Chapter 8

# Research and Development

Since its founding, Toray has worked to create innovative new technologies and expand its existing technologies based on the firm conviction that research and technology development (R&D) provide the key to building the Toray of tomorrow. From their predecessors, Toray's researchers and engineers have inherited a belief in the pursuit of the ultimate, and that drilling down deep into a topic will uncover the next new thing, as expressed in the words "The Deeper, the Newer." They also inherited the spirit of challenge to create advanced materials. Through technology integration of Toray's core technologies of organic synthetic chemistry, polymer chemistry, biotechnology, and nanotechnology, they are researching and developing technologies aimed at creating new technologies and products. This chapter looks at Toray's R&D efforts, from the past to the present, and discusses the main examples of Toray's innovative products and technologies.

## Establishment of R&D Department and Research Laboratories (1927–1959)

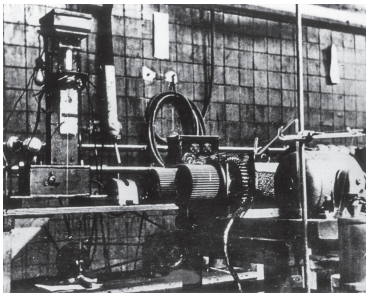
### • R&D with Rayon

In June 1927, just prior to the start of rayon yarn production and a year after the company was founded, Toray announced its first organizational structure. Directly below the Board of Directors was the General Manager of the Shiga Plant, and below him were the Commercial Section and the Plant Department. Within the Plant Department were the R&D Section, Production Section and others. At the beginning, Japanese workers quickly digested and absorbed manufacturing technologies from a group of foreign engineers. They then worked to improve those technologies by themselves to create a range of products with world-class quality and cost. With expansion of the rayon business, the R&D Section changed name to the R&D Department in 1939 and proceeded to enhance its R&D activities.

### • Start of Nylon Research

In 1938, DuPont of the United States announced that it had successfully developed *nylon*. The arrival of nylon heralded the dawn of an era of synthetic fibers. With the shock of this development, Toray's leadership and research team immediately started basic research into synthetic fibers. In 1939, they analyzed samples they had acquired and confirmed that nylon was a linear polymerization of adipic acid and hexamethylenediamine (nylon 66). In the same year, Toray produced these two monomers and successfully polymerized and spun nylon 66. Then in 1941, after successes including spinning multifilament nylon 6 from polymerized

caprolactam, it was able to quickly complete its basic research into nylon and obtain four patents from the results. In 1942, Toray installed test facilities at the Shiga Plant to produce nylon 6 and nylon 66. After deciding on the trade name "Amilan," it started producing and marketing the products.



Original nylon spinning equipment (Shiga, 1943)

Without infringing on DuPont patents, Toray was able to research the industrialization of nylon by itself. It found comparative advantages of using nylon 6 over nylon 66 in the areas of equipment costs and unit material consumption, while finding almost no difference in performance, so instead of the nylon 66 that DuPont developed, Toray focused its development on nylon 6. Development had to be postponed during World War II, but immediately after the war Toray recommenced production of nylon fishing line at the Shiga Plant. Then in 1951, it started production of nylon multifilament for apparel at the Aichi Plant.

While Amilan did not infringe on DuPont's patents, it was more convenient to use DuPont's patents for commercial production. Therefore, later in 1951, Toray signed an (expensive) technology licensing agreement to obtain a patent license, but one that excluded technological know-how such as mechanical engineering drawings. In this manner, Toray was able to improve its production processes, including spinning and fiber drawing, while acquiring technological information to improve productivity and quality. The patent license that included fibers application processing was also useful.

• **Central Research Laboratories Opened**

In 1949, Toray's R&D Department changed name to Research Laboratories (but changed back to R&D Department when the Production Division was established in 1955). In 1951, Toray established the Synthetic Fiber Research Laboratory in the newly-built Nagoya Plant to focus on stable production, quality improvement, and new product development for nylon. At the same time, it worked on developing processing technologies in partnership with fibers application processing manufacturers.

Busy researching rayon and nylon technologies in 1953, Toray made the decision to build the Central Research Laboratories to advance polymer chemistry and enhance basic research. The Central Research Laboratories were opened in 1956 with the roles of (1) Conducting research on basic issues and on common issues faced by research laboratories located in each plant, (2) Conducting research on new products not directly related to existing products, and (3) Conducting research for the future.

After signing a technology licensing agreement with Imperial Chemical Industries Ltd. (ICI) in the United Kingdom in 1957, Toray built the new Mishima Laboratory in 1958 to research industrialization of polyester fiber. It also established the Development Department in 1959, including the Tetoron Film Lab, Fiber-IV (acrylic fiber) Lab, Pylen Lab, and Plastics Research Laboratories (newly established the previous year within the R&D Department), and proceeded to develop technologies for new businesses.

• **Main R&D Activities in the 1950s**

The three major synthetic fibers of nylon, polyester and acrylic were present in the 1950s. With initial development of nylon resin and polyester

film already completed, Toray began production of these products.

**"Tetoron" Polyester Fiber:** Following rayon and nylon, Toray planned to develop a third polyester fiber, so from about 1952, it started into serious research and development. After starting production at the Mishima Plant in 1958 using ICI's technologies, Toray focused on stabilizing production and improving quality while it also started to develop manufacturing methods that would dramatically reduce production processes and costs.

**"Toraylon" Acrylic Fiber:** After Tetoron, Toray started basic research into acrylic fiber in 1952 as its fourth fiber. After a temporary interruption, it installed a three-ton-per-day test facility at the Nagoya Plant in 1959.

**"Amilan" Nylon Resin:** Toray's research and development of plastics for molding applications started with the development in 1954 of cold-resistant, weather-resistant nylon for special procurement electric cable coatings. It went on to develop new product types and grades.

**"Lumirror" Polyester Film:** Using licensed technologies from ICI, Toray developed manufacturing technologies in 1958 with a focus on biaxial orientation (longitudinal and lateral orientation). It started test production at the Mishima Plant in 1959.

## Establishment of R&D Divisions and Business Expansion (1960–1984)

- **Establishing Basic Research Laboratories, and Application Research Center for Fibers and Textiles**

During the 1960s, Toray grew quickly through synthetic fibers. Over the decade through to 1970, companywide net sales grew by more than 12

percent per year on average. With the increasing scale of production and sales, Toray also expanded its R&D structure. It established the new R&D Division in March 1960 (changed later to the Research Division in 1963), and created the Research Department and Development Department. In December 1960, it enhanced its basic research function and established the new Basic Research Laboratories (opened in 1962), within the R&D Division, to enable blue-sky research for the purpose of creating new products for brand new growth lines. At the same time, it established the Technology Research Department, Patent Department, and R&D General Affairs Section (later to become the Research Technology Administration Department).

Completed Basic Research Laboratories (1962)

On the other hand, Toray also transferred its fibers and textiles business-related research laboratories and testing facilities to the Fiber Production Division, while opening Textile Labs, Dyeing Labs, Engineering Labs, Product Labs, and Industrial Materials Labs within the Shiga Plant. It also opened the Application Research Center as a large group of labs researching the application processing of synthetic fibers.

- **Development of a Research Structure and Expansion of Areas of Research**

In 1969, Toray established the R&D Division to coordinate all the research functions spread across various organizations. While following

the policies of expanding its plastics business and strengthening R&D and production of the raw material, Toray established the Petro-chemistry Research Laboratory (1968) and the Development Research Laboratories (a merger of the Central Research Laboratories and the two labs of the Plastics Division) within the R&D Division. It also integrated the fibers and textiles research facilities to establish the new Fibers & Textiles Research Laboratories. It located other labs as well, including the Basic Research Laboratories and the Engineering Research Laboratories, in the R&D Division.

For a while in 1973, control of the three laboratories for fibers and textiles, plastics, and chemicals were returned to their business divisions. But when the whole organization was restructured along functional lines in 1976, all laboratories were brought back together as part of efforts to streamline management. Toray established the SPR (sales, production, and research; predecessor of MPR) System to review and streamline research topics, while also establishing the Technical Information Department and the Analysis Center for physical properties and analysis-related research (spun off as the Toray Research Center in 1978). In 1982, Toray changed direction toward enhancing its research resources in line with the Research Mid-term Project formulated that same year. As a result, it focused particularly on expanding new research areas, and basic and exploratory research.

- **New Business Development**

In January 1970, Toray removed the word Rayon from its name, changing to Toray Industries, Inc. in expectation of the launch of new growth lines as the synthetic fiber market, which had already become a major focus

for the company, moved toward maturity in Japan. In 1971, the company established the New Business Promotion Department, reporting directly to the president. As a core organization driving new business development companywide, the new department brought together research and technology development projects together with business planning, sales development and market research functions. In 1974, it became the New Business Division (name changed to Development Business Division in 1976 and then to New Business Divisions in 1979) to evaluate the potential of commercialization projects identified through research and sales development, and to establish new independent organizations for projects after the development stage. Through this process, many new businesses were advanced, including carbon fiber composite materials, prostaglandin derivative drugs, interferon drugs and other pharmaceuticals, artificial kidneys for dialysis, reverse osmosis (RO) membrane modules, and graphic materials.

- **Main R&D Outcomes: 1960–1984**

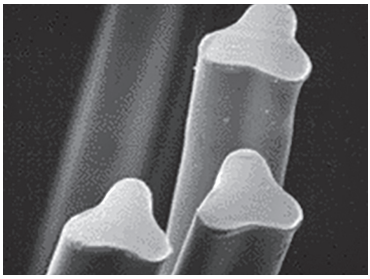
**Fibers and Textiles:** Although the synthetic fibers business grew significantly, it was a time of fierce competition with other companies, so Toray was busy developing new products to reduce costs and generate added value. It developed a range of nylon products including bicomponent fiber, modified cross-section filament, non-sizing yarn, anti-static yarn, and ultrafine yarn, and a range of industrial materials and interior products including tire cord filament, and bulked continuous filament ("BCF") for carpet. Toray applied ideas, from the technologies and value-adding processes developed with nylon, to Tetoron polyester fiber and Toraylon acrylic fiber, and launched

many new products according to the various characteristics and applications of each.

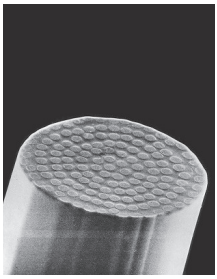
The main examples of those new products are shown in table 8-1. A good example is polyester fiber. In 1964, Toray developed "Sillook," a highly transparent yarn with a triangular cross section. With woven fabrics made from the yarn having a silky feel and elegant gloss, it became a pillar of the company's product differentiation.

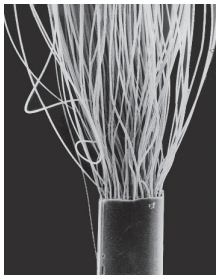
**Table 8-1 Main New Fiber and Textile Products (1960–1984)**

| | New Products |
|---|---|
| Nylon | "Tapilon" bicomponent polymer fiber |
| | "Amick" modified cross-section filament |
| | Non-sizing yarn (NOS) |
| | "Parel" anti-static yarn |
| | "Lupina" thin PTY (producer's textured yarn) |
| | "Royalsofy" ultrafine yarn |
| | Tire cord filament |
| | Monofilament for fishing nets |
| | Various bulked continuous filaments ("BCF") for carpets |
| "Tetoron" | "Sillook" modified cross-section filament |
| | Disperse dye, easy-dying fibers |
| | "Tetwel" anti-pilling staple fiber |
| | "Silgian" modified cross-section staple fiber |
| | "Sillook II" modified cross-section, modified shrinkage blended fiber |
| | "Sillook III" modified cross-section, random crimping yarn |
| | "Sillook IV" modified cross-section, multiple crimping yarn |
| | FINT non-twist and non-sizing Tetoron yarn |
| | "Sumola" PBT (polybutylene terephthalate) fiber |
| | "Severis" antibacterial and deodorant fiber |
| | "Axtar" filament nonwoven fabric |
| "Toraylon" | "Toraylon Unfla" flame retardant fiber |
| Artificial Leather | "Ecsaine" suede-texture artificial leather |
| Fiber Processed Product | "Entrant" moisture-permeable waterproof textile |



Sillook cross section





Ecsaine fiber (multiple fibers from a single thread; left)

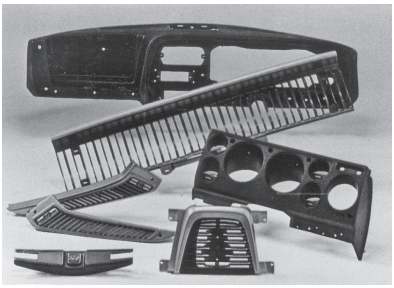
Toray also started developing suede-texture artificial leather from 1968. Using a special composite spinning method, it developed an ultra-fine fascicular fiber with a denier of about 0.1. With a three-dimensional intertwined structure, it had the texture and moisture-permeability of natural leather, and a soft touch and suede effect achieved through surface buffing. In 1971, Toray started mass production of the fiber under the trade name "Ecsaine" (now "Ultrasuede").

Alongside development of these new products, Toray also created several innovative technologies and devices, such as direct spinning and drawing (DSD) equipment, a partially oriented and draw-textured yarn (POY/DTY) process, and a one-step high-speed spinning process (OSP), which contributed enormously to its synthetic fibers business taking a great leap forward.

**Resins, Films, and Chemicals:** In addition to fibers and textiles, Toray developed many new products, including ABS, PBT, PPS and other new resins and high value-added Lumirror products, which have become the foundation products of their respective business at Toray today. The main examples are shown in table 8-2.

## Table 8-2 Main New Products Other Than Fibers and Textiles (1960–1984)

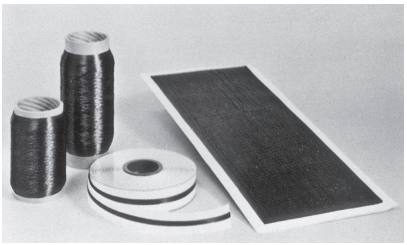
| New Fields Other Than Fibers and Textiles | | New Products |
|---|---|---|
| Plastics and Chemicals | Plastics (Resins) | Nylon 66, nylon 12 |
| | | "Toyolac" ABS resin |
| | | "Toraycon" PBT resin |
| | | "Torelina" PPS resin |
| | Plastics (Films) | "Torayfan" for coatings and electric capacitors |
| | | "Toraypef" polyolefin foam sheet |
| | | "Lumirror" (V37) for home video applications |
| | | "Lumirror" (V-FAP) high-strength film |
| | Chemicals | L-Lysine essential amino acid |
| New Businesses | Carbon Fibers | Polyacrylonitrile (PAN) fiber for carbon fiber |
| | | "Torayca" carbon fiber (T300 grade) |
| | Medical Products | "Filtryzer" hollow fiber dialyzers |
| | | "Anthron" antithrombogenic material |
| | Pharmaceuticals | $PGF_{2\alpha}$ ecbolic injectable solution |
| | | "Feron" interferon-β preparation |
| | Graphic Systems | "Torelief" photosensitive nylon resin relief printing plate |
| | | "Toray Waterless Plate" |
| | Optical Products | "Breath-O" soft contact lenses |
| | Water Treatment | "Romembra" high-performance reverse osmosis (RO) membranes |
| | Electronic and Information Materials | IC carrier tape (ICC, KCC) |
| | | "Semicofine" polyimide (PI) coating material for semiconductors |



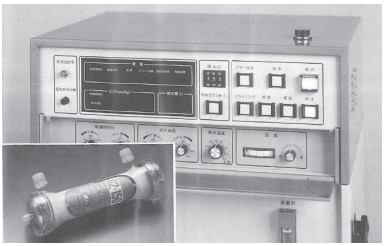
Toyolac molded products (automobile parts)

Lumirror film processing (Gifu Plant)

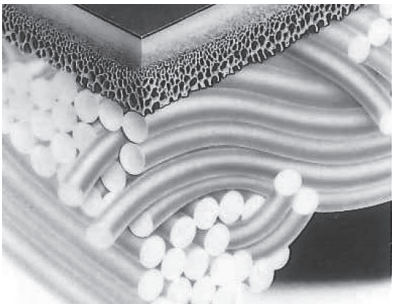
**New Businesses:** This was the period during which Toray mainly started into businesses other than its current fibers and textiles, resins, films, and chemicals businesses. The company pushed forward all at once into research and technology development of new businesses. The main outcomes are shown in table 8-2, but touching briefly on the development of carbon fibers, Toray's research and development started in 1961. This was after an academic presentation about polyacrylonitrile (PAN) based carbon fiber given by Dr. Akio Shindo from the Osaka National Research Institute of the Agency of Industrial Science and Technology (now the National Institute of Advanced Industrial Science and Technology (AIST)). Toray found that by using the new compound hydroxyethyl acrylonitrile (HEN), which had been successfully synthesized at the Basic Research Laboratories, as a copolymer component of PAN, it could dramatically improve the performance of the carbon fiber. Establishing the CROW Project across its laboratories in 1969, Toray proceeded to develop a series of fundamental technologies. In addition, it entered an agreement with Union Carbide Corp. to exchange carbonization and precursor technologies, licensed the basic patents of Dr. Shindo, and started production in 1971.



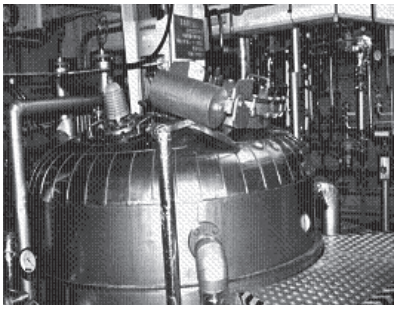
Torayca carbon fiber



Filtryzer dialyzer and patient monitoring device



Romembra RO membrane structure



Feron culture tank

## Establishment of the Technology Center, and R&D in Growth Business Fields (1985–2001)

### • Establishment of the Technology Center

In April 1985, Toray established the Technology Center as the headquarters for research and technology development across the whole company.

The Technology Center in the narrow sense consisted of a core Planning Department and the organizations that conducted the actual development. It also had a broader sense though, which was a virtual organization consisting of the R&D Divisions, Engineering Division, Manufacturing Division, and the various technical departments attached to the business divisions. The mission of the broader Technology Center was to maximize

Technology Center (now TC-2)

limited technological resources in order to "Respond to intensifying competition in Japan and overseas and to rapid technological innovation, to secure advantages in current markets, and to develop new markets" and to "Achieve further efficiencies in technology development linked to marketing strategies." Its basic policies were defined as (1) Reorganize development structures, (2) Strengthen the functions of technical planning staff, (3) Enhance ties with business divisions, and (4) Enhance information functions.

Based on this, the Technology Center established the MPR (manufacturing, production, and research) System to distribute management resources in line with each business strategy. The MPR System is used by executives in the Technology Center and business leaders to coordinate business strategies with R&D policies, and to determine projects and resources for research and technology development each fiscal year. To prioritize and accelerate R&D, the Technology Center also developed various systems including a specific urgent issue system, a priority development issue system, a priority field system, and a subsidiary/affiliated company support system.

When allocating expenses for R&D projects, Toray created a Divisional Research (DR) category of business research where the business divisions bear the cost, and a Corporate Research (CR) category where head office bears the cost. It also added a CR-II category. At this time, the previous CR category was renamed CR-I and related to projects set at the discretion and responsibility of the R&D Divisions, with approvals granted by the Technology Committee. On the other hand, the CR-II category related to head office expenses allocated to development projects at the responsibility of the General Manager of the Technology

Center. This new system played an important role in new business development, cross-industry development, and development at subsidiaries and affiliated companies. These roles, expectations and whole series of measures of the Technology Center have continued and have become the backbone of the current Technology Center operation system.

- **Separation of Research and Development**

In 1987, Toray separated the development function from the R&D Divisions. This separation of research and development marked the start of an important change for the development organization. Research was defined as aiming to create new materials and new functions with competitive advantages, and establish fundamental technologies based on creative ideas regardless of past performance or deadlines. Development, on the other hand, to commercialize the materials and functions created through research, and then developed technologies with a sense of urgency under quality, cost, development lead-times and other restrictions.

In August 1987, R&D Divisions' Development Department function and projects were transferred to the Technology Center as development promotion groups. At the same time, the roles of the Technical Center and the Manufacturing Division's technical departments were clarified, with the Technical Center in charge of technology development in new business fields, and the Manufacturing Division's technical departments in charge of technology development in existing business fields. In June 1991, a New Projects Development Division was established at the Technology Center, thereby completing the process of separating research and development functions.

- **Research System Responds to Business Diversification and Pursues Cutting-edge Technologies**

Around this time, Toray restructured and enhanced its research laboratories, and established independent research laboratories for each area of research. It reorganized or newly established the Polymer Research Laboratories and Electronic and Imaging Materials Research Laboratories in 1987, the Plastics Research Laboratories (Nagoya) and Composite Materials Research Laboratories (Ehime) in 1990, the Chemicals Research Laboratories in 1991, and the Medical Devices and Diagnostics Research Laboratories in 1992.

In 1999, it established the new Basic Research Laboratories (Kamakura) as a division-level organization, and below that established the Pharmaceutical Research Laboratories (name changed from the previous Basic Research Laboratories) and the Advanced Research Laboratories (through a merger between the Polymer Research Laboratories and Medical Devices and Diagnostics Research Laboratories). The Advanced Research Laboratories focused primarily on researching new medical, environmental and functional materials that offered promise for the 21st century. It aimed to research cutting-edge technologies and state of the art technologies covering many business fields.

- **Expansion and Promotion of Development Projects at the Technology Center**

When it was first established, the Technology Center focused on five development projects: (1) "Furtasti" artificial fur, (2) Optical fiber, (3) Ceramics, (4) Medical products, and (5) Toner. By 1990 though, it had

established five new development promotion groups or projects: (6) LCD materials (LCM), (7) Polyacetal resin (RAP), (8) High-speed printers (TNP), (9) Large-scale composite material structures (LSS), and (10) Composites. In June 1991, these groups and projects were incorporated into the New Business Development Division at the Technology Center. From that point, the division added other projects including "Torayrom" water purifying systems, optical disks, STP (Samsung-Toray project for forming and mounting flexible circuits on semiconductors), and plasma display panel (PDP) materials. With the majority of these projects becoming commercialized by business divisions and subsidiaries/affiliates, the Technology Center proved its worth as an incubation center for development projects.

- **Advancement System: From Research to Development, From Development to Production**

Toray separated its functions of research and development, but at the same time developed a system of advancing projects from research to development, and from development to production. Projects needed to be quickly advanced, but at the most appropriate time, because moving projects forward to the next stage too easily posed serious risks, while moving them forward too cautiously would result in lagging behind the competition. For this reason, in 1988, Toray formulated the R&D Advancement System for determining appropriate timing for advancing projects through stages, from research to development or from development to production. This system enabled a more efficient transition from research to development. A new Stage Gate System was then adopted in 1999 to enable more objective judgments for advancing research

according to *gate criteria*. This new system worked to improve the success rate and increase the speed of development projects.

- **Other R&D Measures**

Toray had emphasized the importance of patents for a while, establishing a dedicated Patent Department, but in 1991, it also established the Intellectual Property Department and developed a more comprehensive system of managing and utilizing IP rights, including patents, utility models, trade names, designs, and computer program copyrights. Continuing these activities, the department was separated and is now named the Intellectual Property Division. Toray then launched a program of measures designed to develop and stimulate its HR involved in research and technology development. These measures included establishment in 1988 of the Fundamental Technologies Conference, covering polymerization, spinning, fibers application processing, film formation, and organic synthesis and other technologies, to further deepen and expand the fundamental technologies that are the technology foundations of Toray. They also included establishment in 1992 of the Research Fellow System to develop a culture where researchers were able to devote themselves to extended research and improve through friendly rivalry, and establishment in 1997 of an award system specifically for the R&D Divisions and Technology Center.

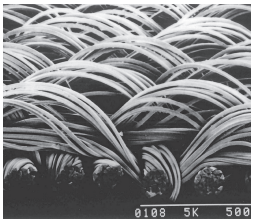
- **Main R&D Outcomes: 1985–2001**

During this period, Toray commercialized a series of *Shin-gosen* (new types of synthetic fiber) products. At the same time, it broadened its R&D areas in pursuit of many new cutting-edge and state of the art

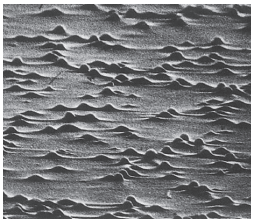
technologies that would become growth business fields for the 21st century. As explained above, it also spun off many development projects, incubated in the Technology Center, as independent divisions.

**Table 8-3 Main New Products (1985–2001)**

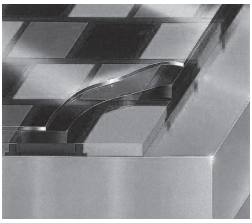
| Business Fields | New Products |
|---|---|
| Fibers and Textiles | "Sillook Sildew" multistage, modified shrinkage blended yarn & textile |
| | "Sanoi" new filament/staple fiber composite spun yarn |
| | Nylon for air bags |
| | "Makspec" non-formalin antibacterial material |
| Resins and Chemicals | "Intercat" interferon for cats |
| | "Siveras" liquid crystal polyester (LCP) resin |
| Films | "Torelina" polyphenylene sulfide (PPS) film |
| | "Mictron" aramid film |
| | "Lumirror" products using new surface-forming technologies (TOP-PTL) |
| | "Lumirror" reflective film for LCD backlight units |
| IT-related Products | "Photoneece" polyimide (PI) coating material for semiconductors |
| | Manufacturing technologies and pastes for forming plasma display panel (PDP) rear substrates |
| | "Toptical" color filters |
| Housing and Engineering | "Torayvino" home water purifiers |
| | "Romembra" two-stage reverse osmosis membrane for production of ultra-pure water |
| Pharmaceuticals and Medical Products | "Dorner" treatment agent for peripheral vascular disease |
| | "Toraymyxin" blood purifier for removing endotoxin |
| | "Toraysulfone" polysulfone membrane artificial kidneys |
| New Businesses | "Toraysee" high-performance wiping cloth |
| | "Torayca" carbon fiber composite material for use as primary structural material in aircraft |
| | Fuel cell electrode material |
| | "Torayca" composites for use as automobile material |




Sillook Sildew fabric cross section



Lumirror product using new surface-forming technologies (TOP-PTL)



Toptical color filters

## From New Toray Reforms to Green Innovation and Life Innovation (2002–2017)

- **Departure from Fiercely Independent R&D (Technology Integration and Internal/External Collaboration)**

During the fiscal period ending March 31, 2002, Toray faced extremely difficult conditions, with non-consolidated operating income falling into the red for the first time since the company was founded. In April 2002, Toray launched the New TORAY21 (NT21) mid-term management program designed to reform every area of the company, from its management systems to codes of behavior. As part of the NT reform, the company began its departure from "fiercely independent R&D" approach to research and technology development.

Looking at Toray's business relationships, including nylon with DuPont, carbon fiber with Union Carbide, and with Boeing and UNIQLO, there are many examples from the beginning of Toray coupling its own technologies with the technologies and know-how of other companies to create new value and grow as a company. Toray took the bold decision to deliberately move away from its "fiercely independent

R&D" approach because it saw a need to implement research and development initiatives using more than just its own product ideas. With an actively outward-looking stance, it would be able to achieve its research and development goals, which had recently become more diverse and sophisticated, with a greater sense of urgency. As a result, Toray was able to participate in more than 40 government-approved projects in fiscal 2016 compared to the 10 projects it participated in fiscal 2001, immediately prior to the change. Also in 2016, it collaborated on more than 300 joint research and development projects with general research institutes and leading companies.

New Frontiers Research Laboratories

Coinciding with this change of strategic direction for the company, in 2002, Toray separated the Specialty Materials Research Laboratories, which was working on polymer research in life sciences, IT, and other areas, from the Pioneering Research Laboratories. At the same time, it established the new Global Environment Research Laboratories, which had initially started as in 1991. Then in 2003, Toray opened the open laboratory-linked New Frontiers Research Laboratories to focus on fields such as biotechnology and nanotechnology.

- **R&D of Advanced Materials**

From October 2006, Toray adopted the basic strategy of expanding advanced materials as part of the Project Innovation TORAY 2010 (IT-2010) mid-term management program it developed under the

"Innovation by Chemistry" corporate slogan. Based on this, the company established two research and technology development strategies: (1) Pursue the outer limits of the Toray Group's core technologies of organic synthetic chemistry, polymer chemistry, biotechnology and nanotechnology, and create advanced materials through integration of these technologies, and (2) Allocate approximately 80 percent of companywide development resources to advanced materials in order to accelerate innovation. It established display innovation materials, automobile and aircraft innovation materials, pharmaceuticals and life sciences, and environment- and energy-related materials as the most important fields for advanced material development. It also established process innovation, advanced nanotechnologies, basic materials and advanced molecular design, and biotechnology innovation as technologies for strategic enhancement. From a range of individual development projects, Toray selected its APEX 40 list of 40 projects that would offer the greatest impact when commercialized. From among those challenges, it also selected an APEX Challenge list of priority development projects with a particularly high level of difficulty.

In 2010, Toray established the new Advanced Materials Research Laboratories, within the Basic Research Center (name changed from Basic Research Laboratories), to enhance the Specialty Materials Research Laboratories function. In 2009, Toray also established the Automotive & Aircraft Center (A&A Center) within the Technology Center as the company's site for technology development in the automobile and aircraft field. Within that A&A Center, it located the Automotive Center, Advanced Composites Center, and Plastics Application Technology & Development Center.

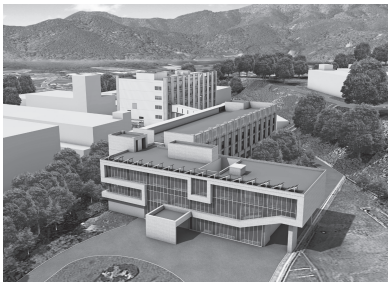
As an 80th anniversary project, Toray held the Toray Advanced Materials Symposium and Toray Advanced Materials Exhibition in 2006 to introduce Toray's advanced materials to the broader community. The Symposium included seminars by four world-renowned speakers. These events were also held in fiscal 2011 and fiscal 2016.

- **Green Innovation and Life Innovation Initiatives**

Toray launched the Action Program for Growth (Project AP-G) as a mid-term management program in April 2011. As part of its Project AP-G 2013, it established business expansion in growth business fields as one of its basic strategies. While maintaining its basic approach to research and development in areas such as open innovation, deepening core technologies and technology integration as previously discussed, this marked a shift to Green Innovation for Toray's important areas of research and development. Positioning its solutions businesses for global environmental issues and resource energy issues as Green Innovation businesses, Toray prioritized efficiency improvement for energy usage, new energy and non-fossil resource utilization, and seawater desalination and wastewater purification, as Green Innovation-related projects.

As part of Project AP-G 2016, launched in 2014, Toray added Life Innovation to its basic strategies as priority fields for research and development, and positioned improvement of the quality of healthcare, easing the burden on medical institutions, and contributing to health and longevity, as Life Innovation businesses. Following this program, Toray allocated 50 percent of its research and technology development budget to Green Innovation and 20 percent to Life Innovation, creating innovative

new materials and technologies as a result. The same strategies were retained in Project AP-G 2019, launched in 2017.



R&D Innovation Center for the Future (artist's impression)

In April 2016, as a 90th anniversary project, Toray made the decision to establish the R&D Innovation Center for the Future as a new research site at the Shiga Plant. (Construction is expected to be completed in December 2019.) It hopes to promote and enhance future-creation R&D—for *kotozukuri* (solution development) that utilize the strengths of materials—and life-enrichment R&D, in search of functions and systems required by the society of the future.

- **Implementation and Acceleration of New Product and Technology Development**

Alongside these R&D initiatives, the Technology Center also worked on accelerating the pace of development. In 2003, the Center brought together the functions of research, technology development, production and marketing, and established what it called the Jet Coaster Program, an awareness initiative to quickly tackle development issues from the customer's perspective. It also established a system for appropriate promotion of development themes in various categories: (1) Business expansion projects able to be developed into core businesses within two to three years, (2) Commercialization promotion projects able to become commercialized within two years, and (3) Commercialization potential

projects for quickly developing commercialization scenarios. In 2009, the Center also created an A1-DASH category, for projects able to produce results within one year, for the purpose of concentrating resources and accelerating technology development.

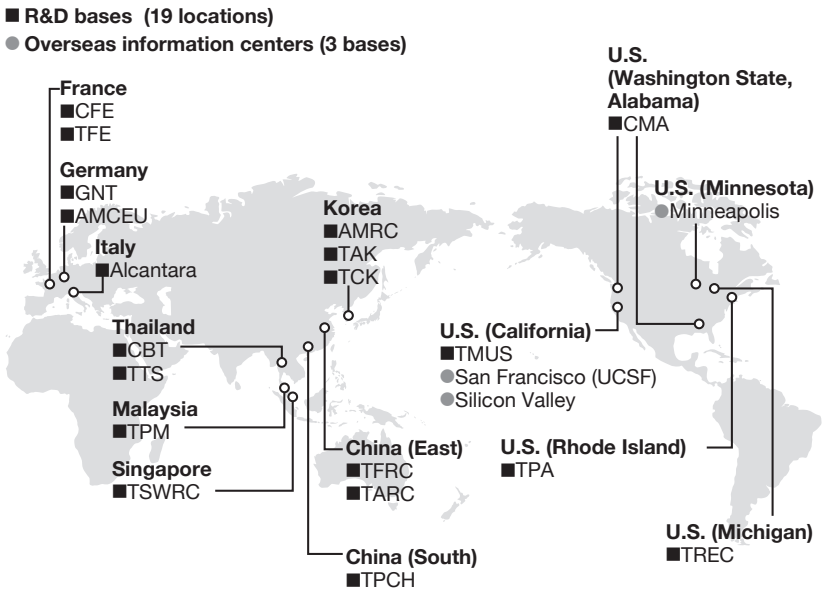
It also introduced pipeline management to continually generate promising projects by also preparing the next project related to the one in development, and the next one after that, at the same time. And it planned and invested in efficient development strategies from the mid- to long-term perspective.

- **Establishment and Expansion of Global R&D Bases**

Together with its business globalization, Toray actively promoted the globalization of its R&D bases. It focused on utilizing top researchers in each country and generating new ideas through an interdisciplinary/cross-cultural integration, while promoting joint R&D activities with local leading customers, universities, and research institutes. In China, where the fiber and textile industry was experiencing particularly strong growth, Toray established Toray Fibers & Textiles Research Laboratories (China) Co., Ltd. (TFRC) in 2002 as an R&D base for all polymer science, fiber and textile technologies. In 2004, it opened a Shanghai branch to develop advanced polymer materials. The branch became Toray Advanced Materials Research Laboratories (China) Co., Ltd. (TARC) in 2012. It also established the Carbon Fiber Composite Materials Technical Center in the U.S. in 2007, Advanced Materials Research Center (AMRC) in Korea in 2008, to develop advanced materials, and Toray Singapore Water Research Center (TSWRC) in 2009 to conduct water treatment research. As shown in table 8-4, Toray currently

has a global research and technology development network covering 19 locations in nine countries, with information centers in three locations.

## Table 8-4 Global R&D Bases (as of October 2017)




TFRC (China)

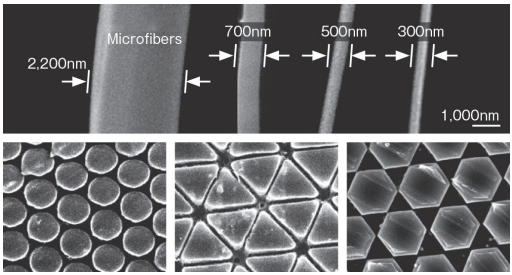
- **Main R&D Outcomes: 2002–2016**

As shown in table 8-5, outcomes of this period often concerned nano-technologies, biotechnologies and research technology integration.

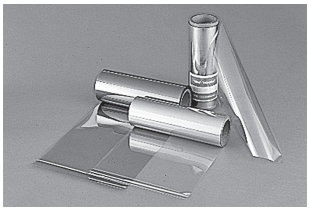
**Table 8-5 Main New Products (2002–2016)**

| Business Fields | New Products |
|---|---|
| Fibers and Textiles | 3GT stretch bicomponent fiber |
| | 'Heattech' heat-generating and heat-retaining innerwear(*1) |
| | Products using innovative nanofiber technologies |
| Resins and Chemicals | Self-organizing "Nanoalloy" products |
| | Chemical-resistant ABS/ polycarbonate (PC) resins |
| | "Ecodear" polylactic acid (resins, films, fibers) |
| Films | Biaxially-oriented "Nanoalloy" film |
| | "Picasus" ultra-thin multi-layer laminate film |
| Electronic and Information Materials and Devices | Organic electroluminescent (EL) red emitting materials and electron transport materials |
| | Polyimide (PI) coating materials for organic EL displays |
| | "Raybrid" photosensitive functional material for touch panels |
| Carbon Fiber Composite Materials | Products using ultra-high-speed press technologies |
| | High-cycle carbon fiber reinforced plastic (CFRP) for automobiles |
| | "Torayca" T1100G high-strength, high-modulus carbon fiber |
| Environment and Engineering | "Membray" submerged flat sheet membrane module for MBR |
| | "Torayfil" ultra-filtration (UF) membrane for wastewater reuse |
| Pharmaceuticals and Medical Products | "3D-Gene" DNA chips |
| | 'Remitch' oral antipruritus drug(*2) |
| | "Toraylight" NV dialysis membrane for inhibiting platelet adhesion |

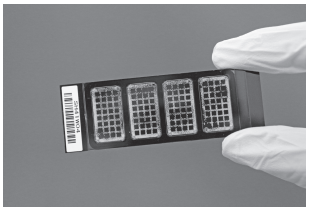
*1. 'Heattech' is a registered trademark of Fast Retailing Co., Ltd.
*2. 'Remitch' is a registered trademark of Torii Pharmaceutical Co., Ltd.




World's first modified cross-section nanofibers



Picasus nano meter-scale multi-layered laminate film



3D-Gene high-sensitivity DNA chips

- **Creating Further Advanced Materials**

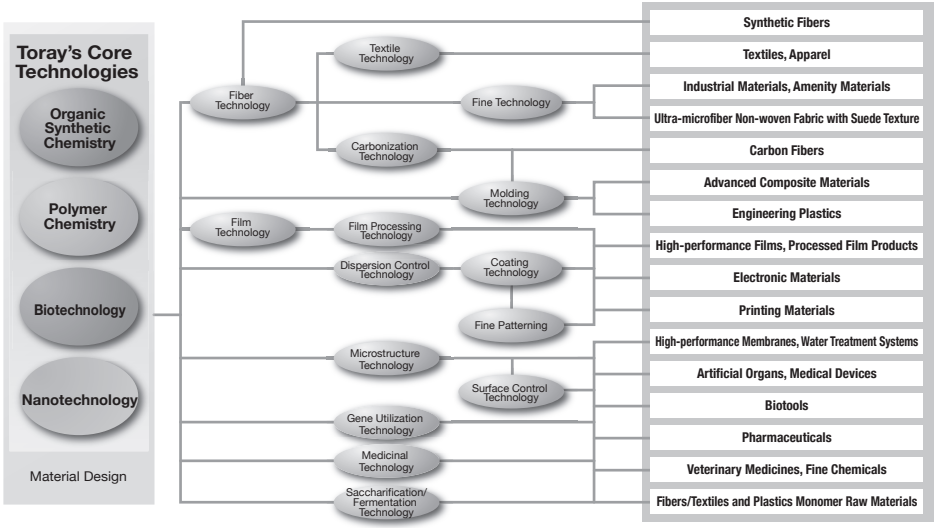
It takes a certain amount of time to develop and commercialize new materials. It is therefore vital to have insight into the value of materials, and to work persistently with a *super-continuity* approach. For example, Toray started researching carbon fibers in earnest in 1961, and started test production in 1971. It always hoped to extend the fiber to aircraft someday, but there was no carbon fiber market at the time. It developed markets for applications such as fishing rods and golf clubs, and kept refining its technologies while maintaining production. Eventually, Toray's carbon fiber composite materials were used as material for aircraft. Usage grew from secondary structural material to primary structural material as applications expanded, and it now accounts for more than half of

the structural materials used on Boeing 787s (a massive 35 tons approximately per aircraft). Commercial operation of 787s started in 2011, and with more than 1,200 confirmed orders for the aircraft as of June 2017 (according to the Japan Aircraft Development Corporation), the material is now flying around the world on a daily basis. The carbon fiber journey, from research and development to this point, has resulted in the creation of an enormous new business thanks to what was truly a massive investment in the future.

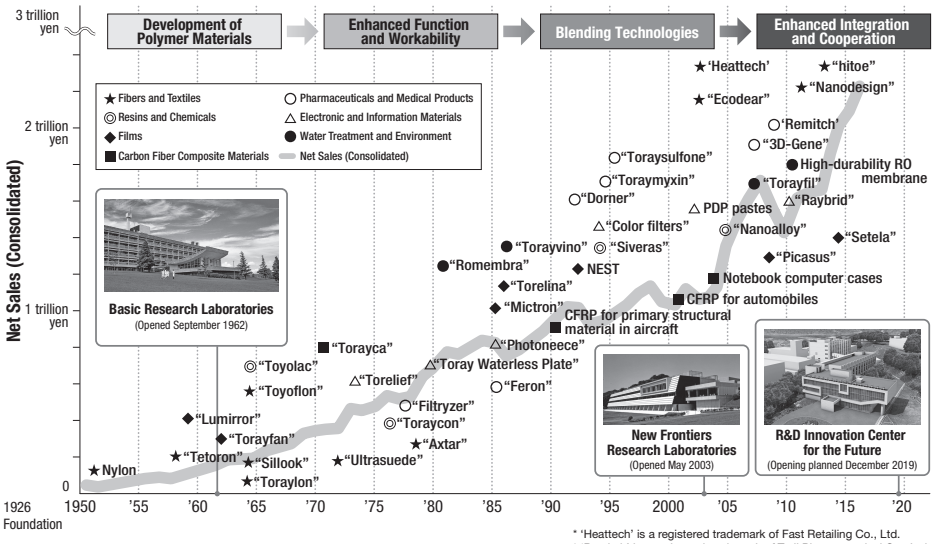
Boeing 787
©The Boeing Company (Photo courtesy of ANA)

Advanced materials, such as "Romembra" reverse osmosis (RO) membranes for water treatment and "Mictron" aramid film, are also the result of working persistently with this *super-continuity* approach. Inventions and discoveries that lead to major businesses do not occur every year. The fact is that it takes a while to commercialize products, so for Toray to continue expanding, it is essential that the seeds of major new businesses are continually planted. Toray believes that without material innovation, it would be unable to deliver essential solutions and attractive new products. Going forward, it will continue to create advanced materials through forward-looking research and technology development according to the needs of the times, and continue to tell the world about these advanced materials.

## Toray Technologies for Creating New Functions and Quality




## History of Toray's Progress and Product Development

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