Chapter 9

International Business Trends

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Several worldwide trends are apparent in the evolving advanced materials industries. These include a shift toward larger, more integrated companies, the growing multinational character of these companies, and increasing government support for development of advanced materials technologies.

In the long run, large integrated materials companies are likely to dominate the high volume markets for advanced materials. One reason is that the capital costs of scale-up and production are higher than most small companies can afford. Also, the close relationships between design, manufacturing, and quality control demanded by advanced materials are more consistent with the capabilities of a large, vertically integrated company. Because most of the value added in advanced materials businesses lies in the production of components and shapes, there is an economic incentive for suppliers of powders, resins, or fibers to vertically integrate into these downstream businesses.

Even so, small companies will also be an important force in advanced materials technology developments. Indeed, because current demand is primarily for research services or limited production of specialty materials for military use, small companies are already playing a major role in advanced materials development, especially in the area of metal matrix composites, Even among the large companies involved, their advanced materials divisions are typically minor sidelights of the main businesses. In the future, small companies will continue to be a source of innovative materials and processes and will continue to supply niche markets too small to attract the large integrated companies.

Through acquisitions, joint ventures, and licensing agreements, advanced materials industries have become markedly more international in character over the past several years. This tends to increase the rate of technology flow across national borders, creating new challenges and, potentially, new opportunities for U.S. companies. This trend also poses problems for the U.S. military, a major consumer of advanced materials, as it attempts to limit the dissemination of these technologies for national security reasons.

Throughout the world, government support for advanced materials development has been steadily increasing. These materials are seen as essential both to national economies and to national defense. Government programs can have a major impact on industry spending, by providing coordination, R&D funding, and markets, especially through the military. However, the real determinant of long-term commercial success is likely to be the commitment of the companies themselves.

Ceramics

The U.S. market for advanced ceramics in 1985 was about $1.9 billion (no data were available on U.S. production). Advanced ceramic production in Japan and Western Europe in 1985 were $2.3 billion and $0.5 billion respectively. In each of these three geographic regions, electronic or optical applications, such as capacitors, substrates, integrated circuit packages, and fiber optics, accounted for over 80 percent of the total. Structural applications, including wear parts, tools and accessories, and heat-resistant products, accounted for the remainder.

By a margin of nearly 2 to 1, the U.S. ceramics companies interviewed by OTA felt that Japan is the world leader in advanced ceramics R&D. Without question, Japan has been the leader in actually producing structural ceramic products for both industrial and consumer use. Japanese end users exhibit a commitment to the use of these materials not found in the United States. This commitment is reflected in the fact that although the U.S. and Japanese governments spend comparable amounts on ceramics R&D (roughly $100 million per year), Japanese industry spends far more on such R&D than does U.S. industry.

Japanese ceramics companies are far more vertically and horizontally integrated than U.S. companies, a fact that probably enhances their ability to produce higher quality ceramic parts at lower prices. However, these companies are probably still losing money on the structural ceramic parts they produce. This commitment reflects the long-term optimism of Japanese companies regarding the future of ceramics technologies.

The Japanese market for structural ceramics is likely to develop before the U.S. market. Ceramics technology already has a high profile in Japan, due in part to the Japanese industry strategy of producing low technology consumer goods, such as scissors and fish hooks, using high technology materials and processes. The overall goal of this strategy is the development of a high-technology manufacturing base to capture larger ceramics markets in the future.

Given the self-sufficiency of the Japanese ceramics industry, the Japanese market is likely to be difficult to penetrate by U.S. suppliers. In contrast, Japanese ceramics firms, which already dominate the world markets for electronic ceramics, are strongly positioned to exploit the U.S. market as it develops. One such firm, Kyocera, the largest and most highly integrated ceramics firm in the world, has already established subsidiaries and, recently, R&D centers in the United States.

West Germany, France, and the United Kingdom all have initiated large government programs in advanced ceramics R&D. West German companies have the strongest position in powders and finished products. Meanwhile, the European Community (EC) has earmarked $20 million for advanced ceramics research through 1989. Although Western Europe appears to have all of the necessary ingredients for its own structural ceramics industry, both the United States and Japan have a strong foothold in the European market for electronic ceramics.

Polymer Matrix Composites

The production value of finished advanced polymer matrix composite (PMC) components produced worldwide in 1985 was approximately $2.1 billion, divided roughly as follows: the United States, $1.3 billion; Japan, $200 million; and Western Europe, $600 million. The U.S. and European markets are dominated by aircraft and aerospace applications, while the Japanese domestic market is primarily in sporting goods. In the United States, advanced composites development is driven by military programs, while in Europe, advanced composites are predominantly used in commercial aircraft.

On the strength of its military aircraft and aerospace programs in PMCs, the United States leads the world in PMC technology. Due to the attractiveness of PMCs for new weapons programs, the military fraction of the market is likely to increase in the near term. However, due to the high cost of such military materials and structures, they are not likely to be used widely in commercial applications.

The commercial application of PMCs is an area where the United States remains vulnerable to competition from abroad. U.S. suppliers of PMC materials report that foreign commercial end users (particularly those outside the aerospace industry) are more active in experimenting with the new materials than are U.S. commercial end users. For example, Western Europe is considered to lead the world in composite medical devices. The regulatory environment controlling the use of new materials in the human body is currently less restricted in Europe than in the United States.

France is by far the dominant force in PMCs in Western Europe, with sales greater than all other European countries combined. West Germany, the United Kingdom, and Italy make up most of the balance. The commercial aircraft manufacturer, Airbus Industrie, a consortium of European companies, is the single largest consumer of PMCs in Western Europe. At the European Community level, significant expenditures are being made to facilitate the introduction of PMCs into commercial applications. In addition, the EUREKA program called Carmat 2000 proposes to spend $60 million through 1990 to develop PMC automobile structures.

In the past few years, the participation of Western European companies in the U.S. PMC market has increased dramatically. This has occurred primarily through their acquisitions of U.S. companies, a move that appears to reflect these companies' desire to participate more directly in the U.S. defense market and to establish a diversified, worldwide business. One result is that Western European companies now control 25 percent of resins, 20 percent of carbon fibers, and so percent of prepreg sales in the United States. A secondary result of these acquisitions is likely to be the transfer of U.S. PMC technology to Western Europe, such that Europe will eventually be less dependent on the United States for this technology.

Although Japan is the largest producer of carbon fiber in the world, it has has been only a minor participant to date in the advanced composites business. One reason is that Japan has not developed a domestic aircraft industry, the sector that currently uses the largest quantities of advanced composites, A second reason is that Japanese companies have been limited by licensing agreements from participating directly in the U.S. market.

Metal Matrix Composites

No estimates were available to OTA of the value of current MMC production in the United States, Japan, and Western Europe. The principal markets for MMC materials in the United States and Western Europe are in the defense and aerospace sectors. Accordingly, over 90 percent ($1 54.5 million of $163.6 million) of the U.S. Government funding for MMC R&D between 1979 and 1986 came from DoD.

The structures of the U.S. and European MMC industries are similar, with small, undercapitalized firms supplying the formulated MMC materials. Some analysts feel that the integration of the small MMC suppliers into larger concerns having access to more capital will be a critical step in producing reliable, low-cost materials,

Currently, the most common matrix used is aluminum. The large aluminum companies have active R&D programs under way, and they are considering forward integration into MMCs. There are also in-house efforts at the major aircraft companies to develop new composites and new processing methods,

Unlike their small, undercapitalized counterparts in the United States and Western Europe, the Japanese companies involved in manufacturing MMCs are largely the same as those involved in supplying PMCs and ceramics; i.e., the large integrated materials companies. Another difference is that Japanese MMC suppliers focus primarily on commercial applications, including electronics, sporting goods, automobiles, and aircraft and aerospace structures.

One noteworthy Japanese MMC development is the introduction by Toyota of a diesel engine piston consisting of aluminum locally reinforced with ceramic fibers. This is an important harbinger of the use of MMCs in low-cost, high-volume applications, and it has stirred considerable worldwide interest among potential commercial users of MMCs.

INTRODUCTION

Advanced structural materials technologies are becoming markedly more international in character. Through acquisitions, joint ventures, and licensing agreements, the firms involved are seeking both access to growing worldwide markets and ways of lowering their production costs. Governments around the world are investing large sums in multi-year programs in collaboration with industry to facilitate commercial development. Critical technological advances continue to come from other countries; e.g., carbon fiber technology from the United Kingdom and Japan, weaving technology from France, and hot isostatic pressing technology from Sweden.

This trend toward internationalization of the technology has many important consequences for U.S. Government and industry policy makers. The United States can no longer assume that it will dominate the technological advances and the applications resulting from them. The influx of foreign technology may be just as significant in the future as that flowing out. Moreover, the increasingly multinational character of materials industries suggests that the rate of technology flow among firms and countries is likely to increase in the future. For the United States as for other countries, it will not be possible to rely on a superior research and development capability to provide the advantage in developing commercial products. Rather, if the technology infrastructure is not in place for quickly appropriating the results of R&D for economic development, those results will first be used elsewhere.

The consequences of globalization of advanced structural materials technologies are perhaps most starkly important for military policy. Military programs are often responsible for the initial development and use of new materials in the United States, and all indications are that the involvement of the military is likely to increase in the future. The military has an interest in preventing the flow of this technology to unfriendly countries, and in securing domestic sources of the materials involved. Both of these interests are complicated by the globalization of the industry. Attempts to erect barriers to the international transfer of technology may result in the United States being bypassed both in the technology and in market opportunities abroad. In effect, U.S. military interests, which are based on a national perspective, are on a collision course with U.S. commercial interests, which have taken on an international aspect. The consequences of increasing military activity in advanced materials R&D are discussed more fully in chapter 11.

This chapter presents a comparative analysis of advanced structural materials industry trends in the United States, Western Europe, and Japan. These regions were chosen because they appear to have the strongest government and industry programs for developing and applying advanced materials. The changing industry structures and relationships with government institutions are examined to illustrate the factors that will determine the relative competitiveness of advanced materials users and suppliers in the future, Data for this chapter were gathered through extensive interviews with government and industry personnel, as well as through literature and computer database searches.[1,2]

[1]Business Communications Co., Inc., "Strategies of Advanced Materials Suppliers and Users, " a contractor report prepared for OTA, Jan. 28, 1987.

[2]Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials, " a contractor report prepared for OTA, Mar. 24, 1987.

CERAMICS

The value of advanced ceramics consumed in the United States, and produced in Japan and Western Europe in 1985 is estimated in table 9-1. (No data were available on U.S. production.) Electronic applications for advanced ceramics, such as integrated circuit packages and capacitors, are considerably more mature than structural applications, and accounted for at least 80 percent of total production. Structural ceramics of the type considered in this assessment accounted for the remainder. This dominance of electronic markets over structural markets is likely to prevail into the next century.[3]

[3]Greg Fisher, "Strategies Emerge for the Advanced Ceramics Business, " *American Ceramic Society Bulletin,* vol. 65, No. 1, January *1986.*

Comparisons among advanced ceramics markets in these three regions are complicated by two factors. First, there is little agreement on what categories of ceramics should be considered "advanced"; Japanese estimates tend to include additional categories, such as alumina catalyst supports, that are normally excluded in Western calculations. Thus, it is important to specify the categories being included along with the numbers. A second factor is that the current U.S. Standard Industrial Classification (SIC) codes used to collect industry performance statistics are too broad to distinguish advanced ceramics from traditional ceramics, such as tableware. Thus, the United States has no reliable index with which to track the performance of its advanced ceramics

Table 9-1 .—Value of Advanced Ceramics Consumed in the United States, and Produced in Japan and Western Europe in 1985 ($ millions)

Region	Electronic[a] applications	Structural[b] applications	Total
United States[c]	1,763	112	1,875
Japan	1,920	360	2,280
Western Europe	390	80	470

[a]Includes packages/substrates, capacitors, ferrites, piezoelectrics, resistors.
[b]Includes automatize parts (pistons, liners, valves, bearings), cutting tools, industrial (bearings, seals, microfilters, grinding media for ball mills, sandblast nozzles, sensors), aerospace parts (space shuttle tiles, etc.), and bioceramics.
consumption in 1985,

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987; and Business Communications Co., Inc., "Strategies of Advanced Materials Suppliers and Users, " a contractor report prepared for OTA, Jan. 28, 1987.

industry. This contrasts sharply with the situation in Japan, where the Ministry of International Trade and Industry (MITI) publishes detailed advanced ceramics production figures each month, broken out by category and including import and export activity. The need for better statistical information on the U.S. advanced ceramics industry is discussed further in chapter 12.

United States

Today, the U.S. advanced ceramics industry faces major challenges from foreign competition. Over the past decade, the U.S. share of the world markets for electronic ceramic components, which constitute about 80 percent of total advanced ceramics markets, has largely been lost to Japan. The race to commercialize advanced structural ceramics is still being run; however, there is ample reason for concern about the outcome. For instance, in spite of large Federal programs aimed at development of ceramic engine components beginning in the early 1970s, and substantial ceramic R&D efforts within the U.S. automobile companies and their suppliers, Detroit has yet to introduce a U.S.-made structural ceramic component in a production automobile. This situation contrasts sharply with that in Japan, where Nissan began introducing ceramic turbocharger rotors in 1985.

The future competitive position of U.S. companies is likely to depend on several factors, including company size and level of integration, participation in cooperative industry/industry or government/industry efforts, and, perhaps most importantly, the willingness of companies (particularly end users) to invest their own capital in long-term development efforts. These factors are discussed further below.

Industry Structure

The most important U.S. participants in the advanced ceramics industry tend to be medium- or large-sized corporations that have experience with traditional ceramics or that are diversifying from other structural materials areas. These include Norton Co., Champion Spark Plug, Standard Oil Engineered Materials, Coors Ceramics, GTE, and Alcoa. The major U.S. companies that have structural ceramics products in production are listed in table 9-2. Most of these products are wear parts, refractories, cutting tools, or military items such as armor and radomes. Those companies that have major ongoing R&D efforts, but few if any commercial products are listed in table 9-3. New participants in the industry may

Table 9-2.—Major U.S. Companies With Structural Ceramics Products in Production, 1986

Company	Products
Advanced Refractories Technologies	Powders, nuclear products
Aluminum Co. of America	Powders, wear parts
Ceradyne	Armor, aerospace products, electronics
Champion Spark Plug Co.	Powders, insulators, jet igniters
Coors Ceramics Co.	refractory tubes, rods, electronics, wear parts
Corning Glass Works	Glass and glass/ceramics, aerospace windows, refractories
E.I. Du Pont de Nemours & co.	Fibers
GTE Products Corp.	Wear parts, radomes, engine parts, electronics, Klystron and X-ray tubes
W.R. Grace & Co.	Grinding media, mill linings
Kennametal, Inc.	Cutting tools, wear parts, armor, gun parts
Norton Co.	Powders, bearings, filters, armor, cutting tools
Standard Oil Engineered Materials Co.	Refractories, heating elements, fibers, heat exchangers, wear parts
Solar Turbines, Inc.	Coatings, heat exchangers
3M Co.	Fibers
Union Carbide Corn.	Powders, coatings

SOURCE: Business Communications Co., Inc., "Strategies of Advanced Materials Suppliers and Users, " a contractor report prepared for OTA, Jan. 28, 1987.

Table 9-3.—Major U.S. Companies With Ongoing Structural Ceramics R&D Efforts, 1986 (littie or no commercial production)

Company	R&D area
Aerospace Corp.	**Space systems**
Air Products and Chemicals, inc.	Coatings
Astromet Associates	Refractories, wear parts, electronics, coatings
Avco Corp.	
Specialty Materials Division	Aerospace materials: heat shields, reentry systems
Brunswick Corp.	Radomes, missile systems
Cummins Engine Co.	Diesel engine parts
Ford Motor Co.	Diesel, turbine, and gas engine components; cutting tools
Garrett Corp.	
AiResearch Casting Co.	Turbomachinery
Garrett Turbine Engine co.	Gas turbine engine components
General Motors Corp.	
Allison Gas Turbine Division	**Gas** turbine engine parts
Detroit Diesel Allison	Diesel engine parts
Howmet Turbine	Wear parts, specialty ceramics

SOURCE: Business Communications Co., Inc., "Strategies of Advanced Materials Suppliers and Users," a contractor report prepared for OTA, Jan. 28, 1987.

come from chemical, petroleum, and other materials-based industries. Such companies, including Dow Chemical, Arco, Mobay, and Manville, already have experience with related processing technologies such as sintering, hot isostatic pressing, or sol-gel powder production methods.

In recent years, there has been a trend toward vertical integration from powder suppliers to finished components. Full vertical integration means the in-house capability to produce powders and process them into a finished product. A vertically integrated company has a high degree of control over all steps in the fabrication of the product, and it profits from sales of the higher value--added finished product. A vertically integrated ceramics supplier may hold an advantage over its more fragmented competitors in that an end user—e.g. an automobile company or a turbine producer–often prefers to obtain a complete system rather than obtaining all of the parts and assembling the product. This is particularly true of new materials used initially in low volumes.

In practice, there are few U.S. advanced materials companies that can be considered truly integrated. Alcoa has plans to move in that direction, and companies such as Corning Glass and Norton already have much of the required capability. Most U.S. ceramics companies are partially integrated; i.e., they perform some combination of powder production, design, assembly, machining, or testing in-house, but rely on outside sourcing for some essential functions. Examples include Cummins Engine Co., Kennemetal, Inc., and Solar Turbines, Inc.

Currently, there are no U.S. companies that could be considered horizontally integrated, i.e., that make a variety of products that use similar materials. Horizontally integrated companies have the capability of transferring knowledge and experience acquired in one ceramic application to another. An excellent example of a horizontally integrated company is the Japanese firm Kyocera, which is a world leader in electronic ceramics but also produces ceramic cutting tools, auto parts, and bearings. Kyocera also has a large subsidiary in the United States.

According to industry executives interviewed by OTA, it appears likely that there will be a restructuring of the U.S. ceramics industry over the next few years. There will probably be some new entrants, such as the chemical companies indicated above; however, overall it is expected that there will be a consolidation of efforts. This is likely to occur for two reasons. First, the small current markets for ceramics can support only a limited number of companies, and, given the technical and economic barriers that continue to plague structural ceramics, these markets are unlikely to expand rapidly in the next few years. Second, the complex technical requirements for successful participation in the industry necessitate a greater commitment of money, skilled personnel, and facilities than can be afforded by most firms.

Consolidation is likely to occur in the form of an increasing number of acquisitions, mergers, joint ventures, and other types of joint relationships. OTA found that 76 percent of the companies interviewed either were engaged in, or were seeking a joint venture.[4] A representative com-

[4] Business Communications Co., Inc., op. cit., 1987.

pilation of recent acquisitions, mergers, and joint ventures in the advanced ceramics industry is given in appendix 9-1 at the end of this chapter.

Foreign Participation in the U.S. Market

Foreign companies are positioning themselves to take a large part of the slowly developing U.S. market for structural ceramics. To date, there have been relatively few actual foreign acquisitions, although appendix 9-I shows that joint ventures between foreign and U.S. ceramics companies are common, and several foreign companies are building plants in the United States. A compelling example of this trend is provided by the Japanese firm Kyocera. Kyocera's U.S. subsidiary is planning a large R&D center at its facility in Vancouver, Washington. Some of the best U.S. advanced ceramics scientists and engineers will be invited to do research there, where Kyocera will also provide condominium-style housing for the researchers and their families. Kyocera has also endowed ceramics professorships at the Massachusetts Institute of Technology, Case Western Reserve University, and the University of Washington.

Government/Industry Relationships

The U.S. Government spends $100 to$125 million annually on advanced ceramics R&D, more than any other country.[5] A breakout of Federal funding for structural ceramics in fiscal year 1987 is given in table 10 of chapter 2. In order of decreasing expenditure, the principal agencies funding structural ceramics R&D are the Department of Energy (DOE), Department of Defense (DoD), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and **National Bureau of Standards (NBS),** for a total of around $65 million in fiscal year 1987. A large proportion of this was spent for R&D performed within industrial laboratories; e.g., in fiscal year 1985, 57 percent of a total of $54.5 million went for work performed in industrial laboratories, 30 percent to Federal laboratories, 12 percent to universities, and 1 percent to non-profit laboratories.[6]

DOE laboratories such as Oak Ridge, Argonne, Los Alamos, Sandia, and Lawrence Berkeley have large ceramics programs and many industrial contractors. Major ongoing programs in ceramic technology development include DOE's Heat Engine Propulsion Program, administered by Oak Ridge National Laboratory. Fiscal year 1987 funding was $22.5 million, including **$4.5 million** for heavy-duty diesel transport, $8 million for advanced Stirling engine development, and $10 million for the Advanced Gas Turbine Program, which became the Advanced Turbine Technology Applications Program (AITAP) in 1987. DOE is also funding the Advanced Heat Exchanger Program in its Office of Industrial Programs, at about $2 million in fiscal year 1987.[7]

As yet, DOE industrial contractors have not deemed it profitable to launch major efforts to commercialize products resulting from these programs. Program cost sharing by industry averages around 20 percent, which is enough to secure an exclusive license for the technology from the government.[8] Over 85 percent of the industry executives contacted by OTA felt that continued government support for the industry was necessary.

The United States Advanced Ceramics Association (USACA) has recently completed a survey that estimates annual U.S. industry investment in ceramics R&D at $153 million, some 20 percent higher than the Federal R&D figure.[9] This situation contrasts sharply with that prevailing in Japan, where industry is estimated to spend some four times more than the government for ceramics R&D. '"

In recent years there has been growing State and regional funding for development of advanced ceramics. Several States, including New York, New Jersey, Ohio, and Pennsylvania, now fund centers of excellence in ceramics based at

[5]John B. Wachtman, "U.S. Continues Strong Surge in Ceramic R& D," *Ceramic Irrdustry,* September 1986.

'According to an unpublished survey performed by S.J. Dapkunas, National Bureau of Standards.

[7]According t. presentation by Robert B. Schulz, Department of Energy, at the Interagency Coordinating Committee Meeting on Structural Ceramics, National Bureau of Standards, *May 1987.*

[8]Ibid.

[9]Steve Hellem, Executive Director, United States Advanced Ceramics Association, personal communication, November 1987.

[10]This estimate assumes that the Ministry of International Trade and Industry (MITI) figures for the industry/government investment ratio for all Japanese R&D holds true for advanced ceramics.

local universities, and some have initiated technology incubation programs designed to assist small start-up ceramics companies. The opportunities for government/university/industry collaboration in advanced materials R&D are discussed in greater detail in chapter 10.

Industry Associations and Professional Societies

Industry associations and professional societies perform two important functions that enhance the competitive position of U.S. companies. First, they organize regular meetings that serve as forums for the exchange of new ideas. Second, they serve as points of aggregation for the needs and concerns of the affiliated companies, and they help to communicate these needs to government.

A variety of professional societies sponsor meetings and other activities relating to advanced ceramic materials, as do such government agencies as DOE, NASA, and DoD. These include the American Ceramic Society (ACerS), ASM international, the Federation of Materials Societies (FMS), and the American Institute of Chemical Engineers (AIChE).

In 1985, a trade association called the United States Advanced Ceramics Association (USACA) was formed to promote the interests of U.S. ceramics companies by gathering and disseminating information on worldwide ceramics activities, identifying opportunities and barriers to commercialization, and providing industry input to government on such issues as process patents, standards, and R&D policy. It is a national association representing more than 30 companies with an interest in the emerging field of advanced ceramics. USACA membership as of 1987 is given in table 9-4.

Table 9.4.—United States Advanced Ceramics Association Membership List, November 1987

Member Company
Air Products and Chemicals, Inc.
Allied-Signal Aerospace
Aluminum Company of America
AVX Corp.
Blasch Precision Ceramics, Inc.
Celanese Corp.
Ceradyne
Champion Spark Plug Co.
Chrysler Corp.
Coors Ceramics Co.
Corhart Refractories, Inc.
Corning Glass Works
Deere & Co.
Dow Chemical Co.
Dow Corning Co.
E.I. du Pont de Nemours & Co,
Electro-Science Laboratories, Inc.
Engelhard Corp.
Ferro Corp.
GA Technologies, Inc.
General Ceramics, Inc.
General Motors Corp.
GTE Products Corp.
Harshaw/Filtrol Partnership
IBM Corp.
Lanxide Corp.
Martin Marietta Corp.
Norton Co.
PPG Industries
Standard Oil Engineered Materials Co.
Sundstrand Corp.
The Titan Corp.
3M Co.
Union Carbide Corp.
W.R. Grace & Co.

SOURCE: United States Advanced Ceramics Association.

Japan

With limited metal and timber resources, Japan has historically placed a great emphasis on ceramics, which can be made from abundant raw materials. Japan has attained a leadership position in advanced ceramics through its eminence in the electronic ceramics market, including capacitors and substrates/packages, a business that was dominated by the United States just a decade ago. The assets, human resources, and experience gained through developing and manufacturing electronic ceramics have put Japanese companies in a strong position to develop advanced ceramics for structural applications.

Japan's commitment to ceramics technology has been highlighted recently.[11] Japanese Government and industry have long been very optimistic about the market potential for advanced ceramics. For example, a recent projection by the Ministry of International Trade and Industry (MITI) put the annual market for all advanced ceramics at $30 billion by the year 2000 in Japan alone.[12] Most estimates of the U.S. market in this

[11] National Materials Advisry Board, "High Technology Ceramics in Japan, " NMAB-418, (Washington, DC: National Academy Press, 1984).

[12] *Materials and Processing Report*, Renee Ford (cd.), vol. 1, No. 5 (Cambridge, MA: MIT Press, August 1986).

time frame are one-third to one-half as large. Although MITI's **estimate includes a wider spectrum of materials and products than most such estimates, it reflects the broad consensus within Japan that advanced ceramics is a key technology** for the future.

Industry Structure

Many Japanese companies participate in the advanced ceramics industry, including roughly 100 powder suppliers, **250** suppliers of finished components, and 150 equipment suppliers. Recent entrants into this field include steel, cement, and petrochemical companies.

Major Japanese powder suppliers are listed in table 9-5. Many are vertically integrated, and also produce shapes. A prime example, Kyocera, manufactures shapes used in both electronic and structural applications from powders produced captively.

Leading manufacturers of finished ceramic components are listed in table 9-6. Kyocera, NGK Spark Plug, and Narumi China are leading producers. Japanese manufacturers of finished ceramic components tend to offer products to more than one end-use market; i.e., they are horizontally integrated.

A critical difference between Japan and the United States is the commitment of Japanese commercial end users to incorporate ceramics in current products. Examples are given in table 9-7. In most cases, this commitment is made in spite of the fact that the ceramic component is more expensive than the metal component it replaces. For instance, the production cost of the ceramic turbocharger rotor used in the Nissan Fairlady Z automobile is reportedly in the range of $60; by comparison, U.S. companies generally feel that costs must fall below $15 per rotor before production would be considered.

Foreign Participation in the Japanese Market

Traditionally, corporate acquisitions within Japan are rare. In fact, there is no simple way of saying "takeover" or "acquisition" **in Japanese.**

Table 9-5.—Major Japanese Powder Suppliers

Supplier	Oxides	Nitrides	Carbides	Other
Asahi Chemical	X			
Chichibu Cement	X[a]			
Daiichi Kigenso	X			
Denki Kagaku Kogyo		X	X	
Fuji Titanium				X
Hitachi				X
Hitachi Chemical Ceramics			X	
Hitachi Metals				X
Japan New Metals		X	X	
Kawasaki Steel	X			
Kyocera	X			X
Kyoritsu Ceramics	X	X	X	
Mitsubishi Chemical				X
Mitsubishi Mining & Cement	X			
Murata Manufacturing	X			
Nippon Kokan	X[a]	X[a]		
Nippon Steel	X[a]	X[a]	X[a]	X[a]
Shin Nippon Kinzoku Kagaku			X	
Shinagawa Refractories				X
Showa Aluminum	X			
Showa Denko	X[a]	X	X	
Sumitomo Chemical	X	X		
Sumitomo Electric	X	X[a]	X[a]	
Toray				X
Toyo Soda	X	X[b]		
Ube Industries	X		X[a]	

[a]Products are under development.
b Minor supplier of silicon nitride.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987,

Table 9-6.—Major Japanese Manufacturers of Finished Ceramic Components

Asahi Glass
Asahi Optical
Figaro Engineering
Hitachi
Hitachi Chemical Ceramics
Hitachi Metals
Koh'a China
Koransha Insulators
Kurosaki Refractories
Kyocera
Matsushita Electronic Components
Mitsubishi Heavy Industries
Mitsubishi Metals
NGK Insulators
NGK Spark Plug
Narumi China
Nippon Denso
Nippon Tungsten
Noritake
Shinagawa Refractories
Showa Denko
Sumitomo Electric
Toshiba Ceramics
Toshiba Tungaloy

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

The Japanese word for it, "nottori," also means "hi jacking." Acquisition of a Japanese firm is considered humiliating for the firm's management. One exception is if a company wants to enter a business and it acquires a company with a declining market position.

Overall, the Japanese Government is gradually making it easier for foreign firms to invest in Japanese companies. However, this is a recent development. Although no official statistics are available, industry sources estimate that the number of investments by foreign firms in Japanese companies is less than a dozen per year in all industries.[13] Initially, foreign investors take a minority interest, with the intent of increasing their share over time.

Formation of joint ventures is increasing in popularity within the Japanese advanced ceramics industry. Although it is most common that both partners are Japanese, some U.S. industry sources believe that joint ventures represent the best means for foreign companies to participate in the Japanese market. Recently formed joint ventures—including some involving foreign corporations—are listed in Appendix 9-2.

Although not actually joint ventures, informal collaboration among Japanese companies to develop ceramic products is common, particularly in the automotive sector, as shown in table 9-8.

Licensing agreements involving ceramics companies are relatively uncommon in Japan. Those

[13] Strategic Analysis Inc., op. cit., 1987.

Table 9-7.—Major Japanese Users of Ceramic Parts or Components

End user	Automotive	Aerospace	Biomedical	Other[a]
Toyota Motors	X[b]			
Nissan Motors	X			
Fuji Heavy Industries	X			
Matsuda Motors	X[c]			
Isuzu Motors	X[c]			
Mitsubishi Heavy Industries		X[b]		
Kawasaki Heavy Industries		X		
Showa Aircraft		X		
Mitsubishi Electric		X		X
Asahi Optical			X[b]	
Kyocera	X[b]		X[b]	X[b]
Koransha Insulators			X[b]	X[b]
Mitsubishi Mining & Cement			X[b]	X[b]
Toray				X[b]
Noritake				X[b]
ARS Edge				X[b]
Fujitsu				X
Toshiba				X[b]
Matsushita Electric Components				X[b]

[a] Includes electronics and wear Parts.
[b] Manufactures ceramic components captively for these applications.
[c] Products under development.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar, 24, 1987,

Table 9-8.—Collaborative Programs Between Japanese Automobile and Ceramics Companies

Automobile manufacturer	Ceramics company	Focus of program
Isuzu Motors	Kyocera	Diesel engine parts
Mitsubishi Motors	Asahi Glass	Auto parts
	NGK Insulators	Rocker arms
Nissan Motors	Hitachi Chemical	Turbocharger rotors
	NGK Spark Plug	Turbocharger rotors
	NGK Insulators	Turbocharger rotors
Toyota Motors	Toshiba	Ermine parts

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar, 24, 1987.

identified primarily involve the processing of raw materials. Some recent licensing agreements are included in appendix 9-2. Technology exchanges that are short of formal licensing agreements also exist between the following Japanese companies and foreign companies: Toshiba and Cummins Engine Co. (USA); NGK Insulators and Cummins; and NGK Spark Plug and ICI (UK).

Government/Industry Relationships

Japan has developed an international reputation for the close cooperation in technology development that exists among government, academia, economic institutions, and industry. From a U.S. perspective, the Japanese system contains several unusual features, including: scientific and technological competence at the highest levels of government and industry policymaking; a mechanism for developing a national consensus among government, industry, and academia as to technological goals; and a willingness of financial institutions and industries to cooperate with the government in achieving the consensus goals.

The role of the Japanese Government in advanced materials development has been reviewed recently.[14 15] Figure 9-1 shows the relationships among the most important Japanese Government agencies responsible for science and technology policy. The three principal agencies involved in advanced ceramics R&D are MITI, the Science and Technology Agency (STA), and the Ministry of Education.

[14]National Materials Advisory Board, op. cit., 1984.

[15]"JTECH Panel Report on Advanced Materials in Japan," JTECH-TAR-8502, a contract study prepared for the National Science Foundation by Science Applications International Corp., May 1986.

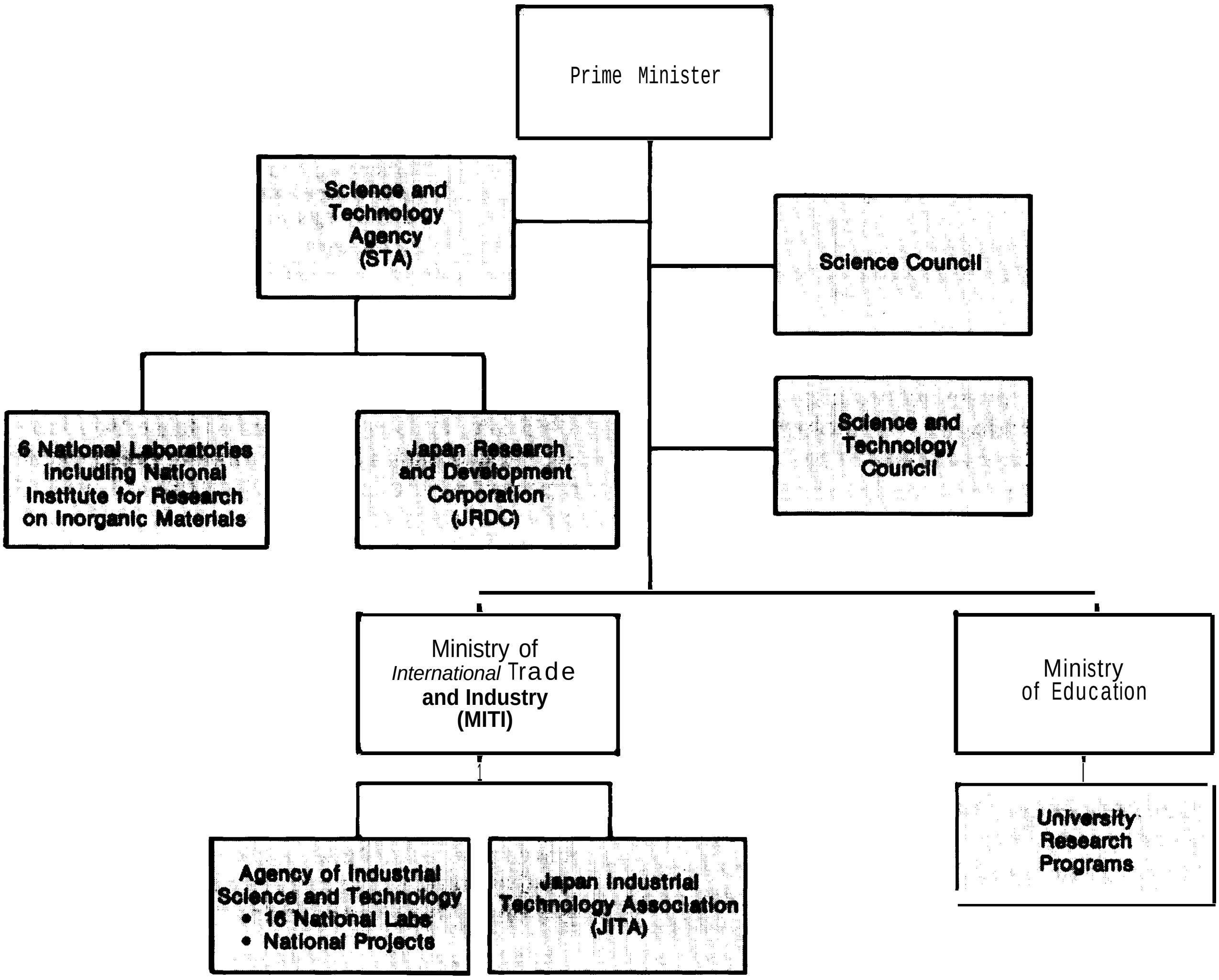
A breakdown of government funding for both structural and electronic advanced ceramics in 1983 and 1985 is presented in table 9-9. However, these data, like other funding data typically reported by the Japanese Government, include only the costs of resources and capital equipment; they omit overhead and salary expenses. Such basic expenses normally account for only about 20 percent of a typical U.S. government contract. Therefore, to compare these figures with similar U.S. figures, they should be scaled up by roughly a factor of five. According to the raw figures in table 9-9, MITI, STA, and the Ministry of Education all spent roughly comparable amounts for a total of about $20 million in 1985. That would scale up to about $100 million when salary and overhead expenses are added—roughly comparable to the estimates of $100-125 million in the United States.[16]

MITI reports that private and government funding sources provide 79 percent and 21 percent, respectively, of the expenses for all R&D in Japan. Although figures are not available for private sector ceramics R&D, industry sources report that the amount funded by private industry is much larger than that funded by government. Assuming that the ratio for all R&D holds for ceramics, this would put industry's investment level at about $400 million per year in Japan.

MITI's primary thrust in advanced materials is through its Agency of Industrial Science and Technology (AIST), which promotes industrial R&D to strengthen the country's mining and manufacturing industries. AIST oversees the opera-

[16]John B. Wachtman, op. cit., 1986.

Figure 9-1.—Japanese Government Agencies Responsible for Science and Technology Policy



SOURCE: Adapted from Science Applications International Corp., JTECH Panel Report on Advanced Materials in Japan, a contractor study prepared for the National Science Foundation, May 1988.

tions of 16 national laboratories, with an annual budget of $600 million in 1985. In 1981, MITI also initiated the R&D Project on Basic Technology for Future Industries, a 10-year, $32 miliion project to be carried out completely in private industry. This program involves extensive government/industry coordination and includes seven projects on advanced materials, among them one on ceramics.[17] In FY 1988, MITI is planning to initiate an 8-year joint R&D project with Toyota, Nissan, Mitsubishi, Kyocera, and Isuzu to develop a ceramic gas turbine engine. Development costs are expected to be 20 billion yen (about $138 million).[18] In addition, a 9-year, $105 million program, aimed at developing a stationary ceramic gas turbine for power generation, has also been requested to begin in fiscal year 1988.[19]

In addition to sponsoring ceramics R&D, MITI promotes the use of new ceramics technologies in industry. For instance, the Japan Industrial Technology Association (JITA), under MITI, promotes the transfer of technology from AIST laboratories to industry, and it serves as a clearing house for domestic and foreign technical infor-

[17] National Materials Advisory Board, op. cit., 1984.

[18] "Deja Vu–Yet Again, " *Forbes, Nov. 16, 1987,* p. *282.*

[19] According t. information provided by Robert B. Schulz, U.S. Department of Energy, November 1987.

Table 9-9.—Japanese Government Funding for Advanced Structural and Electronic Ceramics[a]

Government source	Funding ($ million)[b] 1983	1985
Ministry of International Trade and Industry:		
R&D Project on Basic Technology for Future Industries	***3.2***	***3.5***
National Laboratories	2.0	***2.3***
Agency of Natural Resources and Energy	0.0	0.8
Consumer Goods Industry Bureau	0.2	0.1
Other agencies	0.3	0.6
Science and Technology Agency:		
Research and Development Corp. of Japan	1.2	***1.6***
National Institute for Research On Inorganic Materials	8.0	8.8
Ministry of Education	1.5	1.6
Total	16.4	19.3

[a]Includes Only costs of resources and capital equipment. Does not include overhead and salary expenses.
[b]Constant 1985 dollars. 1 US$ = 200 Yen
[c]Includes funds for all ceramics-related research, primarily advanced ceramics.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials, " a contractor report prepared for OTA, Mar. 24, 1987,

mation. JITA also provides an advisory service on patents. Private organizations that have been set up to license AIST patents and technology are the Japan Patent Information Center (JAPATIC) and the Industrial Technology Promotion Association (ITPA), which are provided with the most promising government patents.

MITI's AIST also has control over disbursement of funds from the Japan Development Bank (JDB), a government financial institution that may make loans to ventures sanctioned by the government at rates lower than market rates. Such interlocking of government, industry, and financial institutions is a very important aspect of Japanese industrial policy.

The STA has responsibility for developing and implementing science policy directives received from the prime minister. These directives are based on recommendations from the Council on Science and Technology and the Science Council of Japan, a cabinet-level advisory group. STA administers six government laboratories, including the National Institute for Research on Inorganic Materials (NIRIM), a major center for ceramics research in Japan. NIRIM maintains an extensive visiting scientist program, to which researchers from universities and private industry are temporarily transferred by their home institutions.

Like MITI, STA promotes the use of advanced ceramics technologies in industry. For instance, STA's Japan Research and Development Corp. (JRDC), a nonprofit, quasi-governmental corporation patterned after the National Research and Development Corporation (NRDC) in the United Kingdom, is chartered to promote commercial exploitation of government and university research results. JRDC selects research results having good commercial potential and underwrites a large fraction of the selected private firm's development costs in the form of interest-free loans. These loans are not repaid if the venture is not successful. JRDC may also serve as a broker between a government inventor or researcher and a small company desiring to commercialize the invention or research result.

The Ministry of Education sponsors R&D activities at universities and attempts to facilitate cooperation among universities. Formal consulting arrangements between industry and university researchers are not permitted. However, interactions among industry, university, and national laboratories are facilitated by personnel exchange programs. It is common for senior visiting scientists from industry to spend 2 or more years in residence in university or government laboratories while on full salary from their permanent employers.[20]

Despite the careful attention to technology development and use embodied in the various government agencies and policies described above, it is important to stress that by far the greater burden of Japanese ceramics R&D is shouldered by industry. Japan has succeeded in developing a national consensus that ceramics technologies are the way of the future, and Japanese industry has made a long-term commitment to the commercialization of these technologies. Particularly significant is the commitment of end user companies, such as automobile companies, to

[20]Robert J. Gottschall, "Basic Research in Ceramic and Semiconductor Science at Selected Japanese Laboratories," DOE/ER-0314, a trip report prepared for the U.S. Department of Energy, March 1987, p. 5.

incorporate ceramics in current products, even though it is not profitable to do so at present. For example, Toyota plans to produce an all-ceramic diesel engine with injection molded, sintered silicon nitride by 1991. It is anticipated that every part will be proof tested, suggesting that this production will be very labor intensive.[21] This "technology push" strategy contrasts sharply with the approach taken by U.S. end user companies, which are oriented toward return on investment in a 3- to 5-year time frame.

Industry Associations

One recipient of MITI's funds is the Japan Fine Ceramics Association (JFCA), established in 1982. Regular members of JFCA include more than 170 suppliers of raw materials and finished components, as well as users of fine ceramics. JFCA's objective is to contribute to the development of the national economy by laying the foundation for the advanced ceramics industry through exchange of information, improvement and diffusion of technology, and diversification of applications.

A national institute associated with JFCA, called the Japan Fine Ceramics Center (JFCC), was established in Nagoya in May 1985. JFCC promotes relationships among universities, government agencies, and industries in Japan and throughout the world. It also integrates technical databases involving ceramics, provides technical know-how, and develops standard methods for testing and evaluating ceramics. Initially, the private sector contributed $40 million and local government contributed $15 million to fund the center.

[21] Ibid.

Western Europe

Industry Structure

Alcoa and ESK are the two largest manufacturers of ceramic powders in Europe and account for about half of the European merchant market. Alcoa is the leading supplier of high-purity alumina; ESK is the leading supplier of various grades of silicon carbide. Some companies—including Philips, Siemens, Norton, and Magnesium Elektron—manufacture powders for captive consumption of ceramic parts, often electronic components. Manufacturers also import ceramic powders from Japan and the United States.

Overall, about 40 European companies manufacture ceramic parts for sale in the merchant market. Another dozen or so, mainly electronic companies, produce components for captive consumption. The 11 largest firms, listed in table 9-10, account for about 75 percent of the merchant market for ceramic parts, excluding imports.

A modest trend exists among powder suppliers to forward-integrate into the production of parts.

Table 9-10.–End-Use Markets Served by Major European Ceramics Suppliers in 1986

Supplier	End-Use Market			
	Automotive	Aerospace	Biomedical	Other[a]
Ceramiques et Composites (F)				x
Cookson (UK)				x
Desmarquest (F)	x	x		x
ESK (FRG)				x
Feldmuehle (FRG)	x		x	x
Friedrichsfeld (FRG)		x	x	x
Haldenwanger (FRG)				x
Hoechst-CeramTec (FRG)	x		x	x
Hutschenreuter (FRG)	x			
Norton,[b] (FRG)		x		x
Societe Europeene Propulsion (F)		x		x
Stettner (FRG)				x

[a] Includes electronic ceramics and other structural ceramics.
bus. firm with manufacturing operations in West Germany.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

However, most major producers of finished ceramic components are not backward-integrated into powders. A trend toward horizontal integration also exists. Horizontal integration is often achieved through acquisitions of existing suppliers. A number of European companies, including Bayer (FRG), Feldmuehle (FRG), and Hoechst (FRG), have recently acquired other ceramics businesses as part of a move toward horizontal integration.

Acquisitions, joint ventures, and licensing agreements involving ceramics have become somewhat more common in recent years among European firms (see app. 9-3). For instance, only one acquisition took place in 1982, whereas 7 took place in 1986. The product areas most often acquired were silicon carbide, silicon nitride, zirconia, and other oxides.

Like acquisitions, the number of joint ventures involving European ceramics companies has increased significantly in the past several years. Although most joint venture partners were already participating in the ceramics industry, many also were chemical companies, end users, or equipment suppliers. Almost half of joint ventures are targeted at the electronic ceramics industry. Some of the most important recent joint ventures are given in appendix 9-3.

Although licensing agreements involving ceramics are still relatively uncommon in Europe, they are increasing in popularity, as shown in appendix 9-3. Two companies, ASEA Cerama, a Swedish consortium, and Lucas-Cookson-Syalon, a British company, license ceramics technology as an integral part of their marketing strategies.

Foreign Participation in the European Market

Europe is now generally self-sufficient in key raw materials and finished ceramic parts. However, Japanese and U.S. suppliers still hold strong positions in certain product categories, as shown in table 9-11. For example, the North American suppliers Alcoa, Reynolds, and Alcan remain major suppliers of alumina. High-purity silicon nitrides from Japanese suppliers–especially Toyo Soda and Ube Industries–are increasingly penetrating the European market. Finished structural ceramic parts are generally supplied by European producers with little or no foreign participation, although U.S. and Japanese suppliers predominate in electronic ceramics.

The major Japanese and U.S. suppliers of powders and finished ceramics to Europe are listed in table 9-12. Most Japanese suppliers merely resell products through European sales offices. Although this is also a common marketing approach used by U.S. companies, several U.S. firms have also established manufacturing facilities in Europe.

European Community Programs

In the early 1980s, the European Community (EC) perceived a greater need for a planned research effort based on a common research policy among participating nations. The EC cited two reasons for this need. First, it was aware of a technology lag in many areas versus its U.S. and Japanese competitors. Second, the EC felt that the fragmented and overlapping research efforts of industrial countries could be unified and harmonized by the creation of a common research strategy.

The EC began funding research on ceramics around 1982. Since that time, the EC has funded research through the program on Technical Ceramics (1 982-85), the Basic Research in Industrial Technologies for Europe (B RITE) Program (1 985-88) and the European Research in Advanced Materials (EURAM) Program (1986-89). In these programs, proposals were requested in targeted areas. The EC is rapidly increasing research and development funding for ceramic programs, From negligible involvement in 1982, the EC spent about $4 million through 1985. About $20 million is committed for ceramic projects in the BRITE and EURAM programs.[22]

in the EC's second Framework Program on Science and Technology (1 987-91), with a total approved budget of $5.4 billion, the budget line for science and technology of all advanced materials is expected to be about $220 million .23 EC

[22]According to information supplied by Wim van Deelen, Delegation of the Commission of the European Communities, Washington, DC, August 1987.

*3 I bid.

Table 9-11.—Impact of Foreign Suppliers on the Western European Advanced Ceramics Market

Product	Dominant source: Europe	United States	Japan
Powders:			
Oxides:			
Alumina	x	x	
Zirconia	x		
Rare earths	x		
Carbides	x		
Nitrides	x		X
Titanates[a]		X	
Titanium diboride	x		
Finished parts:			
Automotive	x		
Aerospace	x	x	
Biomedical	x		
Electronics		x	x

[a]Primarily barium and Strontium.

SOURCE: Strategic Analysis, inc. "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

Table 9-12.—Major Japanese and U.S. Suppliers of Powders and Finished Ceramics to Western Europe

Company	Product: Powders	Finished products	Business activity: Manufacturing	Sales	JV
Japanese:					
Figaro Engineering		x		x	
Kyocera		x		x	x
Matsushita Electronic Components		x		x	
Murata Manufacturing		x	X		
Narumi China		x		x	
Showa Denko	X			x	
Toyo Soda	X			x	
Ube Industries	X			x	
US:					
Alcoa	X		X		
AX		x	X		
Brush-Wellman		x		x	
Cabot		x		x	X
Ceradyne		x		x	
Coors Ceramics		x	x		
Duramic	X			x	
GTE Sylvania	X		x		
Norton		x	x		
SOHIO Engineered Materials		x		x	
TAM	X			x	

Business activity code:
Manufacturing = European manufacturing operation
Sales = Sales network only
JV = Joint venture program with Western European company.

SOURCE: Strategic Analysis, Inc. "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

funding for ceramics research goes to numerous enterprises and research organizations throughout the Community.

National Programs[24]

European government spending on national R&D programs for advanced ceramics is collectively estimated at about $220 million in 1985, as summarized in table 9-13. Recipients of these funds included research centers, universities, and private industry. West Germany, France, and the United Kingdom accounted for about 85 percent of the total. The following are some brief examples of national programs.

West Germany.– Total government funding for advanced ceramics R&D is estimated at about $75 million in 1985. The Ministry for Research and Technology (BMFT) has launched a 10-year, $440 million research program for new materials, including high-temperature metals, new polymers, powder metallurgy, and ceramics. West Germany is considered to be the European leader in structural ceramics, with over 50 companies actively involved; leading companies are Feldmuehle, Friedrichsfeld, and ESK.

France.–The French Government provided $64 million for advanced ceramics research in 1985, as broken out in table 9-14. About 30 percent of the research was carried out in the National Center for Scientific Research (CNRS) in Meudon. French companies have developed a strong position in ceramic composite technology.

[24]Budget figures in this section are drawn from Strategic Analysis, Inc., op. cit., 1987, unless otherwise specified.

Table 9-13.-European Government Spending on National R&D Programs for Ceramics in 1985[a]

Country	Government Expenditures ($ million)
West Germany	*75*
France	*64*
United Kingdom	*51*
Sweden	*7*
Netherlands	*4*
Italy	*6*
Belgium	*5*[b]
Finland	*5*
Other[c]	*3*
Total	$220

[a]Includes government funding for materials, office expenses (such as salaries), facilities, research centers, universities, and private industry.
[b]Includes Neoceram capital of $4 million (see text).
[c]Includes Denmark, Ireland, Norway, and ***Switzerland.***

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials, " a contractor report prepared for OTA, Mar. 24, 1987.

Table 9.14.—French Government Funding for Ceramics Research, 1985

Organization	Funding ($ million)	Percent of total
National Center for Scientific Research (CNRS)	$20.0	31
Commission on Atomic Energy (CEA)	13.1	20
Ministry of Defense	9.5	15
Ministry of Research and Technology	7.7	12
Ministry of Education	6.2	10
Other	7.5	12
Total	$64.0	100

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987,

United Kingdom.–Annual government spending for ceramics is estimated at $51 million. The United Kingdom has two major ceramics programs underway: Ceramic Applications for Reciprocating Engines (CARE), and Advanced Ceramics for Turbines (ACT). These are jointly funded by government and industry at a level of about $9 million over four years.

Sweden.–Swedish Government spending on advanced ceramics in 1985 is estimated at around $7 million. A significant fraction of Swedish ceramics research is carried out at the Swedish Silicate Research institute (SSRI) in Goteborg, which is sponsored by some 30 Swedish companies. In 1986, the Institute operated on a budget of about $1 million and was engaged in cooperative work with Chalmers University of Technology (also in Goteborg) and the Japanese Government Industrial Research Institutes (GIRI) in Nagoya and Kyushu. SSRI and GIRI formed a 3-year cooperative research program involving silicon nitride and sialon.

The leading Swedish ceramics corporation is ASEA Cerama, a 1982 joint venture of six Swedish companies, which was formed to promote applications of ceramic parts made by hot isostatic pressing (HIP). ASEA is the world leader in HIP equipment and technology.

Netherlands.–Research funding for advanced ceramics by the Dutch government dates from 1983 when, with support from the Department of Industry, a task force of scientists and industry representatives created the Innovation-Oriented Research Program–Technical Ceramics (IOP-TK). In 1984, 14 projects were selected in ceramic powder production and fabrication technologies, and in 1985 the IOP-TK was funded at about $9 million over 8 years. Presently, about $4.1 million has been approved over the next 4 years for 10 projects.

Italy.–The Italian Government is reportedly in the process of approving a $50 million program for advanced materials, of which about $25 million is scheduled to be reserved for advanced ceramics.

Belgium.–Government-sponsored R&D in advanced ceramics is estimated at about $1.5 million annually, mainly administered by the institute for the Encouragement of Scientific Research in Industry and Agriculture (IRSIA). The regional Walloon government has recently donated $4 million in starting capital for Neoceram, a joint venture of five Belgian partners.

POLYMER MATRIX COMPOSITES

Advanced polymer matrix composites (PMCs)–often referred to simply as advanced composites—are usually defined as those composites reinforced with continuous fibers having properties comparable to S-glass (high-stiffness glass) or better, and using resins with properties comparable to epoxies or better. Usually excluded are E-glass-reinforced polyester or vinylester matrices, which constitute over 85 percent of all PMCs, as indicated in chapter 3.[25] Advanced composites are the topic of this section.

The advanced composites industry can be conceptualized as having four distinct levels, as indicated in figure 9-2. These are: producers of basic materials such as resins and fibers; prepreggers; shapes producers; and end users. At the primary level are firms producing the polymer resins for the matrix and fibers for reinforcement. Resins, as unformulated monomers, and fibers, in the form of yarn or fabric, are purchased by manufacturers of prepregs. Prepreggers typically formulate a resin system and combine it with various reinforcing fibers to produce prepregs in the form of woven fabric, unidirectional tape, and filament tow. Prepregs are the principal starting materials in fabricating composite structures. The merchant market for prepregs is large and fairly well-defined. Shapes or structures are the next level of the composite industry. Fabricated composite shapes may be made captively for incorporation into other products, or sold on the merchant market to end users in various industries.

The United States is the largest producer and consumer of advanced composites in the world. Much of the pioneering work on these materials was conducted in the United States, and domestic suppliers rank among the most important companies in the worldwide business. In 1985, the total value of advanced composites structures produced in the United States, Western Europe, and Japan was approximately $2 billion. Of this, the United States alone accounted for nearly two-thirds, as shown in table 9-15. European production was less than half this size, although it was similar to the U.S. in its emphasis on aerospace end uses. Japan ranked a distant third in overall production, with the orientation of its advanced composites industry toward the recreational market. The relative composition of these three markets is broken out by end use in table 9-16.

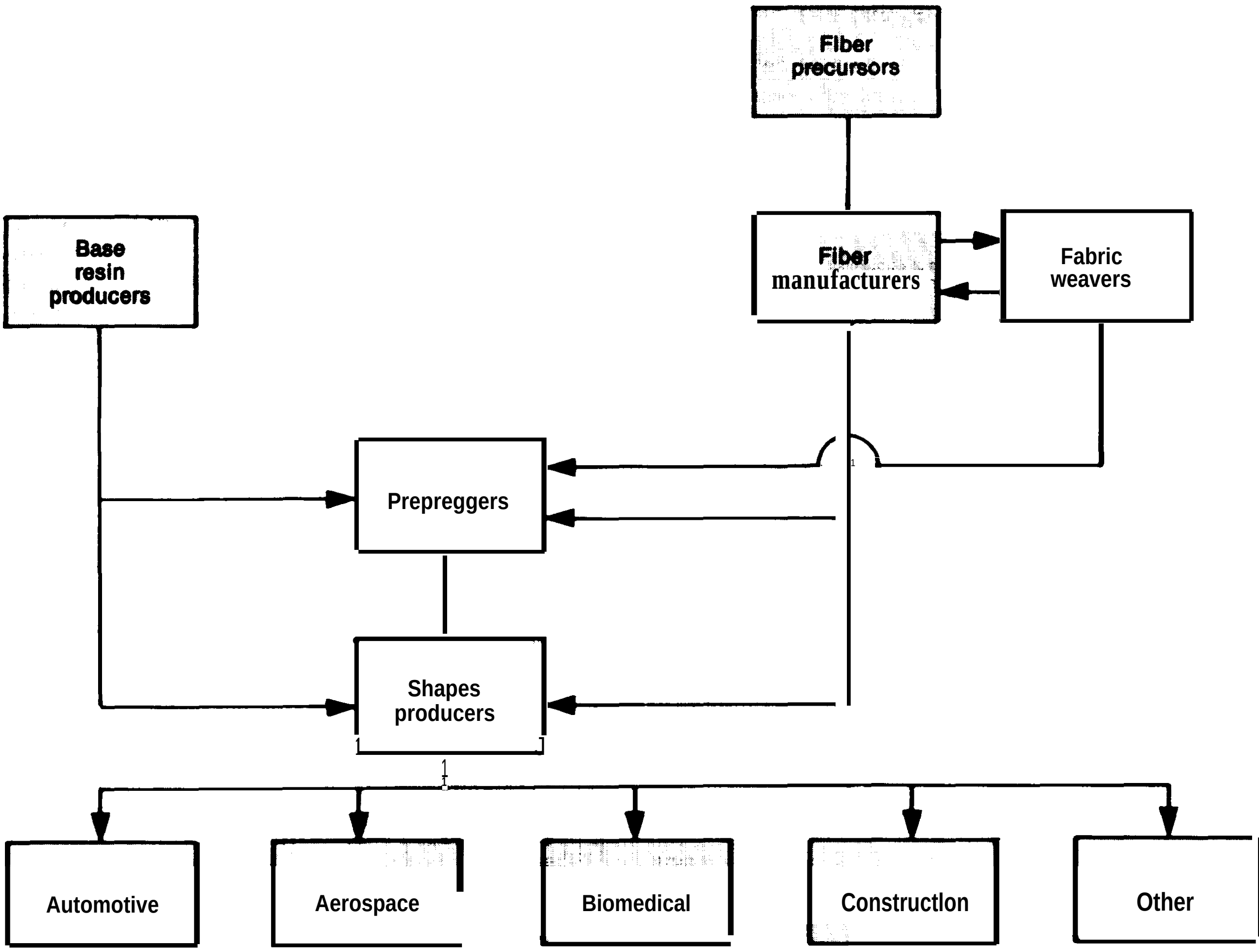
United States

Industry Structure

The structure of the U.S. advanced composites industry is largely a result of its orientation toward aerospace applications. Segmentation has

[25] However, due to their lower cost, E-glass composites are the most likely materials to be used in automotive body structures, as indicated in ch. 7. Given the sophisticated design and manufacturing processes, as well as the high strength and reliability required in automotive structural applications, it would seem appropriate to include such PMCs in the category of advanced composites.

Figure 9-2.–Structure of the Advanced Composites Industry



The advanced composites industry has four primary levels: resin and fiber producers; prepreggers; shapes producers; and end users.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

Table 9.15.—Production Value of Advanced Composite Structures, 1985

Regional market	Sales ($ millions)[a]	Percent of total
United States	$1,350	64
Western Europe	550	26
Japan		10
Total	$2,%	100

[a]Value of finished structures.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

largely occurred along product lines (fibers, resins, prepregs, and shapes). Other important industry characteristics include limited production volumes and a cost structure commensurate with the high value of the end uses.

Hercules, Hexcel, Fiberite, and Boeing are the most important companies in the U.S. composites industry. All possess a strong orientation toward the aerospace industry, the largest and most technology-driven market segment. The U.S. market for finished composite structures in 1985 was valued at approximately $1.4 billion, of which about half was consumed by the aerospace industry, as indicated in table 9-16.

The structure of the advanced composites industry is fairly complex, with significant overlap among the activities of individual firms. Companies such as **Hercules,** for instance, produce carbon fiber, prepregs, and finished shapes for the merchant market, and use them captively as well.

Table 9-16.—Breakdown of Regionai Markets for Advanced Composites by End Use, 1986

Region	End use percentage		
	Aerospace	Industrial[b]	Recreational
United States	50	25	25
Western Europe	56	26	18
Japan	10	35	55

[a]Based on value of fabricated components.
[b]Includes automotive, medical, machinery, and non-aerospace defense applications.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

End users such as Boeing captively produce composite shapes from prepregs and use them in commercial and military aircraft. The business activities of key participants in the U.S. advanced composites industry in 1986 are summarized in table 9-17.

The following is a discussion of key companies in the various levels of the advanced composites industry, including market share and extent of vertical integration

Resin Suppliers.–The suppliers of resins for advanced composites are mainly large, diversified chemical and industrial product manufacturers that produce large quantities of plastics for a variety of end-use markets. Unformulated resins going to the advanced composites market are specialty products that typically account for only a small amount of each supplier's resin sales.

Ciba-Geigy, Shell, and Dow Chemical control almost two-thirds of the U.S. resin market for advanced composites. These three suppliers are epoxy producers that dominate resin sales for all applications worldwide. Leading suppliers of thermoplastic resins are ICI, Amoco, and Phillips. A list of the most important suppliers of base resins by product type is shown in table 9-18.

Fiber Suppliers.– U.S. consumption of fibers for advanced composites totaled over 7 million pounds in 1985. Graphite fibers alone accounted for nearly half of the total amount by weight, and almost two-thirds of the dollar value. Aramid fibers ranked second, with over 20 percent of the weight and value. S-2 glass fibers accounted for 25 percent of the total consumption by weight, but only 10 percent of the total value. The re-

Table 9-17.—Participation of Key Firms in the U.S. Advanced Composites industry, 1986

Company	Advanced material product[a]			
	Base resins	Fibers	Prepregs	Shapes
American Cyanamid			x	
Amoco Performance Products	x	x	m	m
Avco		m	m	x
BASF		x	x	m
Boeing				x
Ciba-Geigy	x		x	m
Dow Chemical	x			
Du Pont	x	x	m	m
Ferro			x	
Grumman				x
Hercules		x	x	x
Hexcel			x	m
HITCO		m	x	x
Hysol Grafil		x	m	m
ICI	x			
ICI Fiberite			x	
Lockheed				x
LTV				x
McDonnell Douglas				x
Northrop				x
Phillips 66	x		m	m
Rohr Industries			x	
Shell Chemical	x			
United Technologies				x

[a]x = major product; m = minor product.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

Table 9-18.—Major Suppliers of Base Resins for Advanced Composites in the United States, 1986

Type of resin	Supplier
Bismaleimide	Celanese Ciba-Geigy Dow Chemical
Epoxy	Celanese Ciba-Geigy Dow Chemical Shell
Phenolic	Monsanto Reichhold
Polyester	Ashland Freeman PPG Reichhold
Polyether sulfone (PES)	ICI
Polyetheretherketone (PEEK)	ICI
Polyimide	Du Pont
Polyphenylene sulfide (PPS)	Phillips
Poly (amide-imide)	Amoco
Vinylester	Ashland Dow Chemical Reichhold

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

maining volume was made up of specialized fibers, such as boron, ceramic, and other polymers, which collectively accounted for only about 1 percent of the total weight of fiber reinforcements.

Nine firms supply carbon fiber for advanced polymer composites in the United States, as indicated in table 9-19. The top three suppliers, Hercules, Amoco, and BASF, together account for approximately 85 percent of the total market. Hercules remains the largest supplier with a market share of over one-third. Amoco, which acquired the carbon fiber business of Union Carbide in 1986, is the second largest firm. Amoco is currently the only U.S. company capable of producing the important polyacrylonitrile (PAN) precursor for carbon fiber production; currently, 100 percent of PAN fiber precursor used by the military is imported from Japan and the United Kingdom. Amoco is currently in the process of qualifying its PAN-based fibers for military use. The third largest firm supplying carbon fiber is BASF, a West German company that purchased the Celion carbon fiber business from Celanese. Despite worldwide overcapacity for carbon fiber, DoD's interest in securing stable domestic

Table 9-19.—Major Fiber Suppliers in the United States, 1986

Aramid	Du Pont
Boron	Avco
Carbon (PAN)[a]	Amoco Avco BASF Fiber Materials Great Lakes Carbon Hercules HITCO Hysol-Grafil Stackpole
Carbon (Pitch)	Amoco Ashland
Carbon (Rayon)	Amoco HITCO Polycarbon
Glass	Owens-Corning

[a]PAN = polyacrylonitrile precursor.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

sources of both fiber and PAN precursor has prompted the planning of new facilities in the United States.

Du Pont is currently the only U.S. producer of aramid fibers. In addition, through its acquisition of Exxon's Materials Division, Du Pont is making preliminary moves toward supplying pitch-based carbon fibers as well. Owens-Corning Fiberglas is the only U.S. producer of high-performance glass for composites. A number of other firms, including Avco, Fiber Materials, and Hysol-Grafil, also produce various other fibers for reinforcement.

Prepreg Suppliers.– U.S. consumption of advanced composites prepregs totaled over 3,000 metric tons in 1985. High-performance graphite fiber prepregs accounted for about 40 percent of total use, followed by glass fiber prepregs with slightly over 30 percent. Aramid fiber-based prepregs contributed an additional 27 percent of total consumption, with the remainder made up of specialty prepregs of boron, quartz, or other fibers.

Overall, it is estimated that more than 80 percent of U.S. sales of prepregs are to the merchant market. Few major shapes producers, such as large aerospace firms, have perceived sufficient benefits to warrant internal manufacture of prepregs.

Suppliers of prepregs are generally large, diversified chemical and industrial product manufacturers that have developed technology and expertise in advanced composites. Eight suppliers account for approximately 90 percent of the market. The three largest firms–Fiberite, Hercules, and Hexcel—together account for about two-thirds of merchant prepreg sales, followed by Ciba-Geigy, Narmco, HITCO, American Cyanamid, and Ferro.

Shape Suppliers and End Users. -Roughly estimated, the U.S. market for aerospace composite structures was valued at about $650 million in 1985. The majority, about 60 percent, of composite shapes were manufactured captively by the major U.S. aircraft firms and prime military contractors. The remaining 40 percent was divided among a number of large and small subcontractors that produce parts for merchant sale.

Outsourcing for composite shapes tends to be more common among manufacturers of civilian aircraft. Major airframe producers such as Boeing rely heavily on merchant fabricators or subcontractors to fabricate composite forms. In many cases, outsourcing for composite parts relates to larger marketing factors, particularly promoting foreign sales of finished aircraft to countries where subcontractors operate. As a result of such "offset" agreements, subcontractors in Japan (Fuji), Spain (CASA), and Italy (Aeritalia) are among those exporting major quantities of fabricated aircraft structures to the United States.

Captive fabrication tends to occur more frequently among the major military contractors. Firms such as McDonnell-Douglas, General Dynamics, Grumman, and Northrop, for instance, are virtually self-sufficient in supplying their own composites needs. In addition, LTV, Grumman, and Northrop also fabricate structures for other firms.

Integration. –Greater consolidation and increased integration have been market characteristics of the U.S. advanced composites industry over the past few years. In some respects, the poor financial performance of the industry as a whole has played a part in both trends. Many of the advantages of forward integration relate to lower raw material costs and better coordination of technologies across product categories. Perhaps the greatest single motivation for this tendency is the desire to move into more profitable product categories. The carbon fiber business, for instance, has demonstrated poor financial performance compared with either prepregs or fabrication.

Of the three areas, fabrication of composite structures provides the greatest returns in the advanced composite industry. Examples of recent moves toward forward integration among U. S.-based suppliers are shown in table 9-20. Hercules, perhaps the most significant player in the market, is vertically integrated from raw materials to final shapes. The firm has long had a competitive advantage **in the carbon fiber business due to its position as an important military contractor and merchant composite fabricator. Rival suppliers, BASF and Amoco, have no such reliable market to support their carbon fiber operations.**

Recently, Boeing Technologies created a stir in the industry by announcing an agreement with Nikkiso (Japan) to license production technology for carbon fiber. While Boeing has a pilot plant under construction, few in the industry believe this move signals Boeing's intentions to eliminate outsourcing of raw materials. Boeing contends that the agreement is nothing more than an outgrowth of the company's longstanding interest in internal materials research.

Acquisitions. —Since 1984, there have been an increasing number of significant acquisitions and consolidations within the advanced composites industry. Some of the more notable are listed in Appendix 9-4. To a large extent, these acquisitions embody a growing investment in compos-

Table 9-20.-Recent Moves Toward Forward Integration Among U.S.-Based Advanced Composites Suppliers

	Manufacturing capability	
Company	Original position	Integration
Amoco	Resins, fibers	Prepregs
Du Pont	Fibers	Prepregs, shapes
Phillips	Resins, prepregs	Shapes

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

ites by large, diversified chemical and industrial firms. overall, the composites industry has not proven to be very profitable for its participants. The industry's greatest returns are thought to lie in the long term as truly large volume applications are commercialized. Acquisitions represent a long-range investment that is most easily made by larger, diversified companies.

Joint Ventures.– The rationale for joint ventures among firms in the advanced composites industry is heavily influenced by issues of marketing and technology. In the case of marketing, joint ventures have provided a means for U.S. firms to assume a local identity when participating in foreign markets.

in the case of technology, the joint venture is intended to provide technological synergies between firms with different strengths. Hercules, for instance, recently teamed with biomedical implant maker Biomet to develop and market orthopedic implants. Hysol-Grafil was formed with the intention of mating Courtaulds' experience in carbon fibers with Dexter's resin technology. In appendix 9-4 are listed recent joint ventures among firms in the advanced composites industry.

Licensing Agreements.– The licensing of basic technology from foreign firms has been a characteristic of the U.S. composite industry since its inception. The basic process for the production of carbon fibers was imported by major U.S. producers from firms such as Toho Rayon, Toray, and Courtaulds. Two of these licensing agreements remain in effect. In other areas, licensing is an important mechanism for the transfer of production and distribution rights for finished products both into and outside of the United States. Appendix 9-4 gives some of the more prominent licensing agreements in effect today.

Foreign Participation in the U.S. Market

The advanced composites industry has become a more international business and one less dominated by U.S. firms. The past several years have seen a dramatic increase in the activity of European firms in the United States. Courtaulds, BASF, ICI, and Ciba-Geigy, for instance, now rank among the major participants in the U.S. market as a result of joint venture and acquisition activity. In terms of market share, foreign-owned materials firms now control 25 percent of the U.S. resin market, 50 percent of prepreg sales, and over 20 percent of the carbon fiber market. The foreign share of the finished structure business is much smaller.

Several motivations appear to be behind the increased involvement of foreign firms in the U.S. market. The most obvious is that the U.S. market is the largest such market in the world, and is likely to grow rapidly, particularly on the military side. As military use grows, so will the emphasis on U.S.-based suppliers. Many of the acquisitions of U.S. firms by large European conglomerates are evidence of a faith in the long-term viability of the industry by those with sufficient resources to ride out the current lean times.

The transfer of technology from U.S. operations back to Europe is also an incentive for foreign participation. In many ways, the European composites market can be viewed as a smaller version of the U.S. market. A strong defense and aerospace orientation is coupled with an equally strong emphasis on local sourcing for raw materials and prepregs. The growth of the European commercial aircraft industry and the potential for channeling composite technology into the automotive industry are also important considerations.

Although Japanese fiber manufacturers hold some of the best production technology for carbon fiber in the world, the activity of Japanese firms in the U.S. has been largely confined to licensing and technology agreements with U.S. firms. The provisions of these agreements have severely limited direct Japanese participation in the U.S. market. As a result, two of the world's largest carbon fiber producers, Toray and Toho Rayon, currently have a very minor role in the largest market for fibers. This situation leads many U.S. observers to suggest that the Japanese will be forced to reassess their posture toward the United States in the near future.

Sources in the U.S. industry point out that the absence of Japanese suppliers from the U.S. market is a major disadvantage for Japanese firms because of their lack of proximity to important technological developments. With leading-edge research in advanced composites oriented toward military applications, Japanese fiber firms are several steps removed from key technological trends and in serious danger of losing their leadership position in fiber technology. This condition is worsened by the absence of any significant Japanese market for military or aerospace products.

There are vague indications of how Japanese participation is likely to change in the future. Some speculate that to support massive investments in technology and productive capacity at home, Japanese firms will break prior agreements and begin selling carbon fiber directly in the United States. In this case, it is envisioned that the Japanese may team with one or more of the major prepreggers that lack captive fiber technology. A second scenario holds that the Japanese will follow the lead of many European firms by acquiring a U.S. firm. In this case, a likely target would be one of the few remaining independent prepreg firms.

In the longer term, there are predictions that other Asian countries, such as South Korea, may become active in furnishing fiber to the U.S. **market. Such countries are envisioned as competing directly with the Japanese in supplying inexpensive, lower performance fibers for cost-sensitive applications** such as the automotive or construction industries.

Government/Industry Relationships

Historically, the U.S. advanced composites industry has been driven by DoD, particularly for aircraft and space applications. To a great extent, this remains true today. DoD sponsored over 70 percent of Federal PMC R&D in **1986** (see ch. 3), and this proportion is expected to increase in the future, fueled by the need for lighter, stronger materials for new weapons systems such as the Advanced Tactical Fighter, the Strategic Defense Initiative, the Stealth bomber, and the LHX helicopter. In addition, use of composites is expected to expand in military ground vehicles, surface ships, and submarines.

Consistent with the industry's military orientation, most of the policy issues of greatest concern to the industry revolve around defense-related regulations and policies, such as export controls on composite products and technology, domestic sourcing of key raw materials, and military procurement programs (see ch. 11).

Industry Associations and Professional Societies

A variety of professional societies and organizations conduct meetings on advanced composites and support the industry. These include the Society of the Plastics Industry (SPI), the Society for the Advancement of Materials Processes and Engineering (SAMPE), ASM International, and the Society of Automotive Engineers (SAE). Recently, a trade association called the Suppliers of Advanced Composite Materials Association (SACMA) was formed to address common concerns of composites suppliers. A list of SACMA members is given in table 9-21. SACMA has been

Table 9-21.—Members of the Suppliers of Advanced Composite Materials Association (SACMA)

Member Company
Allied Corp.
American Cyanamid Co.
Amoco Performance Products
Asahi Nippon Carbon Fiber Co.
Ashland Petroleum Co.
Celion Carbon Fibers
Ciba-Geigy Corp.
Dow Chemical
Dow Corning Corp.
E.I. Du Pont de Nemours & Co.
Enka America
Ferro Corp.
Fortafil Fibers, Inc.
Hercules, Inc.
Hexcel Corp.
Hysol Grafil Co.
ICI Fiberite
Mitsubishi Rayon America
Narmco Materials
Phillips 66 Co.
Rhone-Poulenc, Inc.
RK Carbon Fibers
Shell Chemical Co.
Teijin America, Inc.
Textile Products, Inc.
3M Co.
Toho Rayon Co.
Toray Industries
TPC (Unit of BASF)
U.S. Polymeric, Inc.
Xerkon Co.

SOURCE: Suppliers of Advanced Composite Materials Association.

active in addressing health issues, standardization of composites, export controls, and domestic sourcing requirements of DoD. Consistent with the defense/aerospace orientation of the composites industry today, SACMA is primarily concerned with the defense market, and members consider commercial markets, such as automotive, to be of secondary importance.

Japan

The Japanese advanced composites industry was initiated to supply the aircraft and space industries of the United States. Since that time, however, most of the Japanese domestic growth has been in the recreational markets. This emphasis differs greatly from the U.S. market, which is primarily oriented toward defense applications. The composition of the Japanese advanced composites market is currently 55 percent recreational, 35 percent industrial, and 10 percent aerospace (see table 9-1 6).

Unlike many end uses, the recreation industry frequently accepts higher cost and higher quality materials because the customer is willing to pay a premium for these products. However, Japan is already starting to lose its market share in advanced composites for sporting goods to South Korea.[26]

Industry Structure

Resin Suppliers.– In Japan, most suppliers of base resins for advanced composites are leading chemical companies. Resins for advanced composites comprise a small fraction of total production. Yuka Shell Epoxy, Mitsui Petrochemical, and Asahi Chemical together hold about 70 percent of the Japanese market for resins used in advanced composites. These manufacturers produce epoxy, the principal matrix material. A list of selected suppliers of base resins by product type is given in table 9-22.

Fiber Suppliers. –Japanese consumption of fibers for advanced composites totaled over 2 million pounds in 1985. Graphite fibers accounted for about two-thirds of domestic consumption. Aramid fibers were second, with over one-quarter of the total weight. The remaining volume, less than 10 percent of the total, was made up of specialized fibers, including glass, boron, ceramics, and miscellaneous others. Selected Japanese suppliers of fibers for advanced composites are given in table 9-23.

Five Japanese firms supply carbon fibers, and six supply carbon fiber precursor (PAN). Together, the top two suppliers, Toray and Toho Rayon, account for 80 percent of the total production. The percentage of export production for both companies is as high as 60 percent or more. Toho Rayon exports large quantities of precursor to firms in the United States, while Toray has

Table 9.22.—Major Suppliers of Base Resins for Advanced Composites in Japan

Resin type	Supplier
Bismaleimide-triazine polyimide	Mitsubishi Chemical (Amoco)[a] Mitsubishi Gas Chemical Nippon Polyimide (Rhone-Poulenc-Mitsui Petrochemical)[b] Toray
Epoxy	Asahi-Ciba (Asahi Chemical-Ciba-Geigy)[b] Mitsui Petrochemical Sumitomo Chemical Yuka Shell Epoxy
Polyamide	Asahi Chemical Mitsubishi Chemical Toray
Polyester	Dai Nippon Mitsui Toatsu Sumitomo Chemical
Polyether sulfone (PES)	ICI Mitsui Toatsu (ICI)[a] Sumitomo Chemical (ICI)[a]
Polyetheretherketone (PEEK)	ICI Mitsui Toatsu (ICI)[a] Sumitomo Chemical (ICI)[a]
Polyphenylene sulfide (PPS)	Kureha Chemical Tohto Kasei Toray-Phillips[b] Toso Susteel
Vinylester phenol	Dow Chemical

[a]Resin produced by company in parenthesis and marketed by the Japanese company.
[b]Joint venture partners.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

[26]Presentation by R.A. Fasth, Kline & Co., "Advanced polymer Composites: The Challenges for the Future, " at the Conference on Emerging Technologies in Materials, sponsored by the American Institute of Chemical Engineers, Minneapolis, MN, Aug. 18-20, 1987.

Table 9-23.—Major Fiber Suppliers in Japan, 1986

Fiber type	Supplier
Alumina	Sumika-Hercules
Aramid	Toray
	Teijin
Boron	Vacuum Metallurgical
Carbon, [a]	Toray
	Toho Rayon
	Asahi Nippon Carbon
	Mitsubishi Rayon
	Nikkiso
Carbon [b]	Kureha Chemical
	Mitsubishi Chemical
Ceramic [c]	Ube
Glass	Nittobo
PAN precursor	Sumika-Hercules
Polyethylene	Mitsui
Silicon Carbide	Nippon Carbon

[a]PAN-based (PAN = polyacrylonitrile).
[b]Pitch-based.
[c]Ceramic fiber consisting of titanium, silicon carbide, and oxygen.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

licensed precursor technology to Amoco. Toho Rayon also exports carbon fiber to Southeast Asian countries, including Taiwan and Hong Kong, for sporting goods applications. The position of leader between the two firms frequently alternates whenever one firm expands its production facilities. Toray also supplies aramid fibers, which are imported into Japan through Du Pont-Toray.

Prepreg Suppliers.–In Japan, fiber manufacturers or their affiliates generally produce prepregs for fabricating advanced composites, and all current carbon fiber manufacturers sell prepregs as well as carbon fiber. Sakai Composite and Toho Rayon are the largest prepreggers, followed by Asahi Composite and Mitsubishi Rayon. Sakai Composite, a subsidiary of Toray, manufactures prepregs mainly for sporting good applications. The ranking of prepreggers is roughly the same as that of fiber suppliers because they manufacture prepregs using their own materials. Unlike carbon fiber manufacturers, which are largely Japanese entities (with the principal exception of Sumika-Hercules), many of the prepreg and shapes suppliers in Japan are joint ventures with foreign firms. They include Asahi Composites, Kasei Fiberite, Dia-HITCO Composites, and Toho Badische. The activities of the most important prepreggers are given in table 9-24.

Kasei-Fiberite is a joint venture between Mitsubishi Chemical and Fiberite. Mitsubishi Chemical has begun to produce pitch-based carbon fibers from which it plans to manufacture prepregs. These pitch-based carbon fibers are not the general purpose types that Kureha Chemical manufactures; rather, they are high-strength fibers whose specifications are comparable to PAN-based carbon fiber.

A very important development in the composites business will be the commercialization of low-cost, pitch-based carbon fibers. Many sources in both Japan and the United States expect the availability of these low-cost fibers to accelerate the use of composites in cost-sensitive applications such as automobiles and construction. pitch fiber-reinforced concrete has already been used for curtain walls in buildings in Tokyo.[27] This material is lighter and tougher than

[27]" Panels Use Carbon Fibers," *Engineering News Record,* Aug. 1, 1985.

Table 9-24.–Participation of Major Prepreg Suppliers in the Japanese Market, 1986

	Business activity			
Supplier	Resins	Fibers	Prepregs	Shapes
Asahi Composite			x	x
Hitachi Chemical			x	x
Kasei Fiberite			x	x
Mitsubishi Rayon		x	x	x
Nitto Electric			x	x
Sakai Composite (Toray)	X[a]	X[a]	x	X[a]
Somar			x	x
Sumika-Hercules			x	x
Toho Rayon		x	x	x

[a]Produced by Toray.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar, 24, 1987.

ordinary concrete, permitting the use of less structural steel and lower construction costs.

Shape Suppliers and End Users.–Japanese companies that manufacture finished composite components include Fuji Heavy Industries, Mitsubishi Heavy Industries, Kawasaki Heavy industries, Nikkiso, and Tenryu Kogyo in the aerospace sector, and Somar and Nitto Electric in the recreation industry, End users with a major demand for composite structures in the recreation industry are R.K. Mizuno and Nippon Gakki (Yamaha); those in the automotive industry are Toyota and Nissan. Major end users for advanced composites in these and other fields are shown in table 9-25.

Foreign Participation in the Japanese Market

There are not many foreign manufacturers that have penetrated the Japanese advanced composites market. All of those that have succeeded have done so by establishing joint ventures with Japanese companies, such as Sumika-Hercules, Asahi Composite (Asahi Chemical and Ciba-Geigy), and Kasei Fiberite. Recent joint ventures are given in appendix 9-5. As indicated above, joint ventures are particularly common among prepreggers and shape fabricators.

Companies that recently formed licensing agreements with Japanese companies are shown in appendix 9-5. Many of these involve raw materials manufacture in which Japanese companies have supplied carbon fiber production technology to composites firms around the world.

Government/Industry Relationships

In contrast to the situation with ceramics, in which the names and budgets of the relevant agencies are well known, Japanese Government support for composites research is fragmented and difficult to identify. One of the few exceptions is MITI's budget for the R&D Project on Basic Technology for Future Industries, a 10 year, $32 million project initiated in 1981. The research topics in this project include both composites and ceramics. Total government expenditures dedicated to PMCs under the project were $3.2 million in 1983 and $3.6 million in 1985. This program places greatest emphasis on the aerospace and automotive applications of advanced composites.

Table 9.25.–Major End Users of Advanced Composites in Japan, 1986

Company	Recreational	Automotive	Aircraft/Aerospace	Medical	Construction	Other
Daiwa Seiko.	x					
Shimano	x					
Olympic	x					
Ryobi.	x					
R.K. Mizuno	x					
Honma	x					
Nippon Gakki	x					
Toyota Motors.		X				
Nissan Motors.		X	X			
Matsuda Motors		X				
Fuji Heavy Industries. , ...			X			
Mitsubishi Heavy Industries . .			X			
Kawasaki Heavy Industries . . .			X			
Showa Aircraft			X			
Mitsubishi Electric			X	x		
Power Reactor & Nuclear Fuel Development						x
Mitsutoyo Manufacturing						X
Sankyo Seiki Manufacturing . .						X
Shimazu				x		
Toshiba.				x		
Japan Medico				x		
Mitsui Construction					x	x

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

Other executive branch organizations coordinating research on advanced composites are the Japan Research and Development Corp. (part of STA), the Consumer Goods Industry Bureau (part of MITI), the Agency of Industrial Science and Technology (MITI), the Science and Technology Council, and the Science Council.

The major national laboratories conducting advanced composites research are given in table 9-26. Government-supported research at universities is funded through the Ministry of Education. Total support for advanced composites R&D in the Ministry of Education accounted for less than $1 million in 1985.

At present, the National Space Development Agency of Japan, Mitsubishi Electric, Nippon Electric, and Mitsubishi Heavy Industries are working on the R&D of composite materials for aerospace end uses. Most Japanese companies and MITI consider automotive applications for advanced composites to have the best prospects for near-term development, while aerospace applications are viewed as long term. Obstacles to penetration of the worldwide aerospace market include a small domestic market, which is dominated by government-related projects, and the inaccessibility of the U.S. and European markets to Japanese suppliers. However, some analysts expect Japan to have an increasing presence in world aerospace markets as a result of joint ventures with Boeing, as on the 7J7 airplane.[28]

[28] Robert Poe, "Can Japan Launch a Commercial Aircraft Industry?" *High Technology,* March 1987, p. 42.

Table 9.26.—Major National Laboratories Performing Advanced Composites Research in Japan[a]

National Research Institute for Metals (STA)
National Aerospace Laboratory (STA)
Mechanical Engineering Laboratory (MITI)
National Chemical Laboratory for Industry (MITI)
Research Institute for Polymers and Textiles (MITI)
Industrial Products Research Institute (MITI)
Government Industrial Research Institute. Osaka IMITI)

[a] Laboratories under administration of Science and Technology Agency (STA) and Ministry of International Trade and Industry (MITI).

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

Western Europe

The PMC business in Western Europe is concentrated in four countries: France, the United Kingdom, West Germany, and Italy. Together, these countries account for about 90 percent of the business, as shown in table 9-27. France dominates the advanced composites business in Western Europe, with a 55 percent share of sales. The substantial involvement of the French Government in the major aerospace, automotive, and energy-producing companies makes the French industry by far the most heavily state-subsidized one in Western Europe.

According to industry estimates, total production of advanced composites in Western Europe in 1985 was about 2,500 tons of product, worth about $550 million. This excludes imports from the United States. Significant amounts of advanced composites products are fabricated in the United States and exported to Europe either for assembly of European aircraft or for production of components for U.S. aircraft. For example, British Aerospace and McDonnell-Douglas are jointly producing the Harrier (AV-8B), and many of the composite components are manufactured in the United States. In addition, Aeritalia is manufacturing components for the Boeing 757 and 767. Prepregs are supplied from the United States for fabrication in Western Europe. If imports were added to the 2,500 tons, then total consumption in Western Europe would be twice this figure in 1985.

As in the United States, the aerospace and defense industries are the most important consumers of high-performance composites in Western Europe and are expected to continue to

Table 9-27.—Distribution of the Advanced Composites Business in Western Europe, 1986

Country	Percent of total
France	55%
United Kingdom	15
Germany	10
Italy	10
All others	10
Total	100°/0

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

dominate in the future. Overall, the pattern of Western European consumption of composites is similar to that found in the United States, as shown in table **9-16.**

Industry Structure

Resin Suppliers.–Large, multinational chemical companies dominate the supply of high-performance thermoses and thermoplastics to the European market. The major suppliers of epoxies include Shell, Ciba-Geigy, and Dow Chemical. Ciba-Geigy alone holds over half the market. Table 9-28 lists the major resin suppliers.

Fiber Suppliers.–The most important suppliers of high-performance fibers in Western Europe are shown in table 9-29. They include Hysol Grafil, a joint venture between Dexter (USA) and Courtaulds (UK); Soficar, a joint venture between Elf Aquitaine (F) and Toray (J); and Enka (N L). Total capacity for the production of carbon fibers in Europe is estimated at over 1,100 tons. The capacity in the United Kingdom is the largest, followed by Germany and France.

Production of aramid fibers recently commenced in Europe with the commissioning of Enka's new 5,000-ton plant in the Netherlands. In addition, Du Pont is building a plant in Northern Ireland to serve the Western European aramid fiber market.

Prepreg Suppliers.–Western European production of prepregs is concentrated in France, the United Kingdom, and Belgium. Significant quantities are also imported from the United States from companies such as Fiberite and Hercules, Overall, four suppliers (Ciba-Geigy, American Cyanamid, Hexcel, and Krempel) control about three-quarters of European prepreg production. A list of leading prepreggers and weavers is given in table 9-30.

In addition to these companies, a number of aerospace companies manufacture their own prepregs in-house. These include firms such as Aerospatiale (F), Airbus Industrie, and British Aerospace (UK).

Shape Suppliers and End Users.–Many of the leading aerospace companies manufacture finished components captively. These include British Aerospace, Fokker (N L), **Messerschmitt-Boelkow-Blohm** (FRG), **Dornier (FRG), Aeritalia (I), Airbus Industrie, Agusta Group (I), Aerospatiale (F), and Dassault (F). The most important consumer of advanced composites in the aerospace field is Airbus Industrie, which is using substantial amounts of carbon fibers and epoxy resins** for the Airbus 300 and 310. Other important civil aircraft programs under way at present in Western Europe include Fokker (model F100) and British Aerospace (models 125 and 146). Compared

Table 9-28.—Major Suppliers of Resins in Western Europe, 1986

Company	Location	Resin	Comment
Thermoses:			
Shell	UK	Epoxies	
Ciba-Geigy	SWI	Epoxies	Dominant supplier for composites
Dow Chemical	SWI	Epoxies	Ranks second as supplier to this sector
Thermoplastics:			
ICI	UK	Polyetheretherketone Polyether sulfone	
Phillips	B	Polyphenylene sulfide	Imports from U.S.
Amoco	SWI	Polyamideimide Polyetherimide	Imports from US.
BASF,	FRG	Polysulfone Polyether sulfone	
General Electric	NL	Polyetherimide	Imports from U.S.
Bayer,	FRG	Polyester (thermoplastic)	
Other:			
Rhone-Poulenc	F	Polyamides	Leader in development of polyimide technology
Technochemie.	FRG	Bismaleimide	Owned by Boots Pharmaceuticals

KEY: B = Belgium; F = France, FRG = West Germany; NL = Netherlands; SWI = Switzerland; UK = United Kingdom.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987,

Table 9-29.–Major Suppliers of High-Performance Fibers in Western Europe, 1986

Company	Plant location	Capacity (tons)	Comment
Carbon filters:			
Hysol Grafil	UK	400	20°/01800/0 joint venture between Dexter and Courtaulds
Soficar	F	300	65°/01350/0 joint venture between Elf Aquitaine and Toray
RK Carbon Fibers.	UK	150	Majority share owned by major textile company, Coats Paton
Enka (Akzo)	FRG	350	Based on Toho Rayon technology
Sigri	FRG	50	Investment in plant was $25 million Part of major carbon products company
Aramid fibers:			
Enka (Akzo)	NL	5,000	50%/50% joint venture with Dutch State Development Company
Du Pont	IR	7,000	Currently building plant
Glass fibers:			
Vetrotex	F	—	Division of St. Gobain Only European producer of R-glass
Other ***fibers:***			
Societe Nationale des Poudres et Explosifs	F	1-2	Boron fiber producer owned by French Government
Bekaert NV	B		Stainless steel fibers

KEY: B == Belgium; F = France, FRG - West Germany; IR = Ireland; NL = Netherlands; = United Kingdom.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials,"a contractor report prepared for OTA, Mar. 24, 1987.

Table 9-30.—Major Prepreggers and Weavers in Western Europe

Company	Location	Activity: Prepreg	Activity: Weaver	Comment
American Cyanamid	UK	X	—	
BASF	FRG	X		New facility based on Narmco U.S. plant technology
Bristol Advanced Composites	UK	X	X	Owned by BP Group
Ciba-Geigy				
Bonded Structures	UK	X		Leader in honeycomb structures
Brochier et Fils	F	X	X	Largest weaver of carbon fibers
Fiberite Europe	FRG	X		Part of ICI Group
Fibre & Mica.	F	X		Narmco (BASF) licensee in France Owned by government company, Alsthom-Atlantique
Fothergill & Harvey	UK		X	Leading company in advanced materials, Owned by Courtaulds
Gividi	I		X	Leading weaver in Italy
Hexcel	B	X		Leader in honeycomb
Stevens-Genen	F	X	X	A leading weaver in Europe, turnover of $25 million in 1985
Interglas-Textil	FRG		X	One of largest weavers in West Germany
Krempel.	FRG	X		Leading German prepregger
LNP (ICI)	NL	X		Leading producer of carbon fiber-reinforced nylon
Sigri ., ...	FRG		X	Leading weaver of carbon fibers
Specmat	UK	X		Leader in thermoplastic composites; part of N.R. Smith Engineering Group
Ten Cate Glas	NL	X	X	Part of Nyverdal Ten Cate, large textile group

KEY: B = Belgium; F = France, FRG = West Germany; I = Italy; NL = Netherlands; UK = United Kingdom.
SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials, " a contractor report prepared for OTA, Mar. 24, 1987.

with the United States, however, the monetary value of advanced composites **used** in military aircraft in Western Europe is rather limited.

The recreation market represents the second most important market for advanced composites in Western Europe, accounting for about 18 percent of the total value of fabricated parts. The largest component of this group includes tennis rackets produced by such companies as Don nay (B), Dunlop Sports (UK), Snauwaert (B), and Fischer Ski (A).

The automotive sector ranks third after aerospace and recreation markets. About 60 percent of the advanced composites used in this sector go into specialty racing or other high-performance vehicles. In conventional automobiles, three sectors are under study for the use of composites: drive shafts, suspension systems, and engine components. GKN, a leading British company in automotive components, has recently marketed a glass fiber/epoxy leaf spring. Automotive companies with composite development programs under way include Renault, Ford, Porsche, and Audi.

Many consider Western Europe to lead the world in the biomedical applications of advanced composites. While not fully commercialized, composite joints, usually hip prostheses, are nearing the clinical stage in humans. Leading work in this area is being performed by Schunk und Ebe (FRG), Fothergill and Harvey (UK), and the University of Karlsruhe (FRG).

Integration.–As in the United States, most of the major end users of advanced composites in Europe are also important fabricators of finished components. Among material suppliers, there is evidence of a shift toward higher value-added products such as prepregs and shapes. Courtaulds, among others, has realized that to participate profitably in the advanced composites business in the long term, it must be more than a carbon fiber supplier. Therefore, the company is aggressively attempting to move downstream into the manufacture of components.

Given the limited number of independent prepreggers and component producers in Western Europe, the opportunities **for resin producers** and other fiber suppliers to forward integrate through acquisition are limited. Major resin suppliers such as ICI, Philips, and Akzo are increasingly emphasizing internal integration into thermoplastic composite products to broaden their participation in the business.

At present, most of the major aerospace companies manufacture advanced composite components for internal use. Prepregs are supplied externally. This is not expected to change in the future, since these companies possess the technology and the resources to continue their leadership in the manufacturing of components.

Acquisition activity in Western Europe typically has involved the absorption of smaller firms by major firms, as shown in appendix 9-6. Major acquisitions by European companies have tended to occur outside the continent, particularly in the United States.

Joint venture and licensing activities are typified by the importation of foreign technology into the European market. Recent joint ventures and licensing agreements are shown in appendix 9-6.

Foreign Participation in the European Market

Numerous U.S.-based companies participate either directly or indirectly in the advanced composites business of Western Europe. Among the more prominent is Hexcel, which has manufacturing facilities in France. Most of the other major participants, such as American Cyanamid, HITCO, and Dexter Hysol operate through joint venture companies. Other leading U.S.-based companies such as Hercules, Fiberite, and Narmco presently sell through sales organizations established in the major countries.

The major Japanese influence in the Western European market is in the fiber sector. Teijin is selling aramid fibers in Europe, while Toho Rayon and Toray have either licensed technology to European companies or have established joint ventures in the carbon fiber sector.

Currently, the only areas in which U.S.-owned companies hold major positions are aramid fibers and prepregs. Considering only U.S.-owned subsidiaries, the U.S. share of the European market is roughly estimated at 25 to 30 percent of European production. in the long term, the transfer of U.S. technology to Europe resulting from recent acquisitions in the United States is expected to make the European market even more self-sufficient.

Government/Industry Relationships

The following is a discussion of government/industry relationships in the European Community, as well as advanced composites programs in the leading countries: France, the United Kingdom, and West Germany.

European Community Programs

Two programs of the EC, BRITE and EURAM, sponsor research on advanced materials and their production technology. These programs address themselves to metals, ceramics, polymers and composites; in BRITE the emphasis is primarily on production technology. Ten out of 95 ongoing BRITE projects deal with composite materials.

Outside of the EC framework is the European collaborative program called EUREKA. EUREKA was created at the European technology conference held in Paris on July 17, 1985. To date, 19 European countries, as well as the Commission of the European Communities, are participating in the initiative. The objective of EUREKA is to improve the productivity and competitiveness of Europe's industries and national economies through closer cooperation among enterprises and research institutes in high technology.

At conferences in Hanover and London, 72 cooperative proposals were adopted as projects. To implement these projects, which cover a wide range of technologies, about $3.2 billion will be needed over a period lasting from 2 to 10 years. Although the technological areas covered by EUREKA and EURAM are closely related, the emphasis differs. EUREKA is primarily concerned with developing products, processes, and services having a market potential. Since these projects are closer to the market and involve less risk and uncertainty, financing is provided jointly by governments and private companies. However, financing arrangements vary greatly from one country and project to another.

In EUREKA, projects come directly from companies without reference to a strategic program within the EC. The direct agreement reached on a project by a number of firms is then presented to the EUREKA member States, which check that it is consistent with EUREKA's genera] principles and conditions for eligibility. Project management, including monitoring and evaluation of research, is done by the participating companies themselves.

Two EUREKA programs were approved in June 1986 that are related to advanced materials. The first, Carmat 2000, with proposed funding of $60 million for 4 years, involves evaluating PMCs for automobile structures. This program has 13 participants: eight organizations in France, three in West Germany, and one each in the United Kingdom and the Netherlands. The participants are listed in table 9-31. Peugeot, the principal coordinator, will work with the suppliers in developing a car with much greater use of plastics than today's automobiles. The objective of Carmat 2000 is to introduce a medium-sized car in 1990 at a lower cost by incorporating large amounts of engineering plastics and composites.

National governments will fund the project costs for Carmat 2000 up to a maximum of 50

Table 9-31.—Carmat 2000 Participants

France
Peugeot
Usinor
Facilor
Ecole des Mines (Paris)
Cetim
St. Gobain
Elf Aquitaine
Inrets
West Germany
Bayer
BASF
Battenfeld
United Kingdom
ICI
Netherlands
DSM

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers end Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

percent of the total. The participating companies and organizations will contribute the balance. Research responsibilities are divided among the participants. For instance, DSM is responsible for developing the bumper system, front subframe, rear wheel arches, trunk floor, and integrated plastic fuel tank. ICI is responsible for the doors and trunk lid, as well as the glazing; Bayer and BASF will be contributing their expertise in polymers and composites.

No information was available on the composites component of the second EUREKA program, called Light Materials for Transport Systems, other than that proposed funding is $15 million over 4 years.

National Programs

In addition to EUREKA and the EC-sponsored programs on advanced composites, various programs are underway in several countries.

France.—According to French Government sources, government support for all advanced materials research, including ceramics and composites, was $150 million in 1985. The most important institutes, universities, and companies involved in advanced composites R&D are given in table 9-32. Many of the French companies making major investments in advanced composites are government-owned. One government-owned company, Aerospatiale, the most prominent aerospace company in France, spent $60 to 80 million on R&D for developing composite structures in 1985.

United Kingdom.—To date, most of the government programs have been sponsored by the Ministry of Defence and are primarily aimed at the aerospace field. The government spent over $255 million in a SO-SO cost-sharing program with industry to research a new fighter aircraft in the Experimental Aircraft Program (EAP), The **program was launched in 1983 to investigate technologies applicable to future fighter projects. it was designed to improve the capabilities of the British aerospace industry across a wide range of technologies, including carbon fiber composite structures.**

Table 9.32.–Major French Laboratories Conducting Advanced Composites R&D, 1986

Public laboratories	Location
Ecole d'Application des Hauts Polymerés	Strasbourg
Ecole des Mines de Saint-Etienne	Saint-Etienne
Ecole Nationale Supérieure de Mécanique	Nantes
Ecole Supérieure de Physique Chimie Industrielle	Paris
Institute Nationale des Recherches de la Chimie Appliques (IRCHA)	Paris
Institute Nationale des Sciences Appliques	Vilieurbanne
Laboratoire Nationale d'Essais	Trappes
Office Nationale d'Etudes et des Recherches Aerospatiales (ONERA)	Chatillon
Université de Besancon	Besancon
Université de Bordeaux	Talance
Université de Technologies de Compiégne	Compiegne
Université Pierre et Marie Curie	Paris
Université Scientifique et Technique de Lille Flandres Artois	Villeuneuve
Industry/private laboratories	**Location**
Aerospatiale	Paris
Alsthom Atlantique	Villeurbanne
Centre d'Etudes des Industries Mecaniques (CETIM)	Senlis
Charbonnages de France	Paris
Elf Aquitaine	Artix
Groupement d'Intéret Economique Régienov	Boulogne
Laboratoire de Recherche et de Controle du Caoutchouc et des Plastiques	Vitry
Matra	Paris
Métravib	Ecully
P.S.A.	Audicourt
Péchiney	Paris
Société Nationale des Poudres et Explosifs	Paris
Unirec	Firminy
Vetrotex Saint-Gobain	Chambery

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials)" a contractor report prepared for OTA, Mar, 24, 1987; and Dominique Cotto, Science Attache, Embassy of France, personal communication, November 1987.

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Many of the technologies developed for the EAP could be used on the planned European Fighter Aircraft (EFA), scheduled to enter service in the mid-1990s. Development of the EFA, one of the largest new military aircraft programs, will be undertaken by a consortium of companies from the United Kingdom, West Germany, Italy, and Spain. The United Kingdom and West Germany will have 33 percent of the consortium, Italy, 21 percent, and Spain, 13 percent. The EFA is expected to require considerable quantities of advanced composites.

Next to the Ministry of Defence, the Department of Trade and Industry (DTI) provides the most funding for composites R&D. In **1985,** the DTI funded **$14 million in** PMC R&D, compared with less than $2 million in 1980. Also in 1985, DTI recommended a 5-year program for the development and exploitation of new materials and processes, including plastics, composites, and ceramics. The Materials Advisory Group of DTI recommended that the government should provide half of the funds for the program. Total government funding of this program is recommended at $170 million. Some of the most important organizations in the United Kingdom with research programs in advanced composites are given in table 9-33.

West Germany.—The West German Government has become much more active in providing funds for new materials research. In late 1985, the Ministry for Research and Technology announced that it would spend $440 million over a 10-year period, 1986-95, for materials research in the following fields: ceramics, polymers, composite materials, and high-temperature polymers and metals. The funds will be allocated on a project basis to companies, universities, technical institutes, or trade research organizations that have viable research programs that meet the department's guidelines. The government will provide up to 50 percent of the funding on the projects, with the research performing organizations providing the balance.

Table 9-33.–British Government Organizations With Research Programs in Advanced Composites, 1986

Organization	Location	Comment
Atomic Energy Research Establishment	Harwell	Has composites and polymers group that makes prepregs and components for merchant sale
Royal Aircraft Establishment	Farnborough	Quasi-government agency conducting research on advanced composites for aerospace sector
Experimental Aircraft Program	London	Partially government-funded development program with British Aerospace/Rolls Royce; total funds: $255 million

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials,"a contractor report prepared for OTA, Mar. 24, 1987.

METAL MATRIX COMPOSITES

Like PMCs and CMCs, metal matrix composites (MMCs) utilize a variety of matrices and reinforcements, depending on the performance requirements of particular applications (see ch. 4). Aluminum is currently the most common matrix material, and the most common reinforcements are carbon/graphite, boron, and silicon carbide. Like PMCs, MMC development has been driven by military funding, and current demand for MMC materials in the United States is almost exclusively defense-oriented. High manufacturing costs continue to be a major barrier to the use of fiber-reinforced MMCs in commercial applications; however, particulate-reinforced MMCs, which exhibit moderate strength and stiffness improvements compared to the matrix alone, can be produced at a cost approaching that of conventional metals.

Following is a brief discussion of MMC-related activities in the United States, Japan, and Western Europe. Market information is omitted because data were not available for this assessment.

United States

Industry Structure

Presently, suppliers of MMC materials in the United States are small, undercapitalized companies with limited technical resources. This is because the current market is not large enough to attract large companies. In fact, several experts have characterized the industry as a "cottage" industry. R&D programs have been initiated by larger firms, including major aluminum suppliers such as Alcoa and Alcan. However, the companies actually supplying MMC materials, structural shapes, and components to the industry are either small, entrepreneurial firms or small subdivisions or subsidiaries of large corporations. integration of these smaller producers into concerns having greater capital and R&D resources is considered an important step in the diffusion of the technology into commercial applications. The primary suppliers of matrix, reinforcement, and finished MMC materials in the United States are given in table 9-34.

Table 9-34.-Major Suppliers of MMC Materials in the United States, 1986

Matrix
Alcan
Alcoa
AMAX
Avco/Textron
Dow Chemical
Particulate
Norton
Standard Oil Engineered Materials
Whiskers
Arco Chemical
American Matrix
J.M. Huber
Versar Manufacturing
Fibers[a]
American Cyanamid
Avco/Textron
Du Pont
Standard Oil Engineered Materials
Composites
Advanced Composite Materials
Amercom
Arco Chemcial
Avco/Textron
Cordec
Dural Aluminum Composites
DWA Composite Specialties
Materials Concepts
Novamet
Sparta

[a]See tables 9-19 and 9-23 for suppliers of graphite fibers, which are also used in MMCs.

SOURCE: Compiled by Office of Technology Assessment

At present, the fabrication capabilities of most MMC users are limited to secondary methods, such as machining. These users generally buy MMCs from suppliers in the form of billets, plates, structural shapes, or finished parts. However, a few end users are developing in-house casting, forging, and extrusion capabilities for MMCs. Examples include manufacturers of automotive components (such as diesel engine pistons and connecting rods) and several defense aerospace contractors.

Joint venture and acquisition activity in the industry is increasing. DWA Composite Specialties, for instance, has entered into a joint venture with Revmaster Aviation to produce silicon carbide- and boron carbide-reinforced aluminum alloys for automotive engine parts at a cost of$7to$12 per pound.[29] Pistons, connecting rods, and rocker arms are under consideration. DWA also licensed ceramic particulate-reinforced aluminum technology to Alcoa in 1984.

Recently, several important companies have been put up for sale. Arco Silag has been sold by Horsehead Industries to Tateho America; Amercom, Inc., is being acquired by Atlantic Research Corp.; and Textron has placed its Avco Specialty Materials Division up for sale.[30]

Alcan established Dural Aluminum Composites, which it acquired from SAIC. Dural has

[29]Dural Aluminum Composites has quoted prices as low as $3 per pound in commercial quantities.

[30]Joe Dolowy, President, DWA Composite Specialties, Inc., Personal communication, November 1987.

produced some 20,000 pounds of silicon carbide-reinforced aluminum and has sent it to 65 corporations and laboratories for evaluation .31 Alcoa is developing its ARALL composite (a laminate of aluminum and aramid fibers bonded with epoxy). However, the Alcoa effort is still in the developmental stage, and materials are not being offered for sale commercially.

Lockheed-Georgia, which began work on MMCs in 1980, is working with Arco Chemical Co. and Avco Specialty Materials Division to develop silicon carbide-reinforced aluminum containing whiskers or fibers as reinforcement. This Lockheed group uses a spray process to make silicon carbide fiber-reinforced aluminum composites **for use in-house. This work is aimed at developing material for fins to be used on the next generation of the Air Force's Advanced Tactical Fighter. Lockheed-Georgia will design, manufacture, and test two fighter-type vertical fins made from each** MMC material for a program sponsored by the Air Force.

Government/Industry Relationships

The greatest interest in MMCs has been for defense and space applications. Accordingly, most of the funding for development of the MMC industry has come from DoD ($1 54.5 million between 1979 and 1986) and, to a much lesser extent, NASA ($9.1 million between 1979 and 1986).32 Other agency contributions are negligible. DoD funding of MMCs over the same period is considerably less than that spent on PMCs ($327.7 miilion).[33]

There has been little government funding of MMCs for commercial applications in the United States. Until very recently, companies have shown little interest in developing MMCs for use in commercial applications. Diffusion of MMC technology from military to commercial uses is hindered not only by high costs but also by national security restrictions placed on the dissemi nation of technical data and export restrictions imposed by the Departments of Commerce, State, and Defense. (These restrictions, which have been very confusing to MMC supplier companies, are discussed in greater detail in ch. 11).

Japan

Industry Structure

The principal companies supplying MMCs in Japan are the traditional metals suppliers and suppliers of fibers and particulate for PMCs and CMCs. These include Toho Rayon, Toray, Mitsubishi Aluminum, Kobe Steel, and Nippon Steel. Major organizations involved with MMC materials in Japan are listed in table 9-35. Companies experimenting with MMC products include Hitachi, Ishikawajima-Harima Heavy Industries, Honda, and Toyota.

The MMC industry in Japan differs significantly from that in Western Europe and the United States, in that the same companies that are involved with ceramics and PMCs also produce MMCs. The end user industries in Japan that are interested in MMCs are the automotive, electronics, and aerospace industries. The Japanese do not have a large defense industry, and they are concentrating on developing commercial materials for industrial applications, The domestic market for these MMC materials is small, but there are a few products in limited production.

Perhaps the most significant commercial development is the introduction by Toyota of diesel

Table 9-35.—Principal Organizations Involved in MMC Research in Japan, 1986

Art Metal Manufacturing Co.
B&W Refractories
Daia Vacuum Engineering Co.
Hiroshima University
Honda Motors
Japanese Society on Materials Science
Mitsubishi
Nippon Carbon
Okura Laboratory
Sumitomo
Tokai Carbon
Tokyo University
Tokyo Institute of Technology
Toyota Motors

SOURCE: Jerome Persh, Department of Defense, personal communication, November 1987.

31 Dural is scaling up to a capacity of 100,000 pounds per year of silicon carbide particulate-reinforced aluminum by the end of 1988.

32 According to data supplied by Jacques Schoutens, Metal Matrix Composites Information Analysis Center, March 1987.

33 According to data supplied by Jerome Persh, U.S. Department of Defense, November 1987.

engine pistons consisting of aluminum locally reinforced with ceramic fibers. The composite improves wear resistance, enabling elimination of nickel-cast iron inserts. The insert also reduces piston weight and increases thermal conductivity, improving engine performance and reducing vibration. Estimated annual production is about 300,000 pistons.[34] The example of the Toyota piston has stimulated a considerable worldwide interest in MMCs for pistons and other automotive parts. Components being evaluated include connecting rods, cam followers, cylinder liners, brake parts, and drive shafts.

Western Europe

Industry Structure

The structure of the Western European MMC industry is similar to that in the United States. Current MMC R&D is primarily funded by defense ministry contracts. Among end users, aerospace companies have made the highest R&D investments in MMCs. No automobile companies appear to have plans to use MMCs in the near future, although nearly all have undertaken limited evaluations. The principal countries involved in MMC research and development are the United Kingdom, France, and West Germany. Table 9-36 identifies the principal organizations involved in MMC research in Western Europe.

European Cooperative Programs

There is a joint European MMC research project within the BRITE program. It is a basic research program on silicon carbide-reinforced titanium. Participants include three government research laboratories–the Atomic Energy Research Establishment at Harwell (UK); Office Nationale d'Etudes et des Recherches Aerospatiales (ONERA, F), Deutsch Forschungs und Versuchsanstalt fur Luft und Raumfahrt (DFVLR, FRG), and two companies—Sigma Fiber Supply (FRG) and IMI Titanium (UK).

Another joint effort is being conducted within the aerospace industry. It is solely for basic research and is funded at the equivalent of $800,000. The companies involved are British Aerospace, Westland Helicopters (UK), Rolls Royce (UK), Aerospatiale (F), and Motoren und Turbinen Union (MTU, FRG).

[34] Carl Zweben, General Electric Co., "Metal Matrix composites," a contractor report prepared for OTA, October 1986.

Table 9.36.–Principal Organizations Involved in MMC Research in Western Europe, 1986

Federal Republic of Germany	**Sweden**
Batelle-Frankfurt	Chalmers University of Technology
Berghof GMBH	Kockoms Shipyard
Dornier	SAAB
Messerschmitt-Bolkow-Biohm	Sweden Defense Laboratory
Sigri	Sweden Institute for Metals Research
France	Volvo Flygmotor
Aerospatiale	**Switzerland**
CDF Chimie	Ciba-Geigy
Ecole des Mines (Paris)	**United Kingdom**
Elf Aquitaine	Harwell
Institute St. Louis	Bristol Composites
Société Nationale des Poudres et Explosifs	British Aerospace
Thomson-CSF	Courtaulds
University de Bordeaux	Dunlop
Vetrotex-St. Gobain	Fothergill & Harvey
Italy	Hepworth & Grandage
Aeritalia	Imperial Chemicals
Fiat	Lagstall Engineering Co.
Siai Machetti	Rolls Royce
Netherlands	Royal Aircraft Establishment
Fokker	Wellworthy Ltd.
Norway	Westland Helicopters
Central Institute for Industrial Research-Oslo	

SOURCE Jerome Persh, Department of Defense, personal communication, November 1987.

National Programs

United Kingdom.–In addition to those companies listed in table 9-35, several other companies have MMC efforts under way. Alcan U.K. is producing prototype silicon carbide particulate-reinforced aluminum using a spraying process and is planning to scale up to production by 1989. Two other large British metals companies are also planning to enter the MMC business. Cray (no relation to Cray computers) owns a division called Cray Advanced Materials which has a production facility for MMCs. Using an infiltration process, Cray is developing MMC torpedo hulls in conjunction with the Ministry of Defence. Cray uses many different types of continuous fiber: graphite, alumina, Nicalon, silicon carbide, and boron. A second company, BNF, is a research-only firm (similar to Battelle in the United States), which has some casting facilities for glass and silicon carbide fiber-reinforced composites.

France.—Pechiney, a large French aluminum company, has an MMC division that intends to produce particulate-reinforced composites. Aerospace companies with MMC programs include Dassault (manufacturer of the Mirage fighter), Turbo Mecha (an engine supplier), and Aerospatiale. Not all of these efforts are in-house; Dassault, for instance, is considering buying MMCs from the U.S. company DWA Composite Specialties.

West Germany.– In West Germany, the two main companies showing an interest in MMCs are Messerschmitt-Boelkow Blohm (an airframe manufacturer) and MTU (an engine supplier). Sigma Fiber Supply is a small company developing silicon carbide fiber for use in MMCs.

APPENDIX 9-1: RECENT JOINT RELATIONSHIPS IN THE U.S. ADVANCED CERAMICS INDUSTRY

Table A.—Acquisitions

Buyer	Company	Reason	Date
Air Products	Materials Technology	CVD coatings	1985
Air Products	San Fernando Labs	CVD technology	1986
Alcoa	Ceraver (now SCT) (F)	Manufacturing technology Extrusions	
Alcoa	PAKCO	Manufacturing technology	1986
AVX	Monolithic Components	Electronics	1984
Bayer, AG (FRG)	Montedison, S.P.A (I)	Manufacturing technology	N/A
Bayer, AG (FRG)	H.C. Starck (FRG) (90%)	Zirconia technology	1985
Borg-Warner	Fine Particle Tech. (25%)	Inject-mold ceramic auto parts	1985
Cabot	Augat Tech. Ceram.	Electronic packages	1985
Cabot	Spectrum Ceramics	Electronic packages	1985
Cabot	Rhode Island Elect. Ceramics	Electronic packages	1985
Coors	Alumina Ceramics	Manufacturing technology	N/A
Coors	RI Ceramics	Manufacturing technology	N/A
Coors	Royal Worcester Int. (UK)	Manufacturing technology	N/A
Coors	Siemens Components (FRG)	N/A	N/A
Coors	Wilbanks Int.	Manufacturing technology	N/A
Dow Chemical	Boride Products	Manufacturing technology	1985
Du Pont	Solid State Dielectr.	Ceramic capacitors	1982
Elkem Metals	Ceramatec (minority position)	Ceramic parts	1983
Ford	Ceradyne (minority position)	Heat engine	1986
General Electric	3M (part of ceramic business)	Electrical packages, structural	1983
W.R. Grace	Diamonite	Manufacturing technology	1983
Horsehead Industries	ARCO Chemical	Manufacturing technology	1986
ICI Australia Ltd.	Ferro Corp	Zirconia operations	1986
Iscar Metals (IS) (Iscar Ceramics)	Adv. Ceramic Systems	Manufacturing technology	1983
Koppers Co.	Ceramatec (minority position)	Heat engine	N/A
LRC	Crystal ate	Aluminas	1984
Morgan Matroc Ltd. (UK)	Duramics	Ceramic parts	1986
Norton	Plasma Materials Inc.	Plasma process	1986
Pure Industry (Stackpole)	Frenchtown Amer.	High alumina technical ceramics	1985
Raychem	Interamics	Electronics	1984
Thomas & Skinner	Ceramic Magnetics	Magnetic ceramics	1985
Thomas & Skinner	Electron Energy	Electronic magnetic ceramics	1985

Table B.—Joint Ventures

Partner 1	Partner 2	Reason	Date
Alcan	Lanxide	Technology	1985
Alcoa	American Ceramic Tech.	Technology Production (electronics)	1986
Alcoa	Intercon X	IC ceramic packages	1986
Cercom, Inc.	Intercon X	Silicon nitrides and other refractories	1986
Coors	Started new companies in Scotland, Wales, Brazil		N/A
Corning	Plessco Optronics	Fiber optics	1986
Cummins Engine	Toshiba (J)	Technology	1986
General Motors			
Allison Gas Turbine Division	Int. Energy Agency (with West Germany and Sweden)	Powder characterization	Ongoing
W.R. Grace	Dynamit Nobel (FRG)	High-purity silicon	1983
W.R. Grace	Feldmuehle (FRG)	Heat engine	1983
Hitachi (J)	SOHIO Eng. Mat. (Carborundum)	SiC ceramics	1983
Koppers Co.	Adv. Refrac. Mat.	Powders	N/A
Montedison (I)	Keramont	Powders, products	1986
Norton	TRW	Heat engine	1985
Olin Corp.	Asahi Glass (J)	Electronics	1986

Table C.—Licensing Agreements

Licenser	Licencee	Reason	Date
ARCO Chemical	Martin Marietta	Advanced ceramic composites for tooling and other wear applications	1986
ARCO Chemical	Sandvik, AB (S)	SiC whisker reinforcements	1986
ASEA Cerama (S)	Norton	Glass encapsulation HIP process	N/A
Centre Suisse D'Elect. et Microelect.	Air Products	Chemical vapor deposition (CVD) technology	1986
Greenleaf Corp.	ARCO Chemical	Manufacture and sale of SiC whisker-reinforced ceramic tooling	1986
Iscar Ceramics (IS)	Ford	Cutting tool technology	1986
Lucas (UK)	Kennametal	Sialon technology	N/A
Lucas (UK)	Norton	Hot pressed silicon nitride	1970
People's Republic of China	Corning	Complete factory	1986
PPG	Alcoa	Plasma powder production	1986
ROC TEC (Kelsey-Hayes subsidiary)	Dow Chemical	Powder processing technology	1985
SEP (F)	Du Pont	Ceramic composites	1987

N/A = Not available.

KEY: A = Austria; B = Belgium; F = France; FIN = Finland; FRG = West Germany; I = Italy; IR = Ireland; IS = Israel; J = Japan; NL = Netherlands; S = Sweden; SP = Spain; SWI = Switzerland; T = Taiwan; UK = United Kingdom; US = United States.

SOURCE: Business Communications Co., Inc., "Strategies of Advanced Materials Suppliers and Users," a contractor report prepared for OTA, Mar. 24, 1987.

APPENDIX 9-2: RECENT JOINT RELATIONSHIPS IN THE JAPANESE ADVANCED CERAMICS INDUSTRY

Table A.—Joint Ventures

Joint venture partners	Company formed	Business	Date
Harima Refractories/ Nippon Steel	Micron	Manufacturing and distributing ceramic powders	1985
Hitachi Chemical/ Carborundum (SOHIO)	Hitachi Carborundum[a]	Manufacturing and distributing silicon carbides	N/A
Nippon Steel/ Kurosaki Refractories/ Nippon Steel Chemical	N/A	Development of production method for new ceramics by sol-gel process	N/A
Sumitomo Chemical/ SFE Technology	Sumika SFE	Manufacturing and distributing multilayered ceramic capacitors	1985
Toshiba Ceramics/ Kyoritsu Ceramics	STK Ceramics Laboratories	R&D of fine ceramic materials	1985
Toshiba Ceramics/ SOHIO Engineered Materials	N/A	Ceramic fibers	N/A
Yuasa Battery/ NGK Spark Plug	Ceramic Battery	Sodium-sulfur batteries	N/A

Carborundum (SOHIO) sold its share of the joint venture to Hitachi Chemical in April 1986,
N/A = Not available,

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987,

Table B.—Licensing Agreements

Licenser	Licensee	Agreement description	Date
British Nuclear Fuels Ltd. (UK)	Asahi Glass	Technology for reaction sintering	1985
Gateng Instrument (FRG)	Nippon Sheet Glass	Calcining technology for zirconium oxide	1985
Lucas-Cookson-Syalon (UK)	Sumitomo Electric	Sialon powders and products	1985
	Nippon Steel	Sialon powders and products	1985
	Hitachi/Hitachi Metals	Sialon powders and products	1985

SOURCE Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

APPENDIX 9-3: RECENT JOINT RELATIONSHIPS IN THE WESTERN EUROPEAN ADVANCED CERAMICS INDUSTRY

Table A.—Acquisitions

Buyer (loc.)	Company	Primary business	Date
Alcoa (SWI)	Ceraver (F)	Ultrafiltration ceramic membranes	1986
Bayer (FRG)	Cremer Forschungsinstitut (FRG) (75% share)	Research laboratory and family holdings	1986
Bayer (FRG)	Annawerke (FRG) (through Cremer purchase)	Technical ceramics	1986
Bayer (FRG)	Friedrichsfeld (FRG) (through Cremer purchase)	Technical ceramics	1986
Bayer (FRG)	Starck (FRG) (90% share)	Special metallurgical powders	1986
Coors (UK)	Royal Worcester (UK)	Industrial ceramics	1983
Fairey (UK)	Allied Insulators (UK)	Insulators	1985
Feldmuehle (FRG)	Part of Annawerke (FRG)	Silicon nitride technology	1984
Hoechst (FRG)	Rosenthal Technik (FRG) (90% share)[a]	Advanced ceramics, including electronic substrates and automotive components	1983
ICI (Australia)[b]	Ferro's Bow, NH plant[c]	Zirconia powders	1986
Lucas (UK)	Cookson-Syalon (UK)[d]	Licensing of sialon patent, prototypes, and limited part production	1982
Pechiney (F)	Desmarquest (F)	Technical ceramics	1985
Rauschert (FRG)	Part of Annawerke (FRG)	Textile guides	1984
Rhone-Poulenc (F)	Ceraver's non-oxide technologies	Technology for nitrides of silicon, aluminum and others, and lab equipment	1985
Schunke (FRG)	Dyko Ingenieur Keramik (FRG)	Technical ceramics	1983
Stettner (FRG)	CICE (F)	Electrical ceramics	1985
St. Gobain (F)	Kerland (F)	Ceramic fibers	1985
St. Gobain (F)	SEPR (F)	Refractories, zirconia beads	1985
Ziegelwerke Horw-Gettnau-Muri (SWI)	Metoxid (SWI)	Engineering ceramics; mainly tin oxides	1986[f]
VAW (FRG)	Didier (FRG) (15% share)	Refractories	1985

[a]New comany name is Hoechst CeramTec.
[b]Owned 64% by ICI, UK.
[c]New company name is Z-Tech.
[d]New company name Is Lucas-cookson-syalon.
[e]New company name is Ceramiques et Composites.
[f]Acquired in two steps In June and September.

Table B.—Joint Ventures

Joint venture partners	Company formed	Business	Date
ASEA (50%)/Boliden, Nobel, Sandvik, SKF, and Volvo (each 10%) (all S)	ASEA Cerama (S)	High performance ceramics (HPC), particularly HIP techniques	1982
Belgian Government-Walloon Region (80%)/ Belref, Diamond, Boart, Gechem, Glaverbel (each 5%) (all B)	Neoceram (B)	Develop HPC business	1986
Brush-Wellman (US)/Heraeus (FRG)[a]	—	Develop aluminum nitride electronic substrate business in United States	1985
CICE (F)/Cabot (US)	CERDI (F)	Electronic substrates and packages Presently mainly selling packages from Cabot's subsidiary, Augat (US)	1986
Degussa (FRG)/Hutschenreuter (FRG)	—	Flue gas catalyst supports	1986
Dyko (FRG)/Morgan (UK)[b]	Dyko Morgan Faser Technik (FRG)	Vacuum-formed ceramic fibers	1983
Eurofarad (F) (5%)/Pechiney (F) (95%) (recently joined by Thomson-CSF)	Xeram (F)	Dielectric ceramics	1986
Frauenthal (A)/Simmering (A)	—	Catalytic converters for processing flue gases in power stations	1985
W.R. Grace (US) (50%)/Feldmuehle (FRG) (50%)	Grace/Feldmuehle/ Noxeram	Automotive engine parts	1983
ICI (Australia) (85%)[c]/Sirotech, (Australia) (15%)	Z-Tech (Australia)	Zirconia products	1985
Koor (IS)/Park Electrochemical (US)	·	Electronic ceramics	1984
Montedison (I)/EFIM (I)	—	Research and development for HPC for defense applications	1986
Philips (NL)/Nippon Chemi-Con (J)/ Nippon Steel (J)	PNN	Multi layer ceramic capacitors	1986
Rhone-Poulenc (F)/SEP (F)	·	Composite of SiC whiskers and ceramics	1986
SACMI (I)/POPPI (I)	—	Development of ceramics	1986
Thomson-CSF (F)/Lamination Specialties (US)	—	Soft ferrites	1985
Wade (UK)/Engelhard (UK)/British Steel (UK)	—	Steel-based ceramic substrates	1986
Waertsilae (Fin) (60%)/Partek (Fin) (40%)	WP Ceramics	Wear parts of alumina and zirconia	1986

[a]Started in June 1985 but terminated in December 1985
[b]Morgan recently changed its name to Matroc
[c]64% owned by ICI (UK)

Table C.-Licensing Agreements

Licenser	Licensee	Product technology	Date
ASEA Cerama (S)	Norton (US)	Hot isostatic pressing (HIP) with glass encapsulation technology	1984
ASEA Cerama (S)	Seco Tools (S)	HIP with glass encapsulation technology	1985
ASEA Cerama (S)	GET (US)	HIP with glass encapsulation technology	1985
British Nuclear Fuels (UK)	Iscar (IS)	Silicon nitride for tool inserts	1983
Lucas-Cookson-Syalon (UK)	about 15 licensees throughout the world	Sialon technology	1982
Mitsubishi Petrochemical (J)/Hitachi (J)	Frauenthal (A)	Denox catalysts for power plant flue gas	1985
Mitsubishi Petrochemical (J)/Sakai (J)	Noxeram (FRG)	Smokestack emission catalysts	1986

KEY: A = Austria; B = Belgium; F = France; FIN = Finland; FRG = West Germany; I = Italy; IR = Ireland; IS = Israel; J = Japan; NL = Netherlands, S = Sweden; SP = Spain; SWI = Switzerland; T = Taiwan; UK = United Kingdom; US = United States.

SOURCE: Strategic Analysis, Inc , "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

APPENDIX 9=4: RECENT JOINT RELATIONSHIPS IN THE U.S. ADVANCED COMPOSITES INDUSTRY

Table A.—Acquisitions

Buyer	Acquired company	Primary business	Date
Amoco	Carbon Fiber Group (Union Carbide)	Fibers	1986
BASF (FRG)	Celion Carbon Fibers Division, Narmco, Quantum (Celanese)	Fibers, prepregs, shapes	1985
British Petroleum (UK)	HITCO (Owens-Corning)	Fibers, prepregs, shapes	1986
Du Pont	Carbon Fiber Group (Exxon)	Fibers, shapes	1985
Hexcel	Dittmer & Dacy	Shapes	1984
Hexcel	Hi-Tech Composites	Ply fabrics	1986
ICI Americas	Fiberite Composite Materials (Beatrice)	Prepregs, fabrics	1985
Owens-Corning	HITCO (Armco)	Fibers, prepregs, shapes	1985
Shell[a]	Morrison Molded Fiber Glass	Pultruded shapes	1988
Textron	Avco	Shapes, prepregs, fibers	1985

[a]80% interest.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

Table B.—Joint Ventures

Joint venture partners	Company formed	Primary business	Date
Celanese/Daicel Chemical Industries (J)	Polyplastics (J)	Polyphenylene sulfide (PPS) molding compounds	N/A
Celanese/Kuraray (J)	—	Development of aramid fibers	N/A
Dexter/Courtauids (UK)	Hysol Grafil (US, UK)	Carbon fibers, prepregs	1983
Fiberite/Mitsubishi (J)	Kasei-Fiberite (J)	Prepregs	1983
Hercules/Biomet	—	Composite orthopedic implants	1986
Hercules/Sumitomo (J)	Sumika-Hercules (J)	Polyacrylonitrile (PAN) precursor, prepregs	N/A
Shell/Preform Composites	Xerkon	Composite shapes, woven fabrics	1984

N/A = Not available.

Table C.—Licensing Agreements

Licenser	Licensee	Agreement description	Date
HITCO	Formosa Plastics (T)	Carbon fiber, prepreg tape	1984
HITCO	Mitsubishi Rayon (J)	Carbon fiber technology	1981
Nikkiso (J)	Boeing	Carbon fiber technology	1986
Sumitomo (J)	Avco	Distribution of alumina fiber	N/A
Toho Rayon (J)	Celanese/BASF	Carbon fiber technology	N/A
Tokai Carbon (J)	Avco	Distribution of SiC whiskers	1986
Toray (J)	Union Carbide/Amoco	Carbon fiber technology	1979
Ube (J)	Avco	Distribution of ceramic fiber	1986

N/A = Not available.
KEY: A = Austria; B = Belgium; F = France; FIN = Finland; FRG = West Germany; I = Italy; IR = Ireland; IS = Israel; J = Japan; NL = Netherlands; S = Sweden; SP = Spain; SWI = Switzerland; T = Taiwan; UK = United Kingdom; US = United States.

APPENDIX 9-5: RECENT JOINT RELATIONSHIPS IN THE JAPANESE ADVANCED COMPOSITES INDUSTRY

Table A.—Joint Ventures

Joint venture partners	Company formed	Primary business
Asahi Chemical/Ciba-Geigy (SWI)	Asahi-Ciba	Epoxy
Asahi Chemical/Ciba-Geigy (SWI)	Asahi Composite	Prepregs
Mitsubishi Chemical/Fiberite (US)	Kasei-Fiberite	Prepregs, shapes
Mitsubishi Rayon/HITCO (US)	Dia-HITCO Composites	Shapes
Mitsui Petrochemical/Rhone-Poulenc (F)	Nippon Polyimide	Polyamides
Sumitomo Chemical/Hercules (US)	Sumika-Hercules	Carbon fibers, precursors, prepregs
Toho Rayon/Narmco (US)	Toho Badische	Prepregs, shapes
Toray/Du Pont (US)	Toray Du Pont	Aramid fibers
Toray/Phillips (US)	Toray Phillips	Polyphenylene sulfide

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

Table B.—Licensing Agreements

Licenser	Licensee	Agreement description	Date
Hercules (US)	Sumika-Hercules	Production technology for carbon fibers	1979
HITCO (US)	Mitsubishi Rayon	Calcining technique for carbon fibers	1981
Nikkiso	Boeing (US)	Production technology for carbon fibers	1986
Sumika-Hercules	Hercules	Supplying precursor	1979
Toho Rayon	Celanese/BASF (US)	Production technology for carbon fibers	N/A
Toho Rayon	Enka (NL)	Production technology for carbon fibers	1980
Toray	Société des Fibres de Carbones (F)	Production technology for carbon fibers	1983
Toray	Union Carbide/Amoco (US)	Production technology for carbon fibers	1979

N/A = Not available.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

APPENDIX 9-6: RECENT JOINT RELATIONSHIPS IN THE WESTERN EUROPEAN ADVANCED COMPOSITES INDUSTRY

Table A.—Acquisitions

Buyer	Acquired company	Business	Date
BASF (FRG)	Celanese's advanced materials business (US)	Fibers, prepregs, shapes	1985
BP Group (UK)	Bristol Advanced Composites (UK)	Prepregs	1985
British Petroleum (UK)	HITCO (US)	Fibers, prepregs, shapes	1988
Ciba-Geigy (SWI)	Aero Research (UK)	Composite weaver	1947
	Brochier (F)		1982
Courtaulds (UK)	Fothergill & Harvey (UK)	Composite parts weaver	1987
Dow Chemical Europe	Seger & Hoffman (SWI)	Prepregs	1984
Hexcel (US)	Stevens-Genin (F)	Prepregs	1985
ICI Americas (subsidiary of ICI, UK)	Fiberite (Beatrice) (US)	Prepregs	1985
Montedison (I)	Texindustria (I)	Weaver	1985
Sturgis und Teschler (FRG)	Interglas-Textil (FRG)	Weaver	1981

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.

Table B.—Joint Ventures

Joint venture partners	Agreement description	Date
Akzo (Enka) (NL)/Toho Rayon (J)	Joint venture for carbon fiber products	1982
Courtaulds (UK)/Dexter Hysol (US)	Carbon fiber venture Hysol-Grafil	1983
DSM (NL)Toyobo (J)	High-strength polyethylene fiber	1985
Elf Aquitaine (F)/Toray (J)	Joint venture for carbon fiber production	1982

Table C.—Licensing Agreements

Licenser	Licensee	Agreement description	Date
Aerospatiale (F)	Hercules (US)	Three-dimensional weaving technology	1984
Bell Helicopter (US)	Agusta (I)	Helicopter construction technology	N/A
Hercules (US)	CASA (SP)	Carbon fiber technology	1987
Narmco Materials (US)	Fibre & Mica (F)	Prepregging technology	N/A
Toho Rayon (J)	Enka/Akzo (NL)	Carbon fiber technology	1982

N/A = Not available.

KEY: A = Austria; B = Belgium; F = France; FIN = Finland; FRG = West Germany; I = Italy; IR == Ireland; IS = Israel; J = Japan; NL = Netherlands; S = Sweden; SP = Spain; SWI = Switzerland; T = Taiwan; UK = United Kingdom; US = United States.

SOURCE: Strategic Analysis, Inc., "Strategies of Suppliers and Users of Advanced Materials," a contractor report prepared for OTA, Mar. 24, 1987.