 9th, Okuda stood at the podium to give an opening speech for the "Toyota Environmental Forum" held at the Tokyo Waterfront. He spoke of Toyota's extraordinary commitment. "Humans vested their dreams on automobiles in the 20th century. For the automobile to sustain its position as a useful tool in the 21st century, the auto industry itself must lead society by making environmental efforts. Toyota will position preservation of the global environment as the top priority issue, and will allocate all necessary resources in our commitment. This forum was a part of the "Toyota ECO Project" and showcased the company's environmental commitment. 352 Four hundred guests consisting of university professors, journalists, and environmental experts were invited to the event. Toyota's progress in environmental technology, its policies and future plans were announced. By making this announcement to the experts, Toyota reinforced its determination to emphasize R&D on the environment regardless of market trends. Yaegashi was also at this forum to explain THS in more detail than at the March presentation by demonstrating the planetary gear used in the power split device. Now, not only the auto industry but also environmental experts were looking forward to the arrival of Prius. 353

Chapter 14 The Big 3's Chill - Tokyo, Kyoto and Detroit

In the summer of 1997, Takaoka Plant was in the midst of final coordination prior to the fall line-off. Oi began to commute more frequently to Takaoka Plant as General Manager of RE in place of the two reverse-REs (resident engineers). Of course, Chief Engineer Uchiyamada, Ogiso and Ishida of G21 (Zi), and Muramatsu of the Product Audit Department were traveling back and forth to the Takaoka Plant and to the Head Office as well. As well as checking on every point raised by the Product Audit Department, the staff had to solve every problem that came up in production. Usually, with new models, the car is presented to the public after production has been under way for one to two months. Therefore, at the time of the presentation, the car is 100% ready for launch. Although Prius was to be launched in December, the press conference for its official presentation was held in October, two months prior to the launch, for a particular reason. "Okay people, our goal is not December, it's October instead. Prepare to go into production in September." 354 Line workers were urged to work faster to finish the *tsukurikomi.* However, development of some key parts, such as battery, was not finished at this time. In fact, development engineers were still working through problems even after Prius was presented. They made risky attempts until the very end. There was a reason why Prius was presented in October. In the Japanese auto industry, there are two competitions "Japan Car of the Year" and "RJC New Car of the Year." Those winners are selected by automotive journalists and critics from among the new cars and new models introduced that year. One criterion for inclusion in the contest is that the model must be presented by October of the year in question. In fact, when President Okuda ordered in December
1995 to move the launch date of Prius by a year, he also issued another order. "Enter to win Japan Car of the Year, RJC New Car of the Year, and all other possible awards." This order stayed in the minds of Uchiyamada, Oi, Yaegashi, and all others involved in the development of Prius. In the beginning, the order was considered just more pressure from above. However, as Prius began to take shape, they strongly believed that they were actually building something that deserved such awards. Naturally, they needed to build the best product of the year to receive the award. However, their efforts it would be useless if they could not present the car on time. That 355 was why it was imperative that Prius be officially presented in October.

One surprise after another

There was nervousness and excitement at the ANA Hotel in Roppongi, Tokyo. The Prius finally was to be revealed to the press. Many press members wanted to attend, and the presentation conference was held three times instead of the usual two. The first presentation was for newspapers and TV stations, and the second and third presentations were for magazines and independent journalists. The latter presentations were attended by more than 1,000 people, and even the largest banquet hall, "Phoenix Room," could not accommodate that many people. Toyota's public relations staff had never experienced such a huge response to a new car presentation. After the technical presentation of THS in March, Prius became a sensation and eventually a social phenomenon. Journalists not only from Japan but also from America, Europe, Asia, and other parts of the world came to see Prius.

The first presentation was attended by seven Toyota executives: President Okuda, Executive Vice Presidents Wada and Kosuke Yamamoto, Senior Managing 356 Director Fujio Cho, Managing Director Susumu Uchikawa (now Kanto Auto Works President), and Member of the Boards Hiroyuki Watanabe and Kamio. Okuda addressed the audience with power and confidence. "After thorough preparations, Toyota presents today the hybrid vehicle Prius. This is a car that has dramatically reduced environmental impact in time for the coming of the 21st century, in which the environment will become a global issue. Prius was born from a challenge to innovate." Wada in charge of development followed with a summary of the car. He announced that the price would be 2.15 million yen, and 2.75 million yen with a car navigation package. There was a small stirring in the hall. When THS was presented in March, Wada commented to reporters that the public might not buy Prius if it cost 500,000 yen more than the Corolla. However, some people estimated that Toyota might not really sell at this price range. They thought, "RAV4EV retail price is 4.95 million yen. Could the cost of Prius be close to 5 million yen? Can Toyota really sell such a car for just 2 million yen?" Nevertheless, Toyota actually launched

Prius at the price range that Wada had mentioned in March. After explaining the specifications of the car, Toyota answered questions raised from the media. The first question was about the price. 357 "It seems that the 2.15 million-yen retail price is extremely inexpensive. Is Toyota heavily subsidizing the car?" "It is true that we are subsidizing, but we decided to first set an acceptable price. We think that the price is reasonable. We can make enough profit in the future if we sell in larger quantities and lower cost." Okuda acknowledged that it was a strategic pricing. Another reporter asked Okuda after the press conference. "When will you start making profit?" "It is hard to say, but it should be fairly soon. Even if we sold in larger volume, we still should try to change manufacturing process, though." Okuda replied, leaving the reporter thinking that Okuda meant the next generation Prius. In the second presentation for magazines and other media, the press conference area and location where the car was actually displayed were separated into adjacent rooms. When the speeches were finished, Okuda, Wada, and Uchiyamada stood up and got into the Prius. Uchiyamada took the driver's seat, Wada sat in the passenger seat, and Okuda sat in the rear seat. The famously spacious cabin was comfortable enough for Okuda who is 6 feet tall. Uchiyamada turned the ignition key. The engine turned on, but only for a moment, and the car was ready to go. Prius rolled from the press conference area into the center of the showing area in the next room in EV mode. The distance was 358 about 30 meters. There was no exhaust and almost no noise. Uchiyamada solemnly drove the car on the thick plush carpet, with Okuda and Wada. The journalists in the hall were astounded by the unprecedented driving demonstration inside a hotel. They then fully realized that Prius was a genuine hybrid vehicle. Even experienced automotive journalists were amazed by the novelty. The performance was a great success. Prius took shape after it was initiated by Eiji Toyoda's fear of stagnation against manufacturing practices during the bubble-economy days. Eiji, who had in essence given life to the car, also came to the hall after the press conference. He had occasionally appeared at new car presentations in Nagoya, but had not visited Tokyo for a quite a while. He wanted to witness the release of Prius to the world.

On sacred ground The same day, the Commorative Museum of Industrial Technology in Nishi-Ward Noritake Shinmachi by Nagoya Station was overflowing with media people. It was the Prius presentation for the Nagoya region. This hall was built in June 1994 commemorating the centennial of the birth of Kiichiro Toyoda, the founder of Toyota Motor. 359 "It was established using the site and building of a testing plant founded by Sakichi Toyoda in the 44th year of the Meiji Era (1911) for research and development of automatic loom works, in order to hand down to the next generation the importance of the spirit of manufacturing, creation, and research." Eiji Toyoda had once said that the Commorative Museum of Industrial Technology built inside the old red brick plant is sacred for the Toyota Group. Although most of Toyota's new car presentations in the Nagoya region are held at Toyota's Nagoya Office, there had been two occasions in the past when this memorial hall was used. They were the times when Crown was introduced in August 1995 and the time when sibling models Mark II, Cresta and Chaser were introduced in September 1996. They are all mass produced luxury vehicles that represent Toyota. Prius was the first brand new model that was presented in this hall, and therefore, was an indication of expectations for this car. After Prius, the Vitz model developed by Shuhei Toyoda was presented there in January 1999. That day, most TV stations included the event in their news programs, and many general newspapers printed it on the front page. It was extremely unusual for a new product of a private corporation to be treated in such a fashion. The following week, automotive magazines, business magazines, weekly general magazines as well as 360 publications that seldom feature automotive news, such as women's magazines, sports magazines, and weekly comic magazines covered the official presentation of Prius extensively. Immediately after the presentation, a large-scale test drive event was scheduled for automotive journalists, general media, and foreign media at Hakuba Village in Nagano Prefecture that was being prepared for the Winter Olympics. The Tokyo Motor Show was starting from October 22nd. In December, events such as the Kyoto Summit on Global Warming (COP3) and the 14th Electric Vehicle Symposium (EVS14) at Orlando, Florida were taking place. Prius had to be prepared in optimal shape for these events.

Although product planning members, such as Oi, Ogiso, and Ishida, joined the Prius presentation as speakers, they had no time to enjoy the excitement and had to return to the plant the following day. Oi stared at his schedule completely filled up until the launch date, and spent every day under a great deal of stress. Line-off is the start of mass production of a new model. For several months before line-off, mass-production tests are conducted by producing several cars using the actual assembly lines and facilities as if real production were underway to check for problems. A mass-production test car was used for the new car presentation. At this point, Prius still had some 361 problems, and some processes were not going to be ready in time for line-off. One of them was the instrument panel. **Getting the grained finish** Interior parts, such as the instrument panel are finished to resemble grain leather by creating fine, bumpy pattern on the surface. This is called grain finish, and is achieved by creating such patterns in the mold and then injecting resin into the mold. This finish produces a luxurious feel, so Prius was designed with grained finish instrument panel. However, in the mass- production test stages, grain finish parts are not used. This is because the assembly of resin parts requires high-precision fitting so that engine vibration will not cause them to rub against each other and creak. Once the grain finish is cut into the mold, the mold can no longer be modified. That is why the mold is checked to see if the different parts fit together, then fixed so the parts fit perfectly during the massproduction test, before finally adding the grain finish to the mold. Since there was not enough time, however, the massproduction test vehicles were used for the October test drive event, but those cars did not have the grain finish on the interior resin parts. 362 It was an unacceptable situation from the productplanning standpoint. Journalists actually drive the Prius for many hours during the test-drive event. Their impressions and views would be expressed in newspapers and magazines, and an early evaluation of Prius would be established. Once someone writes "the interior looks cheap," no matter how many improvements are made on the cars before the actual sale, the image of a cheap car will never disappear. Most consumers automatically tend to think that the interior is cheap even after seeing the luxurious grainfinish interior if they have been exposed previously to the wrong information. An incomplete product should never be used in a special occasion like a test-drive event. However, for the people at Takaoka Plant Quality Control Department, which is in charge of ensuring quality, adding the grain finish in the mass-production test stage was unthinkable. It was too risky. If the mold had to be created from zero once again, the date for the test-drive event and even the introduction might have to be delayed in a worst case scenario. Oi told the Quality Control Department, "This is a car that will be launched as Toyota's number one project. It may be a car that augurs or even shoulders the responsibility for Toyota in the 21st century. We can't possibly present an incomplete car for the event, because that is an occasion for Prius to receive its first 363 evaluation. I want to trust Toyota's manufacturing experience and tradition. We've perfected the car this far. Quality problems would not stop Prius from going into mass production. Please work with us." Oi implored. Takaoka Plant gave in.

"Okay, we'll put on the grain finish from the beginning. Inform the parts makers right away." Each staff member was given instructions. Toyota Group companies such as Toyoda Gosei Co., Ltd, Kojima Press, and Inoac Corporation were in charge of interior resin parts. The efforts of these suppliers, who were able to meet Toyota's difficult needs, are noteworthy. Oi's decision was correct. Parts suppliers completed their molds with extreme caution, and provided molds that fit perfectly. Since there were no major changes, everything went smoothly before line-off. The efforts of the reverse-REs, such as Mayumi, who were dispatched from Takaoka Plant prior to the official decision of the manufacturing site, were vital to the success. They worked to perfect manufacturing from the very beginning, and manufacturing was made easier by checking each part in advance during the design stage.

Erase the last bit of noise The product planning staff, who had been thrilled just to see the car move in the early development stage, 364 put all their efforts into improving quality in minute detail until the very end. The staff worked late into the night every day to raise Prius to the level of other Toyota models. The final problem was the issue of noise that can directly affect the perception of a luxury car. Noise that had not been particularly noticeable in the early stages of mass-production tests, even with less sound insulation, became more noticeable as the car approached completion with improved sound insulation material. The first noise that was pointed out was the relay turning on. An experienced staff member at Takaoka Plant's Quality Control Department was the one who noticed the noise. He called Oi after a test-drive. "Oi-san, this car's noise level is no longer as good as the prototype." Oi drove the car, and noticed a clicking sound when the relay kicked in. Oi then called Uchiyamada. "What should we do with this noise?" Oi asked Uchiyamada to take the car out on the test course. "Hmm, we really would like to make it as good as possible, since we have come this far. Don't worry too much about the cost. I'll leave it up to you to deal with this noise," Uchiyamada told Oi. This relay causing the unwanted noise is also used in other Toyota cars. In an engine-powered conventional car, the noise of the relay is not noticeable because the 365 engine noise is present at all times while the car is moving while driving. However, in a hybrid vehicle, the engine stops when the car is driven in EV mode or when waiting at a traffic light. The clicking noise of the relay is quite obvious when the car engine is silent. However, when this problem was pointed out, development was at the final stage, and design changes would have been impossible. Rather than try to deal with the problem at the assembly stage, it was a better idea to modify the part itself, even though that would be more costly. Oi decided to wrap the relay in sound-insulating material as the final solution. Unfortunately, the assembly processes were already rigidly set at the Takaoka Plant, and it was impossible to add the new process of wrapping the relay. Oi then asked Denso, the manufacturer of this relay, to wrap the relay before shipment. At this point, both the new car presentation and Tokyo Motor Show were over, and the next major event was the launch of Prius. This improvement was made at the very last moment. During these days, Oi was making a three-point commute every day from his home in Nagoya to the Head Office to Takaoka Plant to his home. He frequently came home after four in the morning. Some parts were unique to the hybrid vehicle, and Toyota was buying parts for the first time from certain suppliers. It was necessary that these new suppliers understand Toyota's design philosophy from the beginning 366 so that Toyota could maintain its quality standard. One of these new suppliers was an Irish company. It provided a part that switched the motor's analog signals into digital signals using a photo coupler. This Irish company was the only one that manufactured this device, and it had only been used as a desktop device. Through a trading company, Toyota had to patiently and repeatedly let this company know that installing a device in an automobile exposed it to many harsh conditions. Even Matsushita Electric, a giant in the industry, was not initially aware that the product quality level necessary for a car was much higher than that for a home appliance. Oi had another important task - obtaining a certificate from the Ministry of Transport. Oi visited the Ministry of Transport many times to explain the vehicle. The fuel economy issue took the longest time to settle. When Prius is running in the Japanese 10-15 city drive mode, the driving mode results in the battery discharging electricity, since this generally slow drive mode requires Prius to frequently go into the EV drive mode. Therefore, Prius uses gasoline as well as electricity that has been stored from a previous charging cycle. The Ministry of Transport's opinion was that the fuel economy based on the 10-15 city drive mode was not accurate for Prius, since the car used more battery power in the drive mode. Oi came up with a correction coefficient based on the charge and discharge of the battery, and the Ministry coalesced. 367 At the time, the Japanese government was preparing for COP3 in December and wanted to use Prius to create a favorable impression on the global community with its environmental efforts. That was why the Ministry of Transportation dealt with the fuel economy certification issue so promptly. Prius was very fortunate in that sense.

Debut at the COP3 Kyoto Conference

The COP3 Kyoto Conference started on December 1st, prior to Prius' launch on the 10th. Governments, local governments, industries, and civil organizations of 150 nations participated in this conference. Reduction of carbon dioxide (CO_2) to prevent global warming was discussed for 11 days instead of the initially scheduled 10 days. The delegates discussed CO_2 reduction targets for each nation and each industry. While the European Union (EU) proposed a 30% reduction from the 1995 level by 2010 and Japan proposed 20% reduction, the United States stubbornly refused to set a specific numerical target. The United States claimed, "The allegation that CO_2 causes global warming is not scientifically proven, and CO_2 reduction would hinder global industrial growth. We cannot accept an agreement that excludes the participation of developing nations." Both the American economy and the sales by American auto manufacturers 368 were booming, and the United States government was concerned that the CO_2 reduction target would stunt this growth.

At the COP3 conference held in Japan's old capital Kyoto, Toyota showed several Prius that were to be launched in just a few days. The international environmental conference that focused particularly on CO_2 reduction was the perfect stage for the debut of Prius. Conference delegates were offered rides in the vehicle. With twice the fuel economy and half the CO_2 emissions as conventional cars, the Prius was the target of much interest and curiosity by these delegates. Media from all over the world covering the COP3 conference asked for interviews from any available Toyota Board member, and asked questions one after another. "What is the difference between an EV and a hybrid?" "We were expecting EVs to replace gasoline-engine cars. Why did you think of a hybrid?" "How much profit do you make on Prius?" "When do you plan to introduce Prius abroad?" Toyota also showed the Prius at EVS 14 in mid December immediately after the launch. It was America's Big 3 auto makers who were most shocked by this real-life Prius. They probably did not think that it would move so quietly, smoothly, and comfortably. The Big 3 affiliates at Kyoto did not hide their astonishment. The gravity of their shock was 369 immediately conveyed to Detroit.

Detroit in shock In January 1998, on the media opening day for Detroit Auto Show (North American International Auto Show), all the Big 3 American companies showed eco-friendly cars, especially fuel-efficient hybrid vehicles. They were all just concept cars, and it was impossible to say if any of them would achieve a certain level of fuel efficiency or if they would even move. It was an incomprehensible act by the Big 3 that had just criticized the recent COP3 agreement on CO_2 reduction as nonsensical. General Motors introduced EV1, an EV using nickelmetal hydride batteries, and a parallel-hybrid 4WD vehicle. In this hybrid vehicle, the front wheels are propelled by an electric motor, while the rear wheels and the generator are powered by a three-cylinder direct-injection diesel engine. However, GM did not offer any explanation as to how the car switched between or controlled the front and rear power trains on this hybrid vehicle. It was obvious that the car had been assembled and shown on very short notice. GM Chairman Jack Smith himself held a press meeting on environmental issues. Before accepting questions, he went into comparing this hybrid vehicle with Prius and emphasized how much better GM's model 370 was. In addition, he explained, "This car will be productionready by 2001. In 2004, the production for FCEV also will be completed." A reporter raised his hand. "Prius was already introduced in 1997. Why would GM's hybrid vehicle be only production-ready in 2001? Why wouldn't it be available to consumers then?" It was a harsh question. Smith answered, "That depends on how we can prepare the infrastructure, how we deal with cost issues, and also what kind of public support we can get. In Japan, there is a technological subsidy system based on the cooperation between the government and the people." Toyota of course, received no subsidy from the government for developing Prius. This comment by Smith indicated how much of a flurry GM was in. Ford also presented a concept car, "P2000," that focused on the environment. It achieved 63 kilometers (39 miles) to a gallon by using direct-injection diesel engine in a light-weight aluminum body. President Jac Nasser announced, "We are planning to launch a hybrid version of this car within this year. We will also make FCEV available in 2004." Chrysler also presented "ESX-2" which used an electric motor to lightly assist a diesel-turbo engine. Big 3's showing of these many eco-friendly cars apparently was triggered by Prius. The Big 3 thought that Prius definitely would be acknowledged in the market 371 as a practical hybrid passenger car, and also that they should catch up with the hybrid technology without delay. Moreover, they tried to appeal that they were in the forefront in environmental issues by announcing to the media when they intended to launch FCEV that had not yet been put to use by any auto maker in the world.

Toyota's 1,000 engineers that had worked on the development with the intention to shock the American auto makers, and the production team that made the production of Prius possible with Toyota's high quality standards, were taken by many different thoughts upon hearing of the repercussions in Detroit. Uchiyamada was glad and thought, "I was excited and relieved at the same time. Now, other auto makers in Japan and abroad will follow suit by launching their own hybrid vehicles. The hybrid system was acknowledged by all automotive professionals. It became a benchmark in eco-friendly cars." Wada thought, "As an engineer myself, I feel bad that we have caused the R&D engineers of other auto makers to work so hard. But, they have the ability, and their managers are encouraging them with earnestness. We must stay on our guard from now on." Hiroyuki Watanabe, who was promoted to the Board in June 1996 and has been in charge of Electric and Hybrid Vehicle Engineering Division since then, thought, "The first step towards setting a global standard is not the 372 introduction of Prius in particular but the very introduction of a hybrid vehicle. The hybrid control technology will become the core technology of ecofriendly cars of the future. All alternative-fuel cars such as FCEV and CNG cars are, after all, hybrid vehicles whose power system has changed from gasoline to something else. In that sense, having introduced the first hybrid technology is significant." This was Watanabe's impression of the Big 3 mentioning about their development efforts in FCEV as well as hybrid vehicles. President Okuda looked beyond the present and thought, "This is the declaration of an environmental war. We may have woken the tiger that is the global auto industry. The real competition is yet to come. Our position in the future will depend on how we can take advantage of launching Prius in advance of others."

An indispensable legacy In February, when the excitement from Kyoto and Detroit had not yet waned, a Prius closing party was held by the technology division at Toyota's recreation facility "Foresta Hills" just outside of Toyota City. About three hundred people attended, and President Okuda sent a gift of *sake* for the event. When the party began, Chief Engineer Uchiyamada drove a Prius to the hall, recreating the press conference in 373 Tokyo. Participants who had not been informed of this staging applauded and watched the procession with many emotions. As the party went on, the people mingled and talked about the hardships and the rewards of being involved in the project for four years. Oi spoke to Uchiyamada. "Having done product planning for ten years, I was too optimistic. I thought that all cars would be the same. Now, I've learned that there are so many different cars." "Sure. I never dreamed that I would become a Chief Engineer to develop such a car, either." "I think that environmental issues have just begun to come up. The auto industry is not even a mature industry yet in that sense, and we have so many more things to deal with." "Just with the hybrid vehicle alone, we will be surrounded by competitors by the time Prius goes through a modelchange. If we lose to those competitors at that point, we will lose the meaning of launching the Prius before others. We have to keep on working so that we don't lose. The support and opinions of our hybrid vehicle users are invaluable assets that other companies don't have. We have to cherish these things." In fact, favorable owner's feelings towards the car and environmental consciousness among Prius owners are surprisingly high. There is an Internet homepage called "Prius Mania" operated by a Prius owner. Many opinions are exchanged at this site, such as technical 374 problems, reports on problems and accidents, and even environmental statements. Some time after the launch of Prius, a staffer told Uchiyamada about this homepage. In it problems related to the technology were discussed, and some problems were misunderstood. After reading through this homepage for a few days, Uchiyamada told his staff and colleagues. "There are many opinions shared in this homepage, and I think that these are the true voices and opinions of the owners. You may all want to tell them that they are mistaken or not understanding a situation, but let's stay out of it and look at it only as a third person. If you feel the urge to voice your opinions, make sure you do it as an ordinary citizen instead of a Prius engineer. These opinions and complaints are our assets." Ishida, who was in charge of the Prius package and interior design, was frustrated that the consumers only focused on the hybrid system when Prius was launched. However, as days passed, more people were beginning to evaluate the package and speak of it highly. "People who know are appreciating our design. After all, Prius is the forerunner of the future sedan for not only Toyota but also all auto makers of the world." Ogiso remembered what Honorary Chairman Eiji Toyoda said when G21 was starting. "If I were young, I'd love to work on Prius." He finally realized how great the task was that he and his colleagues accomplished. 375 He thought, "Up to now, developing a car was a routine task of creating a product according to a set schedule. With the hybrid vehicle, we had to think and substantiate everything from the very beginning, because we had no parts, no set standards, and no experience using some parts outdoors. That's probably how our predecessors felt when they first developed the Corolla and the Crown. I guess I've finally seen the basics of manufacturing."

Back in those days Ogiso received a call from Eiji's secretary in April 1998. " Is this Ogiso-san? Honorary Chairman wishes to take a long ride in a Prius. Can we ask you to be the driver?" A few days later, Ogiso went to Eiji's home in a Prius to pick him up. He timidly asked Eiji who was in the passenger seat, "Where can I take you?" "Well, drive out of the city along 153, and go through the Mikawa mountains to Shinshiro. Then go to Wada Pass. I used to drive through that area all the time when I was young. It's the best place to test acceleration and cornering. I would also like to see what the regenerative braking is like." Eiji was remembering his days when he was still a 376 young, curious engineer. The two enjoyed the drive the whole morning, and returned to the Head Office. Having fulfilled an important duty, Ogiso was covered with sweat. "You know, Prius is actually pretty nice. That's what you' d call a future vehicle. Have you tried it yet?" Eiji grabbed a young office worker and enthusiastically began his lecture. "Now, let me tell you about the hybrid system." 377

After Prius On the first press day of the Tokyo Motor Show which opened immediately after the official introduction of Prius, President Hiroshi Okuda stood next to Prius and spoke highly of the new car as if he were announcing the arrival of the hybrid era. He looked happy and satisfied. At the same time at the Daimler-Benz booth, Chairman Jurgen Schrempp was talking about the introduction of the FCEV. "We will make our zero-emission fuel cell electric vehicle available by year 2005," he said, obviously trying to highlight his company's competitiveness against Toyota which just proudly announced its environmental strategy.

More competition with hybrid cars About fifteen minutes later, a reporter told Okuda what Schrempp had said. Jokingly and even confidently Okuda said, "Oh really? Then we should introduce our FCEV in 2004. That would be just the right time." Reporters who heard his comments later said they felt that the hegemony in the auto industry would soon be determined by environmental technology, and that Toyota and Benz would lead the way. Behind Okuda's statement was the fact that Toyota 378 had a definite plan of launching its FCEV. In an FCEV, hydrogen and oxygen are used to create electric energy, which is used to power the motor. A FCEV is a type of EV, and is an extremely eco-friendly car since its only emission is water. It is also a type of hybrid vehicle. In the Prius, the engine and the generator fill the role of a fuel cell. Electric energy either goes directly to power the
motor or to charge the battery. Regenerative braking is also used. When additional power is necessary, electricity stored in the battery is sent to the motor to increase power. Prius technology (motor, battery, and regenerative braking as well as the know-how from control and information transmission) can be applied directly to a FCEV. There are still many problems to solve before a FCEV can be introduced. Although Toyota has developed a way to store hydrogen, there is no infrastructure at present to readily supply hydrogen in liquid or gas form to the general public. Hence, a method of storing methanol in the car, altering it and then extracting hydrogen is preferred today. This method produces some CO_2 and other emissions, but needless to say, a car with this system is far cleaner than a conventional car. Water produced as the result of reactions between hydrogen and oxygen is a non-polluting emission, but freezes below zero degrees. One of the unexpectedly difficult problems is how to treat this water in freezing climates. Despite such difficulties, a type of FCEV is 379 expected to be launched by a number of key auto makers of the world. However, industry affiliates also agree that it will take more than ten years or even several decades before cost is reduced and the infrastructure is laid out for the FCEV to finally penetrate the market.

Until then, hybrid vehicles, which need no special infrastructure and can be driven just like conventional cars, are the eco-friendly car of choice. In 1999, Honda and Nissan have plans to launch their own hybrid cars, and Honda has presented its aluminum-body, sporty hybrid vehicle "W" at the 1999 Detroit Auto Show. Mitsubishi is also planning to launch a hybrid vehicle in 2000. The hybrid vehicle market is no longer monopolized by Prius, but is entering an era of competition. One day, each company will be tested for its true competitive edge in technology and overall business.

Prius soars into the world What will happen to Prius? As Okuda had hoped, Prius claimed both "Japan Car of the Year" and "RJC New Car of the Year" awards, making it the first car in history to win both at the same time. In addition, Prius won all major awards from contests on new technology and products sponsored by 380 major newspapers. Even before being introduced there, Prius also accomplished the heroic deed of winning awards abroad, such as the Global Climate Protection Award from the U.S. Environmental Protection Agency. As soon as Prius was officially presented in October 1997, Toyota was bombarded with inquiries. The number of orders received during the month after the launch in December was 3,500 units, more than three times the monthly sales target. Many early customers had to wait three to four months before they finally got their cars, and the sales of Prius were overwhelming the otherwise depressed new car market. One of the noteworthy characteristics in the sales trend is that Prius has been bought by people of disparate age groups, from 30s, 40s, to 50s. Furthermore, unlike other cars, the majority of the buyers was not buying Prius to replace existing cars but was buying a car for the first time. It was the first time in several years that a car costing more than 2 million yen and offering no discounts at all would be bought by so many new drivers. All this indicated how high the public's expectations of Prius were. The New Energy and Industrial Technology Development Organization, a MITI quasi-governmental organization, decided in July 1998 to offer a subsidy of 250,000 yen for each Prius purchased by corporations and individuals using the car for business. Together with other preferential tax measures such as auto acquisition tax, the cost of purchasing a Prius has not been much more 381 than conventional cars, and that factor accelerated its sales. As of the end of March 1999, 15 months after the launch, total sales of Prius reached 22,000 units. In the beginning, most buyers were local governments, corporations, and politicians who wanted to show off their environmental consciousness to the voters. Today, almost 70% of the buyers are private individuals. In July 1998, Okuda officially announced during his periodic press conference that Toyota would sell Prius abroad starting year 2000. Test-drive events were held for government officials and environmental organizations in Washington, D. C., and a technical seminar was held for European journalists in Belgium. Toyota received positive reactions, and was asked repeatedly when Prius would be exported. Toyota also introduced its hybrid technology by holding test-drive events in the countries and areas to which Toyota will not be exporting Prius for a while, such as Australia and South Africa. Because, Prius was designed for the Japanese market it was not necessarily suitable to overseas markets. Prius achieves its fuel efficiency advantage over conventional cars in congested urban traffic situations, and displays its true value in such stop-and-go conditions. Prius runs mostly in the EV mode in congested traffic, and can achieve much higher fuel efficiency than conventional cars that must run at the inefficient, low-rpm range. Moreover, Prius' engine turns off when the car is stopped in traffic. Thus, the car also has the advantage of 382 producing no noise or emissions from an idling engine. In contrast, Prius cannot get much fuel advantage on highways and open suburban roads, since it goes into the engine-mode. In the United States and Europe where the average cruise speed is faster than in Japan, the Prius cannot display its advantages to the fullest. In order to sell Prius abroad, engine power must be increased. In addition, overall control modes need to be changed, such as assisting the motor with regenerative energy from braking and battery energy by more effective timing. Oi now leads the "Zi" project. He became the second Chief Engineer, succeeding Uchiyamada, who had been appointed to the Board in June 1998 and left the Prius project. The team is currently busy developing Prius for foreign markets.

Auto industry enters mega-reorganization Meanwhile the auto industry has recently entered an era of international mega-reorganization and megacompetition. Daimler-Benz of Germany merged with Chrysler. Ford bought Volvo's passenger-car division. In addition, Renault of France has equity in Nissan and participates in the management of the company. It was immediately after Prius shocked the Big 3 that the news of Daimler-Chrysler merger was released from 383 Europe. Because of the timing, some view the merger as having been triggered by Prius. In fact, Daimler-Chrysler announced the reasons for the merger as being mutual complementation of American and European markets and drastic reduction of investment cost for environmental technology such as the FCEV. As far as FCEV development efforts are concerned, Ford has joined Daimler-Chrysler, and Honda is also approaching this group. Later, one may look back on the auto industry's mega-reorganization on the eve of the 21st century and define the era as being "post-Prius." Meanwhile, Toyota's Okuda said of the industry reorganization: "About 10 companies will survive into the early 21st century. We would like to be a winner." Okuda emphasized that Toyota would not consider financial tieups with foreign companies but would compete globally as the Toyota Group by fortifying its relationship with Daihatsu, which makes mini-cars, and with Hino, which makes heavy trucks. With environmental technologies, however, Okuda stated, "Regarding individual technologies, there is possibility of technical partnerships." Toyota has already begun joint research of car-navigation and recycling with Volkswagen (VW). Since Toyota once jointly produced cars in Germany and currently sells VW cars at Toyota's domestic dealerships, the relationship between the two is close. Also, Toyota has operated a joint auto production 384 facility with General Motors (GM) in the United States for more than ten years, and is cooperating with GM in the electricity supply method for EV and in the establishment of a uniform standard for automotive multimedia. At the same time, there are constant rumors of Toyota signing a large-scale partnership with GM in environmental technology, such as the FCEV. Also, there is still a possibility of Toyota and GM cooperating with VW to create a trilateral union of the three regions.

On January 8th, 1999, the Toyota organization was surprised during its New Year's celebration when President Okuda was unofficially selected as the Chairman of the Japan Federation of Employers Associations (Nikkeiren). Nobody in the company had anticipated this development. That evening, Okuda invited inside 12 journalists who had been waiting for him at his home on a hill in Okazaki City, Aichi Prefecture. He told them of his intention to retire as President of Toyota, stating, "I consider my course of action within the context of larger organizational reforms at Toyota, such as the potential institution of a holding company. Since I have advocated a more youthful Board for the company, it is not right for me to stay on as President for three or four terms. Okuda, however, was not retiring from the forefront of Toyota's management anytime soon. Toyota is considering 385 new methods of managing the Toyota group of companies, such as creating a holding company, and is also trying to create a greater Toyota union under the Toyoda family. Okuda naturally, will be part of the nucleus. In his statement, he was commenting for the first time on Toyota in the 21st century.

A moment later, a reporter asked, "Have you accomplished the three tasks that you assigned yourself when you were appointed?" "I have left many tasks behind, but I'll have to leave them to my successor. Well, the legacy of a President is mostly doing what he inherited from his predecessor. We always will feel regrets no matter when we retire," Okuda said, smiling. As for the primary task of reversing the delay in building offshore operations, Okuda built plants in the United States, France, and India one after another. As for the second task of regaining domestic market share, Okuda was unable to meet the 40% market share target from past decades, he did achieve it in 1998 fiscal year (April 1998 through March 1999) for the first time in four years at 40.1% (Toyota figure; including models produced abroad). And for the third task of accelerating product planning, Okuda introduced the hybrid vehicle Prius before any of the other auto makers in the world. The greatest achievement of Prius is that it succeeded in changing the public perception of an eco-friendly car 386 from a special product to a popular car. The auto makers of the world are now engaged in a new competition with Prius as the benchmark. What kind of eco-friendly cars will appear in the 21st century to exceed the significance of Prius? The excitement of the search and answers are yet to come. 387