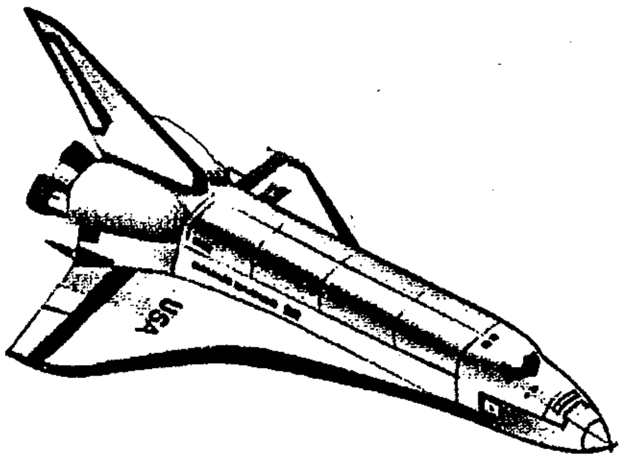
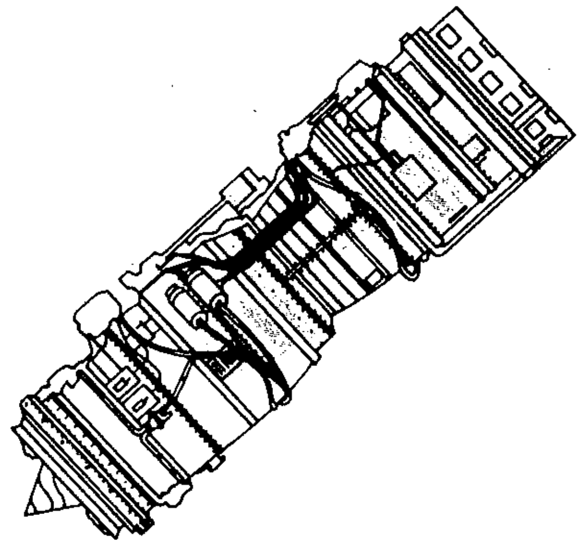
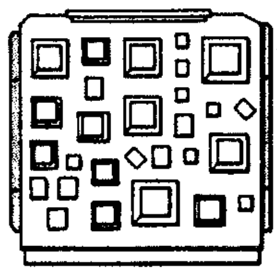
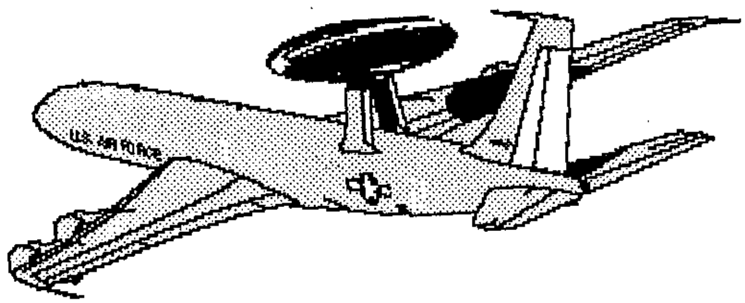
CRITICAL TECHNOLOGY ASSESSMENT OF THE U.S. ADVANCED CERAMICS INDUSTRY









U.S. DEPARTMENT OF COMMERCE
BUREAU OF EXPORT ADMINISTRATION
OFFICE OF INDUSTRIAL RESOURCE ADMINISTRATION
STRATEGIC ANALYSIS DIVISION

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Critical Technology Assessment of the U.S. Advanced Ceramics Industry

Prepared by

U.S. Department of Commerce
Bureau of Export Administration
Office of Strategic Industries and Economic Security
Strategic Analysis Division

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Overview

It was estimated that the 1990 U.S. market for advanced ceramic components was $3.6 billion. Products destined for electronics end uses account for approximately 80 percent of this figure. Ceramics are used in such electronic applications as ceramic packages, capacitors, and sensors. They are also used extensively in structural applications, such as engines, cutting tools, armor, and wear components. Defense applications of advanced ceramics are wide-ranging, covering both electronic and structural applications. Ceramic semiconductor packages, for example, have innumerable uses in defense electronics. Other defense applications include vehicle and personnel armor and aircraft parts. Although commercial markets for advanced ceramics predominate, the industry has been adversely affected by recent cuts in defense spending. The decrease in these markets has combined with a general decline in the economy, resulting in lower profits and higher debt loads for the industry. The repercussions are significant: defense-dependent firms lack the financial strength to convert their operations; companies find themselves unable to fund research and development needed to remain competitive; and firms cannot afford to maintain their defense production capabilities.

Background

This critical technology assessment of the U.S. advanced ceramics industry was initiated under Section 825 of the National Defense Authorization Act for Fiscal Year 1991. Section 825 required the Secretary of Defense and the Secretary of Commerce (acting through the Under Secretary for Export Administration) to submit annual reports to the Armed Services Committees of the Senate and the House of Representatives on the financial and production status of industries supporting technologies deemed by the Department of Defense (DOD) to be critical to the performance of current and next-generation weapon systems. The National Defense Authorization Act of Fiscal Year 1993, Section 4215, further expanded the scope and requirement for technology and defense industrial base capability assessments. The advanced ceramics industry is one of six chosen for assessment.

The primary objective of these assessments is to provide government policymakers and industry executives with comprehensive information and analysis on the production and technology status, economic performance, and international competitiveness of private sector firms involved in critical technologies, in light of declining defense budgets. While DOD has deemed these technologies essential to the development of the next generation of weapon systems, they are also crucial to the nation's ability to compete in the global economy.

The Department of Commerce's Office of Industrial Administration (OIRA), Strategic Analysis Division, is the office within the Bureau of Export Administration responsible for conducting these critical technology assessments. OIRA created an advanced ceramics advisory team made up of experts from government agencies and the private sector. The team included representatives from Commerce's Technology Administration (including the National Institute of Standards and Technology) and International Trade Administration,

DOD's Advanced Research Projects Agency (ARPA), and the Department of the Interior's Bureau of Mines. The assistance of the United States Advanced Ceramics Association (USACA) and a number of individual member firms was particularly instrumental in survey design, technical advice, mailing lists, on-site visits, and establishing company contacts.

The FY 1991 and FY 1993 National Defense Authorization Acts require that the assessment address a number of factors. These factors include the financial ability of U.S industries supporting these technologies to conduct R&D, apply the technologies to the production of goods and services, and maintain a viable production base in the wake of reductions or terminations in defense procurement; trends in profitability, investment, and R&D for these critical industries; international competitiveness and market trends; consequences of mergers, acquisitions, and takeovers; effects of dependence on foreign or foreign-owned suppliers; results of DOD spending on these technologies; efforts of DOD to expand its use of commercial technology and equipment; and the need and effort of industry in the area of defense conversion.

OIRA sent comprehensive questionnaires to U.S. industry under authority of the Defense Production Act of 1950 (DPA), as amended, and related Executive Order 12656. Information regarding the foreign advanced ceramics industry was gathered by BXA's Office of Foreign Availability (OFA). In preparing this separate assessment, OFA contacted industry specialists in domestic and foreign firms as well as experts in government and academia.

Scope

Advanced ceramics possess properties which allow their use in a variety of defense and commercial applications. In comparison with metals, these materials demonstrate superior wear resistance, high temperature strength, favorable electrical properties, chemical resistance, dimensional stability, and high strength-to-weight ratios. Advanced ceramics are used in functional (electronic), structural, and coating applications.

Defense applications for advanced ceramics are wide-ranging. One of their most important uses is in ceramic semiconductor packages, which are utilized extensively in defense electronics. Apart from the myriad electronic applications, other defense applications include vehicle and personnel armor, aircraft parts, and gas turbine engine parts. Other applications include catalytic converters, bearings, cutting tools, capacitors, sensors, and power tubes.

Industry Overview

OIRA's questionnaire to firms in the U.S. industry was the main source of information for this assessment. Fifty-three firms responded to the survey, providing information on 103 manufacturing establishments scattered throughout the United States. Twenty-two were small firms, with less than 50 employees. Twenty-five indicated that they were owned by another firms; of these nine had foreign parents. Forty-seven firms identified themselves as manufacturers, 11 as research facilities, five as resellers, three as distributors, and one as a trading company. (Many firms perform more than one function.)

Electronic, or functional, applications are the most mature and largest endmarkets for advanced ceramics. Ceramics used in functional applications offer high thermal conductivity, low electrical conductivity, and small dielectric constant. Functional applications include electronic packages and substrates, capacitors, varistors, transducers, and sensors.

Ceramics used in structural applications offer hardness, wear and abrasion resistance, corrosion and heat resistance, and lightness and are the second largest endmarket. Key structural applications include engines, cutting tools, armor, and heat exchangers.

Raw materials are critical to the eventual quality of ceramics. The composition of the materials, their impurities, and the characteristics of their particles all contribute to material quality and affect reliability.

Ceramics are also used as coatings to protect or lubricate a variety of materials including metals, composites, and other ceramics. Coatings are especially useful in parts that must withstand heavy wear.

Commercial and Defense Shipments

Shipments of advanced ceramics grew steadily between 1989 and 1993 (estimated). Shipments per respondent grew from approximately $39 million in 1989 to $47.5 million in 1993, an increase of almost 22 percent. In the same period, aggregated total shipments for the 27 firms who provided data for all five years rose by nearly 29 percent. Structural ceramics accounted for approximately 30 percent of these shipments, functional applications made up about 60 percent, and production of raw materials and ceramic coatings accounted for the remainder.

Defense shipments as a percentage of total reported shipments peaked in 1990. Defense shipments constituted 4.6 percent of shipments that year, then fell to 1.5 percent of shipments by 1993. This figure is likely low, since not all respondents were able to identify defense specific shipments. For those firms who reported defense shipments, such shipments constituted nearly 17 percent of their total shipments in 1989 and peaked in 1991 at about 22 percent, ending the period in 1993 with 20 percent of shipments destined for defense.

Firms responding to this survey provide advanced ceramics products to more than fifty military systems. Systems identified included numerous missiles, aircraft, space craft, satellites, and communications and radar equipment.

Defense Conversion

Most respondents indicated that they are not taking any steps to convert their defense capabilities for domestic uses. Thirty-six of the 49 firms responding to this question indicated that they were not taking any steps to convert; only five said that they were. Another six indicated that their production facilities were already used for both defense and commercial applications. Two indicated that, for their operations, defense conversion was not possible.

Most respondents were unaware of any government programs designed to assist them in their defense conversion efforts. Those who were aware of any such programs mentioned the Department of Energy's (DOE) Cooperative Research and Development Agreements (CRADAs) and Defense's Advanced Research Project Agency. Some respondents gave ideas for programs which might help them in their conversion efforts. Suggestions included end-user education, funding for research and development, capital gains and research expenditure tax credits, and government-industry consortia.

Few respondents were aware of any efforts made by DOD to expand its use of commercially-viable products. Many respondents made suggestions about how Defense could do more in this area. The ideas included improving ARPA's Ceramic Insertion Program, the creation of more CRADAs, and a commercial market awareness program for Defense.

Employment

Employment fell slightly over the assessment period. The average total employment per firm fluctuated during the period, beginning at a high of 360 employees per firm, hitting a low of 259 employees in 1991 (a figure that is influenced by the presence of small firms reporting 1991 data only), and ending the period in 1993 with 348 employees per firm.

Employee training costs rose dramatically over the period. For firms providing both employment and training costs, the training cost per employee more than doubled, growing 138 percent between 1989 and 1993. Comments received from respondents suggest that this growth can be attributed to two factors: (one) that employees required more advanced training as the years passed; and (two) that new hires required extensive training on basic skills.

Those firms who indicated that labor problems have adversely affected their manufacturing operations most often mentioned educational and skill-related deficiencies. More than half of the respondents indicated that they had not experienced any labor-related difficulties. Those who did experience problems told of workers lacking skills in basics such as math, reading and writing as well as ceramic-specific knowledge. Firms reported fewer difficulties in recruiting and retaining research and development personnel. For the minority of firms who experienced problems recruiting these employees, attracting qualified applicants to the firm's location was a frequently-cited difficulty. Others mentioned a shortage of engineers and technicians with ceramic-specific knowledge.

Investment/Research and Development (R&D)

Privately-funded investment in plants, machinery and equipment peaked in 1991, then fell to a low point in 1993. Private investment per company rose from just over $8 million in 1989 to $10.3 million in 1991; by 1993, investment per firm had fallen to an estimated $4.8 million per firm. Throughout, funding was predominantly sourced from within the firm.

Government-funded investment in plants, machinery and equipment was small compared to private funding. Government funds were greatest in 1989, at a total of $5.4 million; funding ended the period in 1993 with a total of $3 million. The Department of Defense and Energy were the primary sources of funding, always providing at least 70 percent of total government financing.

Total reported R&D funding started and ended the period at about the same level, peaking in 1991. As with investment, funding for R&D was almost entirely private, accounting for at least 85 percent of funds in each year. In-house resources were the predominant source for private funding; domestic customers also played a small part but never grew to more than 5 percent. Public funding of R&D peaked in 1993, with 15 percent of total spending. As with investment, Defense and Energy played the largest roles; other sources included the National Science Foundation, the National Institute of Standards and Technology, and the National Aeronautics and Space Administration.

Defense spending cuts have had relatively little impact on firm R&D activities. When rating, on a scale of 0 to 10, the impact of defense cuts on R&D activities, 48 firms responded, with the most frequent response was 0, that cuts have no impact, and the average response was 2.85.

The majority of research funding was allocated to one of two areas. Respondents indicated that 43 percent of funds went to the support of existing business, and 35 percent was used for new business projects support. Projects in development included enhanced versions of current products as well as new products. Work with powders was most frequently mentioned, highlighting the overall importance of quality powders to ceramics. Products under development or improvement included armor, bearings, engine components, ceramic packages, and multi-chip modules. Firms indicated that processing and preparation of powders were the areas of the production process where they considered the application of new technologies to be the most important.

Firms highlighted several problems that they had encountered in marketing ceramics as substitutes for other materials. Cost was frequently mentioned; also important is the lack of customer awareness. There is a lack of quantitative performance data, making potential endusers of advanced ceramics hesitant. Moreover, changing to ceramics requires new machining systems and special design criteria.

Corporate-level sales rose between 1987 and 1991, while net income decreased. On a per company basis, net sales, peaked in 1990, at $4.4 billion (this includes non-advanced ceramic sales). Per company net income that year was $329.7 million, its second-highest level of the period. The average profit margin in 1990 was 6.1 percent. In 1991, both per company sales and net income fell dramatically, narrowing the average profit margin to just over 3 percent.

Division-level data indicate that divisions dedicated to advanced ceramics were in much worse financial condition than their corporate counterparts. Using per respondent data, net sales in 1991 were 34 percent lower than in 1987. Average profit margins in 1987 were 2.8 percent; they peaked at about 5 percent in 1988, then fell, eventually becoming negative in 1990 and 1991. The financial information portrays an industry that has suffered, particularly in the later years of the reporting period, showing declining income, negative profit margins, and relatively high debt ratios. This will make it difficult for the industry to afford the research and development necessary for competitiveness in world markets; it will make it difficult for the industry to maintain defense production capabilities.

Competitiveness Issues

U.S. firms generally ranked themselves as behind Pacific Rim competitors and ahead of European competitors on a variety of measures. Competitive factors rated include quality, application of R&D, price, delivery, customer satisfaction, capital costs, labor supply, and government support.

Numerous countries around the world were mentioned as emerging competitors in advanced ceramics. The most frequently mentioned region was the former Soviet Union, which possesses good powder technology and production capabilities for pumps and electronics sensors. Other areas that respondents mentioned include Eastern Europe, the People's Republic of China, South Korea, Taiwan, Australia, India, Brazil, Africa, Israel and Mexico.

Companies mentioned a wide range of issues which impact the U.S. advanced ceramics industry in the world market. *Company- and market-specific* factors included problems with capital availability, declining defense spending, increased competition, lack of customer knowledge, and lack of cooperation among firms in the industry. *Business environment* factors mentioned included a lack of tax incentives for R&D, the need for an inducement to make long-term investment decisions, the cost and quality of labor, a lack of cooperation among government, ceramics manufacturers and endusers. *Legal, regulatory and other governmental* factors mentioned included patents, a general lack of government support for R&D, export controls, OSHA standards and other environmental regulations, and a lack of a consistent trade policy. *External* factors affecting the industry included foreign trade practices, trade tariffs, competing against low labor costs of some producing regions, and the existence of more positive government-industry relationships in Asian and European countries.

The majority of firms expect their competitive prospects to improve either somewhat or greatly in the next five years. These firms mentioned increased emphasis on cost of production and product quality, broader product lines, lower costs of production, new markets, and increased investment in equipment and facilities. Those firms with more negative outlooks cited the presence of stronger and more numerous foreign competitors, declines in the defense and aerospace markets, the lack of funding for R&D, and the negative impact of government regulations.

Companies were almost evenly split over the impact of mergers and acquisitions. The industry has experienced a proliferation of such agreements over the last few years, making giants of some previously-small firms. Several noted that the increase in the number of larger firms, some foreign-owned, made it more difficult for remaining smaller firms to compete. Those involved in mergers and acquisitions were said to have greater access to R&D funding and capabilities as well as better manufacturing facilities. Further, some foreign firms have gained access to new markets through such arrangements.

Most firms do not perceive antitrust laws to be a barrier to strategic alliances. Forty-seven of fifty firms responding also indicated that they had not had any experiences where U.S. antitrust laws has created a barrier to cooperation with other firms in either R&D partnerships or manufacturing relationships. The vast majority of firms responding would consider forming vertical alliances with supplier, manufacturers, or distributor firms in the advanced ceramic field.

Foreign Government Support

Several firms stated that the governments of Germany, Japan, and other Pacific Rim countries provide tax incentives for investing in new technologies to their indigenous advanced ceramic firms. The German government is said to share R&D costs through grants, provide investment tax credits, and give tax rebates for the construction of new plants. The Japanese government offers similar rebates, and, through MITI, provides funds at low interest rates to advanced ceramics firms. Similarly, the governments of China and Taiwan are said to share R&D costs and subsidize capital costs with very low interest rates.

Surveyed firms stated that some foreign governments allow banks and other financial institutions to own a share of advanced ceramics manufacturers. Based on survey responses, in both Japan and Germany many large advanced ceramic manufacturers are frequently part of vertically-integrate corporations, and banks generally hold some stock. Small independent manufacturers may or may not have banks as shareholders. One potential advantage of such an arrangement is that access to capital is assured. Apart from providing support for R&D, foreign governments are believed to enter into procurement arrangements and other assistance to guarantee purchase of all or part of the product manufactured using new technology. Survey respondents stated that the governments of France, Germany, and Japan engage in such agreements.

An assessment of the foreign advanced ceramics industry suggests that all of the leading foreign advanced ceramics companies benefit directly or indirectly from national technology policies designed to promote their commercial competitiveness. The U.S. and Japan are at parity in terms of technology, but Japan is better able to commercialize the technology. Japanese firms are ahead in using enabling technologies such as flexible manufacturing and robotics, and are also adept at cooperative research.

CRITICAL TECHNOLOGY ASSESSMENT
OF THE U.S. ADVANCED CERAMICS INDUSTRY

I. INTRODUCTION

A. BACKGROUND

This critical technology assessment of the domestic advanced ceramics industry was initiated under Section 825 of the Defense Authorization Act for Fiscal Year 1991. This section of the law requires the Secretary of Defense (acting through the Under Secretary for Acquisition) and the Secretary of Commerce (acting through the Under Secretary for Export Administration) to submit annual reports to the Armed Services Committees of the Senate and the House of Representatives on the financial and production status of industries supporting technologies deemed by the Department of Defense (DOD) as critical to the performance of current and next generation weapon systems. The National Defense Authorization Act of Fiscal Year 1993, Section 4215, further expands the scope and requirement for technology and defense industrial base capability assessments.2

The primary objective of these assessments is to provide government policymakers and industry executives with comprehensive information and analysis on the production and technology status, economic performance, and international competitiveness of private sector firms involved in critical technologies, in light of declining defense budgets. While DOD has deemed these technologies essential to the development of the next generation of weapon systems, they are also crucial to the nation's ability to compete in the global economy. Not surprisingly, almost all of the DOD critical technologies are also found on the Department of Commerce's list of Emerging Technologies and the White House Office of Science and Technology Policy's 1991 list of National Critical Technologies.

Six of the DOD critical technologies were selected for review and submission to the Congress during FY 1992-1993. Advanced Ceramics is one of the six chosen; the other assessments cover Advanced Composites, Artificial Intelligence, Flexible Computer Integrated Manufacturing, Optoelectronics and Superconductivity.

The Department of Commerce's Office of Industrial Resource Administration (OIRA), Strategic Analysis Division, is the office within the Bureau of Export Administration (BXA) responsible for conducting these critical technology assessments. For each technology, OIRA created an advisory team that is made up of members from the Department of Commerce's Technology Administration (including the National Institute of Standards and Technology - NIST) and International Trade Administration, and the Department of Defense's Advanced Research Projects Agency (ARPA). Input was also provided by the White House Office of Science and Technology Policy. OIRA also sought out private sector associations and consortia which specialize in the six critical technologies selected for review. Associations and consortia participating provided support in the area of industry survey design and field testing, technical advice, mailing lists, on-site visits, and in establishing company contacts. The assistance of the United States Advanced Ceramics Association (USACA) was particularly instrumental in this assessment.

In accordance with the requirements of the FY 1991 and FY 1993 National Defense Authorization Acts, the following factors were addressed in each of the critical technology assessments:

A. *The financial ability of U.S. industries supporting these critical technologies:*

   1) to conduct research and development relating to critical defense technologies;

   2) to apply those technologies to the production of goods and services;

   3) to maintain a viable production base in critical areas of defense production and technology in the wake of reductions or terminations in defense procurement;

   4) to expand the defense production base in national security emergencies.

   5) to maintain a viable defense production base in each critical area in which terminations of major Department of Defense procurements are planned; and

   6) to engage in any other activities determined by the Secretary to be critical to national security.

B. *Additional analysis is to be undertaken on such factors as:*

1) trends in profitability, investment, research and development and debt burden of businesses involved in research on, development of and application of critical defense technologies;

2) international competitiveness and market trends;

3) consequences of mergers, acquisitions and takeovers of such businesses;

4) effects of dependence on foreign or foreign-owned suppliers;

5) results of Defense spending for critical technologies in the current fiscal year, as well as the likely future levels;

6) efforts of Defense to expand the use of commercial technology and equipment; and

7) the need and efforts of industry in the area of defense conversion.

With industry and interagency assistance, OIRA devised a comprehensive questionnaire to collect information to respond to the assessment factors listed above. The questionnaire was field tested with regard to availability of data, technical accuracy, clarity of instructions, disclosure and reporting format. As part of this effort, OIRA co-sponsored a Critical Technologies Workshop with Commerce's Technology Administration and NIST on February 6, 1992, to gather and incorporate industry input into our draft survey instruments and assessment outlines for each of the six studies. Approximately 500 experts from academia, industry, and government attended the workshop with many providing comments on our six draft survey forms. Approximately 60 representatives were present at the afternoon session devoted to the advanced ceramics study.

OIRA disseminated the six separate questionnaires to U.S. industry and selected U.S. government laboratories and universities under authority of the Defense Production Act of 1950 (DPA), as amended, and related Executive Order 10480. Section 705 of the DPA authorizes the Department of Commerce to collect information when necessary to accomplish analytical activities regarding the domestic defense industrial base.

To enhance Commerce's effort to assess the industry's international competitiveness and the effects of dependence on foreign or foreign-owned suppliers, BXA's Office of Foreign

Availability (OFA) conducted a separate review of the efforts of leading foreign companies, governments, and research institutions in the six technologies. To conduct this review OFA contacted industry specialists in leading domestic and foreign firms, as well as in government agencies and universities. Department of Commerce foreign commercial officers in U.S. embassies and consulates in Europe and Asia also collected and forwarded information to OFA to supplement the data collected from industry. The executive summary of the OFA review is included in the international portion of this report.

B. IMPORTANCE OF INDUSTRY TO NATIONAL SECURITY

Advanced ceramics are inorganic, nonmetallic materials which differ from conventional consumer ceramics in their greatly improved properties, in the sophisticated processes used to produce them, and in their applications. In comparison with metals, advanced ceramics demonstrate wear resistance, high temperature strength, favorable electrical properties, chemical resistance, dimensional stability and strength-to-weight ratios three times higher than metals. For the purpose of this assessment, advanced ceramics are limited to monolithic ceramics only and related powders and coatings; advanced composite materials are not included.

The key to these advanced properties lies in the manufacturing process. Extremely pure, inorganic, nonmetallic powders of highly uniform size and shape are used in the manufacture of these ceramics; they are based on oxides, nitrides and carbides of silicon, aluminum, titanium, and zirconium. The powders are processed at high temperatures, and frequently at high pressures, to achieve these properties.

For the purpose of this study, advanced ceramics can be divided into four categories: those used for electronic, or functional, applications; those used for structural applications; raw materials; and ceramic coatings. The electronics sector is relatively mature; according to one estimate, it accounted for 80 percent of the approximately $3.6 billion U.S. advanced ceramic component[1] market in 1990. Structural ceramics and ceramic coatings each

[1]This figure excludes raw materials.

accounted for 10 percent in 1990. However, structural ceramics is a fast-growing sector; by 2000, the source projected, it will account for 20 percent of the then-$9.2 billion U.S. market; electronic applications will fall to a 70 percent share, and coatings will remain at about 10 percent.[2]

Defense applications of and activities in advanced ceramics are wide-ranging. One of the primary functional applications of advanced ceramics is in semiconductor packages, which have innumerable uses in defense electronics. Direct and indirect military consumption account for approximately 20 percent of U.S. apparent consumption of ceramic packages.[3] Other defense applications include vehicle and personnel armor, aircraft parts, submarine shaft seals, and gas turbine engine parts. Industry experts predict that defense applications for advanced ceramics will increase over time.

Both DOD and the Department of Energy (DOE) have sponsored programs exploring the application of advanced ceramics in gas turbine engines. DOE programs have included the Advanced Turbine Technologies Applications Program (ATTAP) and the Ceramic Technology for Advanced Heat Engine program (CTAHE). DOD has sponsored the Integrated High Performance Turbine Engine Technology initiative (IHPTET) and the DOD/NASA National Aerospace Plane (NASP). It has been estimated that ceramics will account for approximately 30 percent of the weight of turbine engines in high performance military aircraft by the year 2000.

Advanced ceramics see wide application in many other areas as well. These include catalytic converters, seals and valves for pumps, bearings, cutting tools, capacitors, sensors and power tubes. In some areas, advanced ceramics are established as materials of choice; in others, ceramics compete with other materials for acceptance.

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[2]Abraham, Thomas. "The US Advanced Ceramics Industry: The Growth Continues." JOM. The Minerals, Metals, and Materials Society. January 1992. p. 6.

[3] US Department of Commerce, Office of Industrial Resource Administration. The Effect of Imports of Ceramic Semiconductor Packages on the National Security. Washington, DC: DOC. August 1993. p. IV-12.

C. Survey Methodology and Scope

Survey questionnaires were distributed to a variety of organizations in the U.S. advanced ceramics industry. OIRA's questionnaire was the primary source of data for the domestic portion of this assessment. A copy of the cover page and table of contents for the survey is attached as Appendix 1.[4] The organizations surveyed included large and small manufacturers of a wide range of advanced ceramics, as well as firms dedicated to research and development and those who perform sales/marketing and distribution functions. In addition, a search of available literature was conducted and related industry visits were made.

The products of the advanced ceramics industry are found in a wide variety of Standard Industrial Classification (SIC) codes, making it difficult to rely on this Census Bureau information for market data. Data for advanced ceramic products are combined with data for the same products manufactured using other materials; it is not possible to accurately determine the portions attributable to ceramics from the SIC codes.

To collect information from such a broad spectrum of company types, an extensive product list was formulated and provided as part of the questionnaire. Participants were asked to classify their work in the advanced ceramics field using this coded product list, and to report all data on a product code basis, as appropriate. This product code list is attached as *Appendix 2*.

This listing is subdivided into the following categories: **functional or electronic** applications, **structural** applications, **coatings** and **raw materials**. These specific categories are defined and discussed below. The endmarkets covered in this assessment end-use applications in **manufacturing, transportation**, **electronics**, **communications**, **space** and **other** applications. "Other" applications include armor, nuclear, medical, research, textiles and power generation.

[4]Due to its length, the complete survey has not been attached but is available upon request by contacting the office at the phone number listed on the title page.

II. INDUSTRY OVERVIEW[5]

The use of ceramics goes back many thousands of years, when prehistoric people discovered that clay could be baked in a variety of shapes until hardened. The technology for making traditional ceramics has remained the same throughout history: clay and similar materials are treated by firing. Technically, ceramics are processed inorganic, nonmetallic materials. These would include glass, porcelain, pottery, refractories and construction bricks.

Advanced ceramics differ from these older ceramics in that they are made from highly pure raw materials produced by chemical processes, rather than by naturally-occurring materials. Advanced ceramics are meant to function in much more challenging environments, typically in either structural applications (engine parts or cutting tools) or functional applications (packages/substrates). They are capable of much higher levels of mechanical, thermal, and electrical performance than are traditional ceramics, and they exhibit excellent resistance to corrosion and oxidation.

The production process begins with synthetically-produced powders, the basic raw materials of ceramics. These powders must have a low impurity content as well as the proper distribution of particle sizes in order to optimize the eventual performance of the material. Achieving these properties is an expensive undertaking and is the focus of much research in both the industry and the government. The powders are processed at high temperatures, and

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[5] Most of the information for this section came from the following sources:

ASM International®, Engineered Materials Handbook, Volume 4: Ceramics and Glasses. December 1991.

McDonough, William, and Robert Brown, Bureau of Mines. Annual Report: Advanced Materials. Washington, D.C.: U.S. Department of the Interior. 1991.

Nagai, Akira, and Yoshitaka Kimura. "Synthetic Raw Materials for Ceramics." Advanced Technical Ceramics. Tokyo, Japan: Tokyo Institute of Technology. 1984.

The National Critical Technologies Panel, "Report of the National Critical Technologies Panel." March 1991. p. 19.

sometimes also at high pressures, to form dense, hard structures. Hot isostatic processing (HIP) is one commonly-used process. In HIP, ceramic powder is placed in a mold which approximates the desired shape of the final product, then heat and pressure are applied. Because the shape is not distorted much during processing, very little machining is required to bring it to its final form. Machining is typically done by diamond grinding.

A. PRODUCT CATEGORIES

Organizations in the industry manufacture products falling into one or more of four broad product categories: structural; functional; coatings; and raw materials. Larger companies, not surprisingly, are more likely to diversify between functional and structural applications, or to be vertically-integrated, producing raw materials as well as end products. Smaller firms typically offer a smaller range of products. The product categories mentioned above are shown in greater detail in Table 1. A longer form of this table served as the product code list for our questionnaire (see *Appendix 2*). Following Table 1 is a discussion of each category, starting with raw materials, the beginning components in the manufacturing process.

Table 1.
List of Product Codes

A.	**MATERIALS**		
A.1.	ALUMINUM OXIDE	A.10.	ORGANIC PRECURSORS (specify)
A.2.	ALUMINUM NITRIDE	A.11.	SILICATES
A.3.	ALUMINUM TITANATE	A.12.	SILICON CARBIDE
A.4.	BORON CARBIDE	A.13.	SILICON NITRIDE
A.5.	CERMET	A.14.	TITANATES (BARIUM)
A.6.	DIAMOND	A.15.	TUNGSTEN CARBIDE
A.7.	DOPANTS, OTHER SINTERING AIDS	A.16.	ZIRCONIA
A.8.	FERRITES	A.17.	OTHER (specify)
A.9.	NIOBATES		
B.	**COATINGS**		
B.1.	ALUMINUM OXIDE	B.4.	ZIRCONIA
B.2.	SILICON NITRIDE	B.5.	OTHER (specify)
B.3.	TUNGSTEN CARBIDE		
C.	**STRUCTURAL APPLICATIONS**	**D.**	**FUNCTIONAL APPLICATIONS**
C.1.	ENGINES: INTERNAL COMBUSTION/DIESEL	D.1.	PACKAGES/SUBSTRATES
		D.2.	CAPACITORS
C.2.	ENGINES: AUTOMOTIVE, AIRCRAFT AND STATIONARY TURBINES	D.3.	MAGNETS
		D.4.	FUEL CELLS
		D.5.	MICROWAVE
C.3.	PUMPS	D.6.	VARISTORS
C.4.	CUTTING TOOLS	D.7.	TRANSDUCERS
C.5.	HEAT EXCHANGERS	D.8.	ACTUATORS
C.6.	ARMOR	D.9.	SENSORS
C.7.	WEAR COMPONENTS	D.10.	INSULATORS
C.8.	CORROSION RESISTANT COMP.	D.11.	WINDOWS
C.9.	"SEVERE ENVIRONMENT" COMP.	D.12.	NUCLEAR
C.10.	OTHER	D.13.	HEATING COMPONENTS
		D.14.	POWER TUBES
		D.15.	VACUUM INTERRUPTERS
		D.16.	ADVANCED GLASSES
		D.17.	OTHER

SOURCE: OIRA Questionnaire

1. Materials

Powders derived from a variety of metallic oxides, carbides and nitrides are usually the basis for advanced ceramics. These synthetic materials are used rather than natural ceramic raw materials, like clay, in order to minimize defects. Selecting pure powders is a critical first

step in the production process. The composition of the materials, their impurities, and the characteristics of their particles all contribute to material quality and affect reliability. The properties required for the endproduct dictate the characteristics sought in the powders, which are controlled during processing.

The materials used for advanced ceramics can be divided into three groups: oxides, carbides, and nitrides. **Oxides** include alumina, which is used in spark plugs, substrates, and wear applications, such as cutting tools, nozzles, and bearings. Zirconia is another oxide; it is found in oxygen sensors in automotive exhaust systems, which help optimize fuel consumption. It is also used for wear applications, such as tooling dies, and thermal barrier coatings. Titanates are oxides which commonly are combined with barium for use in capacitors. Barium titanate is used in capacitors because of its unusually high dielectric constant. Finally, ferrites are oxides which are used in permanent magnets, magnetic recording heads, memory devices, temperature sensors, and electric motor parts.

Carbides found in advanced ceramics are limited mainly to silicon carbide and boron carbide. Silicon carbide is known for its extreme hardness and resistance to thermal shock, characteristics which make it an excellent choice for engineering wear parts, such as seals, pump parts, bearings, and dies. It also displays electrical conductivity at high temperatures and thus is used for heat exchanger applications. Boron carbide is also very hard and abrasion resistant, and it absorbs neutrons, making it useful for nuclear applications.

Silicon nitride, Sialon, and aluminum nitride are **nitrides** commonly used in advanced ceramics. They are both utilized in wear applications and cutting tools. Silicon nitride resists corrosion and oxidation over a wide temperature range and retains its strength in temperatures as high as 1300°C. Sialons are silicon nitride derivative structures containing aluminum and oxygen; they cannot withstand the same high temperatures as silicon nitride but are frequently used in wear parts such as bearings and nozzles. Because of its high thermal conductivity, aluminum nitride is used for electronic substrates.

It is as important to be competitive in materials as in the endproducts, since the quality of the material helps determine the performance of the endproduct. Apart from having a ready supply of the necessary minerals, processing capabilities are critical. Ceramics are prone to brittleness and failure, but increasing knowledge of the structure of these materials will alleviate these problems during processing and lead to greater acceptance of advanced ceramics.

2. Coatings

Ceramics coatings are used to protect or lubricate a variety of materials including metals, composites, and even other ceramics. Typical coatings include those derived from aluminum oxide, silicon nitride, tungsten carbide, and zirconia. Adding a ceramic coating to a substrate imparts physical and mechanical properties to the substrate that are not normally possessed by the substrate itself. Coatings are especially useful in parts that must withstand heavy wear, either from temperatures (thermal barrier coatings) or mechanical loads. Many times, these parts fail merely because of surface imperfections; ceramic coatings protect the surface.

There are several advantages to using coatings. First, coatings make it possible to maximize the best characteristics of both the coating and the material being coated. For example, by coating a metal with a ceramic, the toughness of the metal and the positive surface properties of the ceramic are both utilized. Second, thin coatings are sufficient, so the size and shape of the original components remain very nearly the same. Third, it is less costly to use relatively expensive materials for coatings than for entire components. Next, it is often less expensive to recoat a part than to replace it.[6] Finally, coatings are more easily accepted than solid ceramic parts, by some users; customers see them as an improvement to an existing part, not a new technology.

One large application for coatings is in high performance aerospace bearings, aircraft engines and other aerospace settings. Coatings have also gained acceptance for extending the life of

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[6] U.S. Congress, Office of Technology Assessment. Advanced Materials By Design. Washington, D.C.: U.S. Government Printing Office. June 1988. p. 41.

industrial cutting tools. Aerospace and cutting tool applications constitute the majority of the market for coatings.

3. Structural Products

Structural applications take advantage of ceramics' hardness, wear and abrasion resistance, corrosion and heat resistance, and lightness. These ceramics demonstrate relatively high mechanical strength at high temperatures. In 1990, structural ceramics made up approximately 14 percent of the world market for advanced ceramics.[7] As development work continues on using ceramics in engine parts and in other applications such as process equipment, structural ceramics will increase dramatically as a share of the total ceramics market.

Substituting ceramic parts for metallic components offers several advantages. The cost of raw materials is lower; there is less dependence on foreign sources of strategic materials than is the case for comparable alloys; and there is a cost savings associated with using lighter weight ceramic components.

Automotive Engines

Ceramics are an attractive choice for engines because ceramic parts are light weight and display strength while operating at extremely high temperatures, yet they require less cooling than do metals. For an automotive engine, these favorable characteristics result in greater fuel efficiency because the fuel is burned more completely. Ceramic parts also offer reduced friction and improved wear resistance. Ceramics used include Sialons, silicon carbide, and silicon nitrite. The key to improved reliability lies in the manufacturing process, and that is the focus of research. Engine parts in development include precombustion chambers, rotors for superchargers, piston heads and cylinder liners.

Ceramics are already in use for some auto parts. Ceramics are found in spark plug insulators and in oxygen sensors which regulate exhaust fumes. They are used in riser

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[7] Munford, Christopher. "Ceramics Use Seen Increasing." American Metal Market. September 25, 1991.

heaters, which warm the intake air, and in knock sensors, which help the engine use fuel more economically. Ceramics have been in use in catalytic converters for many years.

Other Engines

Heat engines transform heat into mechanical energy. For these devices, the higher the cycle temperature and cycle pressure, the higher the thermal efficiency rate. So, the higher the temperature a material can withstand, the better. Metal-based alloys have traditionally been used in heat engines, but their melting points are eventually reached, limiting any desired increase in operating temperatures. These limitations have encouraged research into the use of ceramics, which have much higher melting points. Engine producers are experimenting with ceramics in turbines for stationary and aerospace applications. These materials can be used for rotating and stationary turbine parts.

Cutting Tools

Cubic boron nitride, Sialon ceramics, and reinforced alumina are frequently used in cutting tools. Cutting tool applications take advantage of some of the most useful properties of ceramics—namely, high hardness at a range of temperatures as well as high thermal conductivity, which helps reduce the temperature of the cutting surface. As a result, ceramic cutting tools offer high cutting speeds, accuracy, and the ability to finish many materials which other cutters cannot. Because ceramic cutting tools can operate at higher cutting speeds, they reduce cutting time and increase tool life.

Heat Exchangers

Ceramics' ability to withstand very high temperatures and resist corrosion make them a beneficial choice for heat exchangers. These devices reuse heat that is being wasted in order to reduce fuel consumption. For example, in a furnace application, heat collected from the exhaust is reused to preheat air entering the system, eliminating the need for extra fuel for this purpose. The higher the operating temperature, the greater the benefit.[8] Silicon carbide traditionally has been the ceramic of choice for heat exchangers.

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[8] Advanced Materials By Design. p. 57.

4. Functional Products

Functional or electronic applications are the most mature market for advanced ceramics, as well as the largest. The majority of the functional applications are electrical or electronic, as shown in Table 1. Because of their excellent thermal conductivity, ceramics have enabled the miniaturization of electronics, allowing manufacturers to respond to demands for smaller, more reliable, and more energy efficient devices. Computers are a good example of this miniaturization: their performance has improved greatly while the internal components have become much smaller.

Packages/Substrates

Recent articles and reports have highlighted the importance of semiconductors in both civilian and domestic applications. Ceramics are ideal for packages and substrates because of their high thermal conductivity, low electrical conductivity, and small dielectric constant. Substrates are the supporting material for semiconductor chips. With increasing demands on the circuits, substrates must be excellent electrical insulators and good thermal conductors. Frequently used ceramics include aluminum oxide, aluminum nitride, beryllium oxide, and boron nitride. Ceramics are also used in packages, which consist of the substrate and the coatings applied to the entire circuit to cover and protect semiconductors from moisture, heat, and other unfavorable environmental conditions.

Other Electrical & Electronic Applications

Ceramics are used in many electrical and electronic parts. They are used in capacitors, which store electricity and filter out electric "noise." As mentioned above, barium titanate is used widely in capacitors because of its extremely high dielectric constant—a measure of the amount of charge that a material can hold. Also, ceramics are excellent electrical insulators, which makes them the materials of choice in many industrial applications. Varistors are another application for ceramics. Varistors are similar to resistors, which are devices that oppose the passage of current and cause the electric energy to be converted into heat. A

varistor can be defined as a resistor whose resistance changes according to applied voltage.[9] They are primarily used in circuit overload protection. Ceramics are also used in transducers, which receive energy from one system and retransmit it, usually in another form. They are used in electronic instrumentation and control and communications systems. Sensors are like transducers, in that they detect changes in their surroundings and output an electrical signal. Actuators also make use of ceramics; they can produce large forces by application of voltage.

Fuel Cells

Ceramics are used in the solid electrolyte of fuel cells and oxygen sensors. The surfaces of the solid electrolyte are exposed to gases of unequal oxygen partial pressure. When heated to 700-800°C, because of the different concentrations, the oxygen ions move to the side with the lower pressure, creating an electric current. The process is continuous, so as long as gases are supplied, electrical power is produced.[10]

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[9] Wakino, Kikuo, Murata Manufacturing Co. Ltd. "Electrical and Electronic Properties." Advanced Technical Ceramics. San Diego, CA: Academic Press, Inc. 1989. p. 113.

[10] Wakino. p. 119.

B. Company Participants/Industry Structure

In order to develop an accurate picture of the state of the domestic advanced ceramics industry, OIRA, with input from industry and government experts, created a questionnaire which was distributed to firms in the U.S. industry. Fifty-three firms responded to the OIRA questionnaire; the information gathered from these responses forms the backbone of this assessment. The data and insights provided are extremely valuable and unique, in that no other such comprehensive source of information exists.

The advanced ceramics industry is made up of many different kinds of organizations, ranging from job shops to multinational corporations, including vertically-integrated divisions of large corporations as well as small-to-medium sized businesses operating independently. According to one estimate, there are more than 300 companies involved in the advanced ceramics field in the United States.[11] The OIRA survey sample of the industry reflected this; of the 53 firms responding to the survey, 22 indicated that they were small firms, with fewer than 50 employees. Of the 53 firms, 25 indicated that they are owned by another firm. Nine of these are owned by foreign firms; two parent companies are located in Germany, two in Japan, and one each in Australia, Britain, France, Sweden and Switzerland.

The 53 firms reported 103 domestic manufacturing establishments located in 30 states and an additional 24 facilities located in 15 foreign countries. The distribution of the U.S. locations is shown in Graph 1 below. As can be seen, the largest concentration of plants (by number of facilities) is in New York, followed by California, North Carolina, Ohio, and Pennsylvania.

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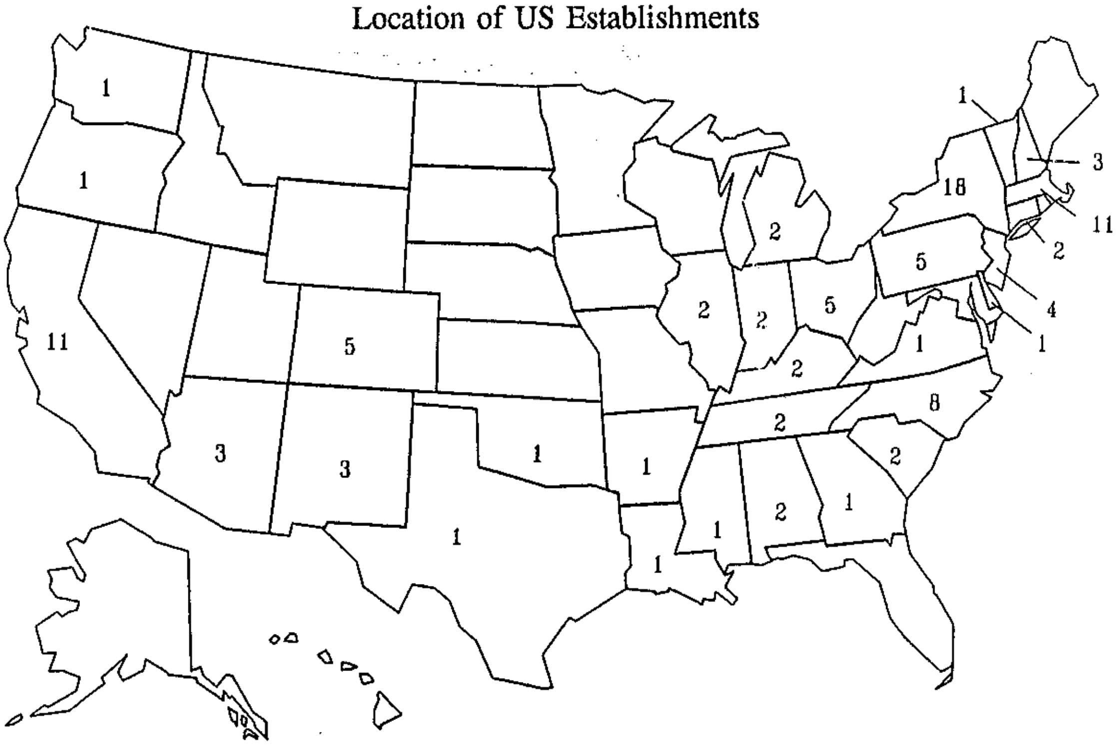
[11]Abraham, Thomas. "The U.S. Advanced Ceramics Industry."

Graph 1
Location of US Establishments



SOURCE: OIRA Survey

OIRA requested information on the age of the domestic facilities, and received data for 96 of the domestic establishments. They were built as early as 1885 and as late as 1993. The average age of the facilities was 20 years, showing that the dates of establishment were skewed toward the later years in the 100-plus year span. Indeed, more than half of the facilities were constructed between 1980 and 1993, and the 1980s saw the most construction, with 39 of the 96 facilities. The industry has demonstrated continuous investment in facilities since the 1920s. The fact that over 40 percent of all reported domestic establishments have been built in the last 13 years reflects the high level of investment and thus commitment on the part of the U.S. industry.

For the location of U.S.-owned foreign plants, the United Kingdom led with five establishments. Mexico followed with four, then Germany with three. Two were located in both Canada and Australia, and Brazil, the Czech Republic, El Salvador, France, Indonesia, Israel, Japan and Singapore were each home to one establishment. U.S. advanced ceramic

manufacturers have only recently invested in foreign operations. The average age of the foreign plants was ten years. The oldest was built in 1915, but the rest were built in 1969 or later. In fact, of the 24 foreign sites identified, half were built in 1990 or later.

The focus of this assessment is advanced ceramics industry operations located in this country; data for foreign establishments are not included. Moreover, the number of foreign plants reported is probably understated, since this information was not required and not all responding firms chose to report their overseas facilities. In spite of these limitations, activities in the foreign advanced ceramics industry are discussed in the foreign industry performance section of the report.

Survey respondents were asked to indicate the nature of their advanced ceramics business, checking all categories that would apply. Many firms identified more than one function for themselves. Forty-seven firms identified themselves as **manufacturers**, 11 as **research facilities**, five as **resellers**, three as **distributors**, and one as a **trading company**. There is some overlap: eight manufacturers also classified themselves as research organizations; one manufacturer is also a research organization, distributor and reseller; and one manufacturer is also a distributor and reseller.

Firms who identified themselves as manufacturers were also asked to indicate their primary function - whether they are material suppliers, integrators or parts fabricators. Twenty-five said they were parts fabricators, seven said they were material suppliers, and three said they were integrators. Again, there was some overlap. Two of the materials suppliers also are parts fabricators, and two firms indicated that they perform all three functions.

1. Capacity Utilization

The survey asked firms about the average practical capacity utilization of their advanced ceramics facilities in 1991. Practical capacity is the greatest level of output that a plant can achieve using a realistic work pattern, assuming a normal product mix, use of machinery and equipment already in place, downtime for maintenance and repairs, and normal use of subcontractors and other outside facilities. The average practical capacity utilization rate for

survey respondents was 61 percent in 1991, with 43 of 53 firms responding. The range of these responses is displayed in Table 8 below. In all, 14, or one-third, of the firms were operating at 50 percent of capacity or less. The average number of weeks required for these firms to reach full capacity from the rate indicated was almost 14 weeks.

The average capacity utilization rate for those producing structural ceramics did not differ significantly from the rate for those producing functional products; both were approximately 60 percent. Interestingly, the firms who produced a mixture of products from two or more of the product groups had a slightly higher rate, averaging 65 percent. These firms may have been more protected from the business cycles in different industries because of the variety of markets served.

Next, firms were asked what factors would allow them to increase capacity utilization and/or decrease the number of weeks required to reach full capacity. The most frequently mentioned item was labor - specifically the availability of a skilled, technology-oriented workforce displaying low turnover. Many also brought up raw material and machinery availability, given known lead times for these items. Factory capacity, particularly in firing, was mentioned. Finally, and perhaps most fundamentally, a demand would have to exist for their increased output before they would be enticed to increase production levels.

Table 2
1991 Capacity Utilization:
Ranges and Frequencies

Range of Capacity Utilization	Number of Firms
0-20%	3
21-40%	5
41-60%	12
61-80%	17
81-100%	6
	43

SOURCE: OIRA Survey

III. U.S. INDUSTRY PERFORMANCE

This section presents data on common industrial measures for the companies included in OIRA's survey. Industry shipments (defense and non-defense), employment, investment, research and development, and financial information are discussed, as reported by the respondents to our survey.

Small businesses - those employing fewer than 50 - were responsible only for supplying 1991 information. Of the 53 firms responding to the survey, 22 firms identified themselves as small. Also, some respondents chose to not provide estimates for 1993 performance. As a result, the raw data are skewed somewhat for 1991 and 1993. In order to give a full picture of industry performance and trends, the results will be presented in three ways.

1. The data will be presented as is, **incorporating all respondents.**
2. This data will be shown as an **average per respondent.**
3. Data will be provided for only those **firms providing data for all 5 years.**

No approach is perfect: the first is skewed, the third eliminates the influence of small firms from the data. The per-respondent approach should make up for the weaknesses of the other two methods.

A. SHIPMENTS

1. Total Shipments

Survey respondents were asked to provide the dollar value of their advanced ceramics product shipments for the years 1989 through 1993. As discussed earlier, the OIRA survey form provided a list of product codes classified in four categories of advanced ceramics products: structural; functional; coatings; and raw materials (see Table 1). Respondents were asked to break down their shipment data for each year by the codes provided. Table 2 below displays shipments data, in dollars, for the surveyed firms. It shows shipments results for all respondents, the total for all respondents as an average per response for each year, and the total shipments for firms providing answers for all five years. Finally, the table represents the percentage of shipments for a given year going to each of four product categories.

Table 3
Advanced Ceramics Shipments
($000)

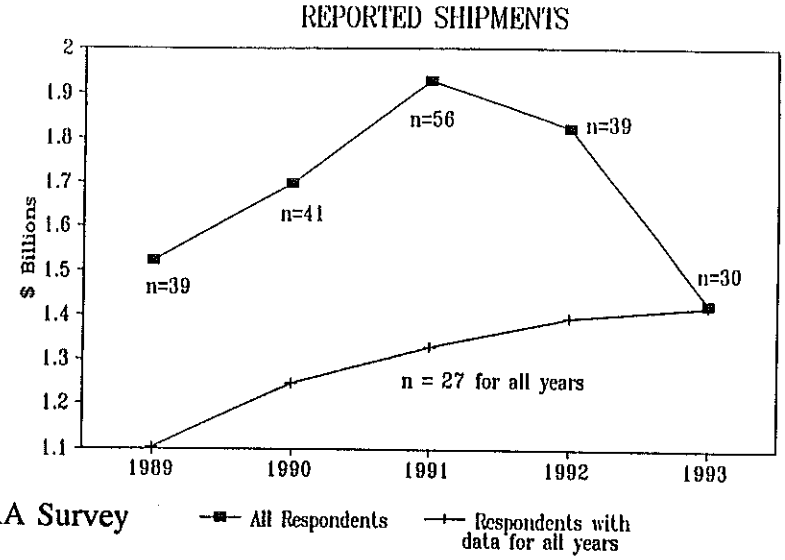
	1989	1990	1991	1992	1993e
Total - All respondents	$1,522,376 (n=39)	$1,697,223 (n=41)	$1,926,665 (n=53)	$1,821,359 (n=39)	$1,425,527 (n=30)
Per Respondent	$39,035	$41,396	$34,405	$46,702	$47,518
Total - Firms with data for all years	$1,103,028 (n=27)	$1,246,504 (n=27)	$1,328,660 (n=27)	$1,393,160 (n=27)	$1,419,337 (n=27)
% Structural	25%	24%	25%	25%	23%
% Functional	63%	65%	61%	66%	67%
% Coatings	0%	0%	<1%	0%	0%
% Raw Materials	12%	11%	14%	9%	10%

e = estimate
SOURCE: OIRA Survey

The percent of shipments going to the four product categories was derived from the data provided by those firms who allocated their shipments by product code. A few firms were unable to provide shipment data by our product codes because their accounting systems were not set up to handle such a request. Those firms indicated a total shipment figure for a year and listed all of the appropriate product codes. Data for these firms were included in the total shipments calculation but were not used in calculating the percentage of shipments going to different product categories.

Bearing in mind the distortions present in the "all respondents" results for 1991 and 1993, the data in Table 3 above and Graph 2 below indicate that, by all measures, shipments grew steadily between 1989 and 1993. Per respondent figures, based on data from all respondents, grew an average of 21.7 percent, while shipments for firms providing data for all years grew 28.7 percent.

The allocation of shipments reported by our respondents agrees with that found in outside estimates,[12] which show structural ceramics as about 30 percent of the total market for advanced ceramics, functional as about two-thirds, and production of raw materials and coatings as a small percent of the total.



SOURCE: OIRA Survey

2. Endmarkets

Beyond providing information on the types of ceramic products shipped firms were also asked to specify the proportion of their shipments going to various endmarkets. The results are shown in Table 4 below. The companies included in these calculations are only those who allocated 100 percent of their shipments.

Table 4
Allocation of Shipments to Endmarkets

Manufacturing	26.2%
Transportation	21.9%
Electronics	21.4%
Communications	9.3%
Space	1.6%
Other (Armor, Nuclear, Medical, Research, Textiles, Power Generation)	19.6%
	100.0%

SOURCE: OIRA Survey

[12] Sorrell, Charles A., Bureau of Mines. "Advanced Materials." Materials Yearbook 1989. Washington, D.C.: U.S. Department of the Interior. 1989. p. 3.

3. Defense Shipments and Exports

Respondents were asked to estimate the portion of their total shipments going to defense applications and exports for each year. For those firms providing such estimates, the percentages for defense and export were multiplied by the firm's total shipments. These figures were summed for the survey pool, then divided by total shipments for all respondents. The average portion of shipments going to defense for those firms who who reported defense shipments was also calculated. Results are displayed in Table 5 below. Not all firms supplied this data, but for each year a significant number of responses were received. For the percent of total shipments going to defense, between 20 and 39 firms responded each year; for percent of shipments exported, between 20 and 42 responded. The true percentage of total industry shipments going to defense probably lies between the two percentages presented each year. Both methods show defense purchases declining after the middle of the period. Defense shipments peaked at that time, a time of high defense spending in the United States and elsewhere. Exports increased significantly between 1989 and 1991, then decreased; this trend mirrors the world economy, which fell into a recession at that time.

Table 5
Advanced Ceramics: Total Shipments, Percent for Defense and Exported
($000s)

	1989	1990	1991	1992	1993e
Total Shipments	$1,522,376	$1,697,223	$1,926,665	$1,821,359	$1,425,527
% for Defense:					
All Respondents	3.7%	4.6%	3.1%	2.5%	1.5%
Defense Suppliers	16.8% (n=20)	20.2% (n=23)	22.1% (n=30)	17.3% (n=20)	20.1% (n=16)
% Exported	9.8%	11.8%	17.5%	12.5%	12.0%

e = estimate
SOURCE: OIRA Survey

4. Military Systems Supported

The survey asked respondents to identify the military systems for which they had supplied advanced ceramics products since 1987. Many firms pointed out that they did not supply products directly to the Defense Department; rather, they were third or fourth tier suppliers,

supporting subcontractors. Some 50 military systems were identified. A sampling of the responses is given in Table 6 below. Two foreign systems, the PAH Tiger and the Super Puma, both helicopters were supported.

Table 6 Military Systems Identified

Missiles	Trident, Patriot, AMRAAM, Penguin, Standard, Hawk, Tomahawk, MX, SCRAM, DMSP, Sadarm, Sparrow, Phoenix, Poseidon, Sidewinder, Harpoon, Stinger
Aircraft	AWACS, C130 Gunship, B1 & B2 Bombers, Advanced Tactical Fighter, F-16, F-18, F-22, & F-100 Fighters, Comanche, Apache, Cobra, Blackhawk, Super Puma, PAH Tiger Helicopters
Space & Satellites	Space Shuttle, Global Positioning Satellite, MILSTAR, LandSat, Mars Observer, Space Station Freedom.
Communications & Radar	Pave Paws Radar, VRC-12, PRC-77, Avenger Radar System, SINCGARS

SOURCE: OIRA Survey

5. Impact of Defense Cutbacks & Defense Conversion

With the worldwide decline in defense spending, many industries are losing major markets for their products. The advanced ceramics industry is no exception. Firms were asked to indicate which of their lines of business will be affected by cuts in defense spending. The responses covered nearly 20 items, including most of the structural and functional categories of our product code list. Raw materials received little mention, while coatings were not mentioned at all, perhaps because these two product categories are even more broadly applicable to commercial applications than are the finished items. The results are shown in Table 7 below.

Of the 42 responses, 31 indicated that defense cuts would have some impact on their business, and the remaining eleven reported that defense cutbacks would have no impact. For those who expected an impact from cutbacks, the predicted effect varied in intensity. Some reported that virtually all product lines would be affected; an abrasives producer that

all of its lines could be affected if less metalworking is performed. Another firm reported that its business is currently more than 50 percent defense-related, but, while cutbacks will have a heavy impact, the firms has so far held its own because weaker domestic competitors have bailed out.

Table 7
Lines of Business Impacted by Defense Cuts

Structural	Functional	Raw Materials
Aerospace Engine Parts	Packages/Substrates	Aluminum Oxide
Rotors	Capacitors	Abrasives
Stators	Microwave Products	Silicon Carbide
Submarine Shaft Seals	Sensors	Zirconia
Cutting Tools	Insulators	
Armor	Radomes	
Bearings	Heating Components	
Crucibles	Cathodes	
Molten Metal Filters		

SOURCE: OIRA Survey

In order to cushion the blow of lowered Department of Defense purchasing, many have suggested that firms should be encouraged and helped to convert to commercial operations, and to apply their defense production expertise to commercial products, with the goal of gaining leadership in world commercial markets. In March 1993, President Clinton announced a Defense Conversion and Reinvestment Initiative, calling for the distribution of $1.4 billion Congress appropriated in 1992 for defense conversion plus an additional $300 million. About $500 million will be available in fiscal year 1993 for the Technology Reinvestment Project (TRP), an interagency initiative which will accelerate the application of military technology to civilian manufacturing, develop extension programs and partnerships and support education for manufacturing employees.[13] (For more information, call 1-800-DUALUSE.)

[13] "NSF Welcomes Role in President's Defense Conversion Initiative." PR Newswire. March 12, 1993.

The survey asked respondents if they were taking any steps now to convert their defense capabilities for domestic uses or if they planned to do so within the next five years. Of 49 firms and divisions responding, 36 indicated that they were not. Only five said they were converting. Of these, three were specific about their plans. One is exploring opportunities in commercial satelites; one is considering other applications for a bearing material it developed; and one is switching its focus from armor to engine and wear parts.

An additional six indicated that conversion was not needed: production facilities are already used for both commercial and defense applications; they had no strictly defense-related products; or they had always tried to develop parallel applications. Two others indicated that conversion was not possible.

6. Awareness of and Suggestions for Government Programs

Respondents to the OIRA questionnaire were queried on their awareness of any federal, state or local government programs aimed at defense conversion and, also, what kind of programs would be helpful. Thirty-three of thirty-seven of those questioned were unaware of any such government programs. Those who were aware mentioned DOE's Cooperative Research And Development Agreements (CRADAs) and ARPA; others mentioned a state bond issue offering matching funds and the establishment of the Defense Conversion Commission.

Additionally, five respondents made suggestions for programs that might help in their conversion. One mentioned funding consumer-education programs to inform clients about the possibilities of new materials and encourage their adoption. Others mentioned funding for research and development; one proposed strong R&D tax credits which, combined with a low capital gains tax, would allow firms to raise venture capital for new projects. Also, some firms not currently producing for defense suggested government-industry consortia, like those found in Europe and Japan, to develop the performance experience of ceramics in real applications. While not falling under the defense conversion category, this suggestion could result in expansion of the commercial market, which would benefit defense firms trying to enter this area.

Finally, some companies felt that the government should have no role in defense conversion. One respondent stated that defense conversion programs are ineffective, and that the only way DOD could have helped was by following a long range plan indicating how long the procurements would last, reducing requirements more gradually. Another more bluntly stated that government should just stay out of the way.

7. DOD's Use of Commercially-Viable Products

Next, respondents were asked if they knew what efforts DOD has made to expand its use of commercially-viable products. Of the twenty firms responding, nine indicated that they were aware of any efforts. ARPA funding was mentioned several times, for its support of the production of specific dual-use products that are critical for defense. Another stated that DOD has implemented a new effort for dual-use technologies, but was not specific. And one said that such efforts have been marginal and inadequate, and that compliance with acquisition regulations has been a major impediment.

We then asked for and received many suggestions about how Defense could do more to accommodate use of and development of commercially-viable products. Ideas for improving ARPA's Ceramic Insertion Program (CIP) were the most popular.[14] One respondent stated that it should be more comprehensive; another said that there should be more insertion programs and procurement programs to follow the insertion programs. Another suggested that the CIP should devote more effort and funding to end-use testing and less into material development; this would hopefully encourage automotive and aircraft engine manufacturers to learn how to apply ceramics.

Additionally, some respondents mentioned the initiation of more CRADAs. Others had more generic suggestions, asking for funding for reduction of long-term costs, and the elimination

[14]The goal of the Ceramic Insertion Program is to encourage systems integrators to consider using advanced ceramics in fielded weapon systems. The integrators are typically reluctant to go back to suppliers and suggest new materials, such as ceramics, once other materials have been "designed in." ARPA provides funding as an incentive to conduct research into the use of new materials, even after a system has been manufactured using other materials.

of excessive testing and data accumulation. Finally, one respondent felt that DOD could use an awareness program to learn about the commercial market.

B. EMPLOYMENT

1. Employment Data

Survey respondents were asked to provide employment data by category of employee for 1989 through 1993. The results are given in Table 8 below.

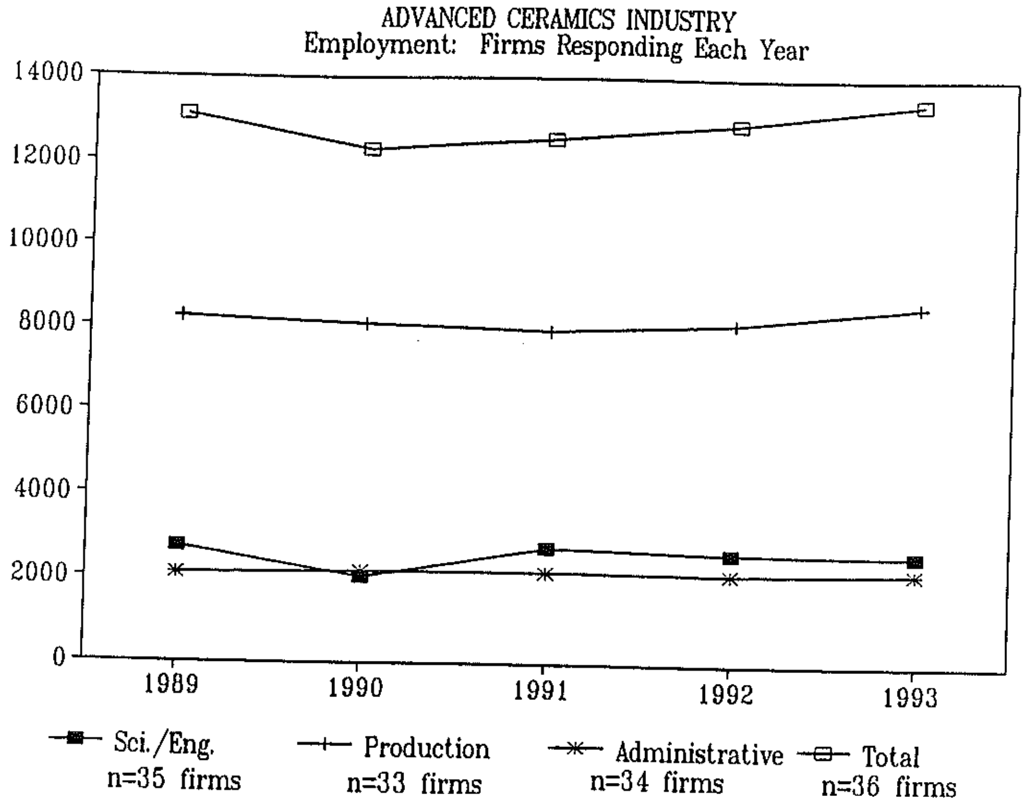
Table 8
Employment Data: Total and Percent for Category of Employee

	1989	1990	1991	1992	1993e
Total Employment	14,779	15,297	17,378	16,468	15,291
Total per Respondent	360	348	259	317	348
Scientists & Engineers	18.4%	14.7%	18.8%	18.3%	19.1%
Production Workers	64.5%	67.4%	63.0%	64.8%	64.3%
Administrative	17.1%	17.9%	18.2%	16.9%	16.6%

e = estimate
SOURCE: OIRA Survey

As with the other survey data, the total employment figure for 1991 is inflated when compared with information for the other years because firms with fewer than 50 employees provided data for that year only. However, while the total is larger, the average displayed for 1991 is pulled downward by the presence of small firms. Still, it appears that employment fell between 1989 and 1992, in contrast with the growth in shipments.

For another view of employment trends, we reviewed the results for those who provided data for each year. The number of such firms for each employee type is designated as "n" in Graph 3 below. Using these data, production employment grew 4.7 percent over the period, hitting a low in 1991. Also, using these data, total employment grew 2.4 percent between 1989 and 1993, hitting a low point in 1990. These results are strongly influenced by larger firms, which may explain the overall growth in these data versus the decline in employment per respondent shown above. Larger firms, theoretically at least, are better-equipped financially to make it through difficult times and may not have to decrease employment immediately in response to a downturn. Additionally, large firms may have other product lines where employees can be utilized when there is a slowdown in one area.



SOURCE: OIRA Survey

2. Training Costs

Total training costs as reported grew steadily over the five years between 1989 and 1993, rising nearly 137 percent for the 33 firms who provided training data for all years. For the 25 firms providing <u>both</u> training costs and total employment data for all years, the training cost per employee is shown in Table 9 below.

Table 9
Training Cost Per Employee

1989	1990	1991	1992	1993e
$162.61	$202.65	$256.51	$372.11	$386.42

Note: This data was taken from only those respondents who provided both the training costs and total employment for each year.

e = estimate
SOURCE: OIRA Survey

For these firms, training cost per employee more than doubled, growing 138 percent between 1989 and 1993. It could be that these firms provided more advanced and expensive training to their employees as the years passed. Or, as some of the comments outlined below suggest, it could be that the employees, particularly new hires, required extensive training on basics.

3. Labor Concerns—Manufacturing Workforce

The survey asked firms if, in the last five years, they had experienced any labor concerns that adversely affected their manufacturing operations. More than half of the respondents indicated that they had no such difficulties. Of those who had experienced problems, the majority mentioned educational and skill-related deficiencies. Many of these indicated that workers lacked strength in basics such as math, reading and writing as well as ceramic manufacturing-specific knowledge. Respondents reported a lack of applicants for specific positions, such as manufacturing engineers, technicians, CNC-trained machinists, and tool and die makers. Other respondents were less specific but reported general local labor shortages. In addition, some firms complained about poor work ethics and attendance efforts. Finally, two mentioned problems with the collective bargaining process.

The survey also asked firms if they foresee experiencing any of the labor problems mentioned in the previous question during the next five years. Here, the split between those who did and those who did not was smaller. Of those who did not foresee any problems, some mentioned that they had an adequate supply of labor to draw upon; one firm in the West mentioned that with defense firms closing in the area, there were many skilled workers available. In contrast, respondents from the Southwest and Northeast said that while they had relied on a pool of workers from closed businesses in the past, this was not an unending supply. These responses reflect the demographic movements of the nation as a whole - away from the Northeast and formerly booming southwestern areas, such as Texas, and toward the West and South.

Other firms blamed social ills and educational problems as a source of labor concerns in the future. The deteriorating condition of public schools, and the weakness in basic education of

their graduates, combined with increased drug use and instability at home, contributed to a shortage of qualified, dependable workers, according to one respondent. Another mentioned that highly-skilled new hires would become increasingly important in order to maintain competitiveness. Among the kinds of workers that firms felt would be harder to come by were hourly machine shop workers and experienced process people.

Vocational education programs in one form or another already exist in many areas. We asked firms to discuss the quality of local or regional vocational training programs, and to indicate whether they relied on them as a source of skilled workers for their advanced ceramics operations. Responses were fairly evenly split between those with positive opinions of the programs and those with negative views. Of those who used the programs and/or found them adequate, some relied on local community colleges and vocational schools for in-house training programs, while others used these programs as a source of mechanics, machinists and electricians. In some cases, local colleges and universities offered technical training and advanced ceramics programs. One respondent pointed out that any vocational training that offered some carryover, such as mechanics and machining, would be useful when combined with a high school diploma.

Of those who found vocational programs in their region to be inadequate and/or did not rely on them, the chief complaint was that there were no programs in the area directed at ceramics. These firms take it for granted that they will have to provide on-the-job training for their new hires. One mentioned that the programs in the area were excellent, but that the placement service of the vocational school required that graduates be hired at a wage higher than the company was willing to pay. Finally, one firm did not rely on vocational school graduates because of a steady supply of unemployed workers in the area due to plant closings.

4. Recruitment of Research and Development Personnel

The survey asked firms to discuss any difficulties that they had encountered in recruiting R&D personnel. Most firms reported no difficulties. For those who did, location played an important role. Some firms found it hard to attract applicants because of the high cost of

housing in the area and high crime rates; another mentioned that its firm's rural location was not attractive to potential hires. One firm that had relocated within the last ten years moved to an area lacking in local expertise in ceramics.

Skill- and education-related problems were also mentioned. Several complained that it was hard to find engineers and technicians with experience in ceramics materials and processes. Others mentioned a shortage of materials scientists with advanced degrees, as well as a lack of engineers who were practical, not abstract, thinkers. Some indicated that, because ceramics is a specialized field, the recruitment process is slow and somewhat difficult.

C. INVESTMENT

Responding firms were asked to report their total investment in plants, machinery and equipment for 1989 through 1993, and to indicate whether the funds came from private or public (meaning government) sources. Table 10 below presents reported privately-funded investment, and Table 11 reports government-funded investment. Total funding generally decreased between 1989 and 1993, with the exception of 1991, when a greater number of companies provided data. *Total investment* fell from $399.5 million to $184 million over the five years.

Reported *private funding* was generally found within the company, with only very small amounts coming from other sources. Apart from 1991, total funding fell consistently over the period, dropping 54 percent between 1989 and 1993.

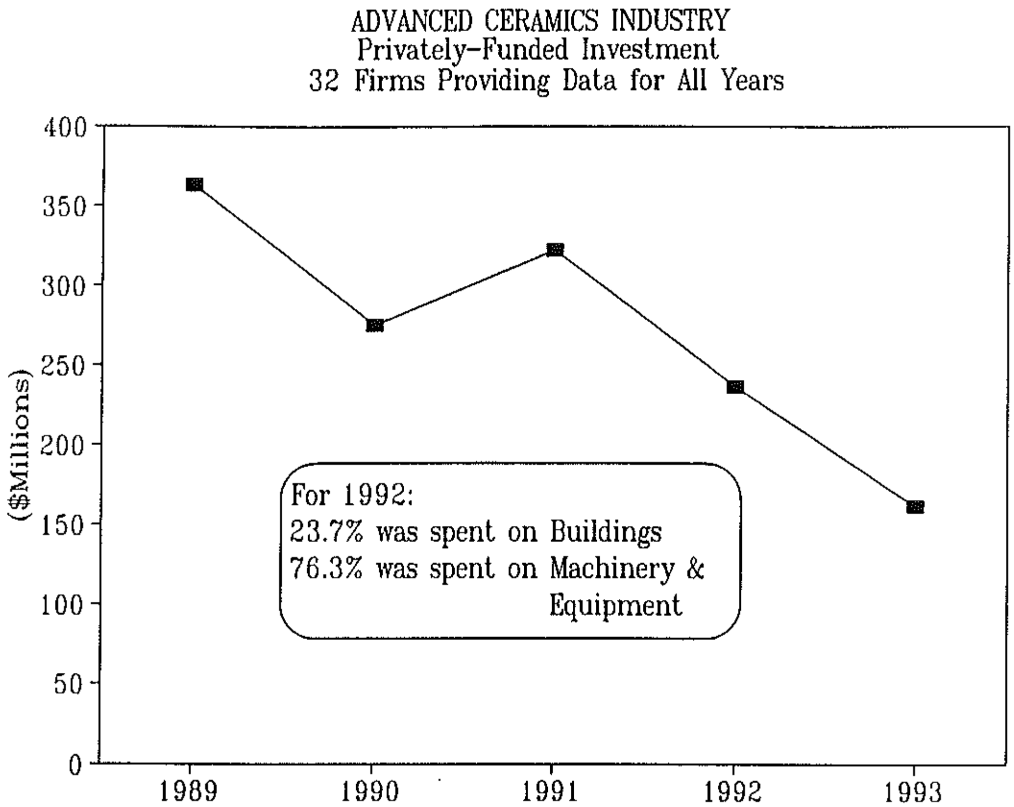
Table 10
Privately-Funded Investment

	Private Investment			Funding Sources			
	Total (000s)	# of Responses	Per Company	In-House	Customer	Joint Venture	Other
1989	$394,098	49	$8,043	98%	<1%	1.6%	<1%
1990	$308,135	52	$5,926	99%	<1%	<1%	<1%
1991	$701,494	68	$10,316	98%	<1%	<1%	1.8%
1992	$268,062	51	$5,256	94%	<1%	<1%	5.6%
1993e	$181,032	37	$4,893	98%	<1%	<1%	1%

e = estimate
SOURCE: OIRA Survey

While 1991's figure looks quite inflated, the per company data reflects the same trend. And, when looking at the data for those 32 companies that reported for all years, given in Graph 4 below, the trend is repeated. It is reasonable to assume that many of the small firms who reported investment for 1991 only were in the process of building up their facilities. This would explain the high "per company" figure. The overall drop in private investment is not surprising; as shall be seen in the financial performance section below, firms both large and

small were experiencing declining and even negative profit margins by 1991, and were unable to use funds for investment.



SOURCE: OIRA Survey

Respondents were asked to indicate whether they were using the funding on buildings or machinery and equipment. For 1992, 23.7 percent was used for buildings, while 76.3 percent went to machinery and equipment.

Reported *government-funded* investment levels were very low, with only a handful of firms providing the data. Government funding never topped 2 percent of the reported total investment. Government-funded investment and sources of funding are shown in Table 11.

Table 11
Government-Funded Investment

		Funding Sources		
	Gov't. (000s)	DOD	DOE	Other
1989	$5,400	91%	2.2%	6.6%
1990	$1,600	0%	75%	25%
1991	$2,475	0%	80%	20%
1992	$2,000	0%	65%	35%
1993e	$3,000	27%	43%	30%

Note: Only one firm mentioned funding from other government sources; the specific source was not listed.
e = estimate
SOURCE: OIRA Survey

No data was provided on the eventual use of the funds. Here, there is substantial variation in sources of funding. The Departments of Defense and Energy traded off most of the funding; however, the sums obtained from other sources were substantial.

D. RESEARCH AND DEVELOPMENT

1. Funding of Research and Development

In order for the U.S. advanced ceramics industry to remain competitive in the domestic and world markets, there must be continuous work in development of new products and processes. Survey respondents were asked to indicate their level of spending on research and development, and also to identify their sources of funding - public or private.

As shown in Table 12 below, total R&D expenditures for the period rose 48 percent from 1989 to 1991, then fell in 1992 and 1993, reaching 1989's level. The percentage of total funding accounted for by public sources grew steadily throughout the period, with the exception of 1990. In 1989, public funds accounted for 5.3 percent of money used for research; in 1993, it accounted for 15 percent. Most of this growth took place between 1991 and 1993. In looking for a cause for this increase, it may be wiser to look instead at the decreasing role of private funding. Companies may have lowered their research expenditures in response to shipments volume, which showed slow growth between 1991 and 1993, profit declines, and to uncertainties about the state of the economy as a whole. Table 13 below provides reported private R&D expenditures.

Table 12
Total Funding of Research and Development

Year	Total Funding (000)	Percent Public	Percent Private
1989	$155,436	5.3%	94.7%
1990	$197,578	4.4%	95.6%
1991	$229,305	6.8%	93.2%
1992	$210,408	9.6%	90.4%
1993e	$156,321	15%	85.0%

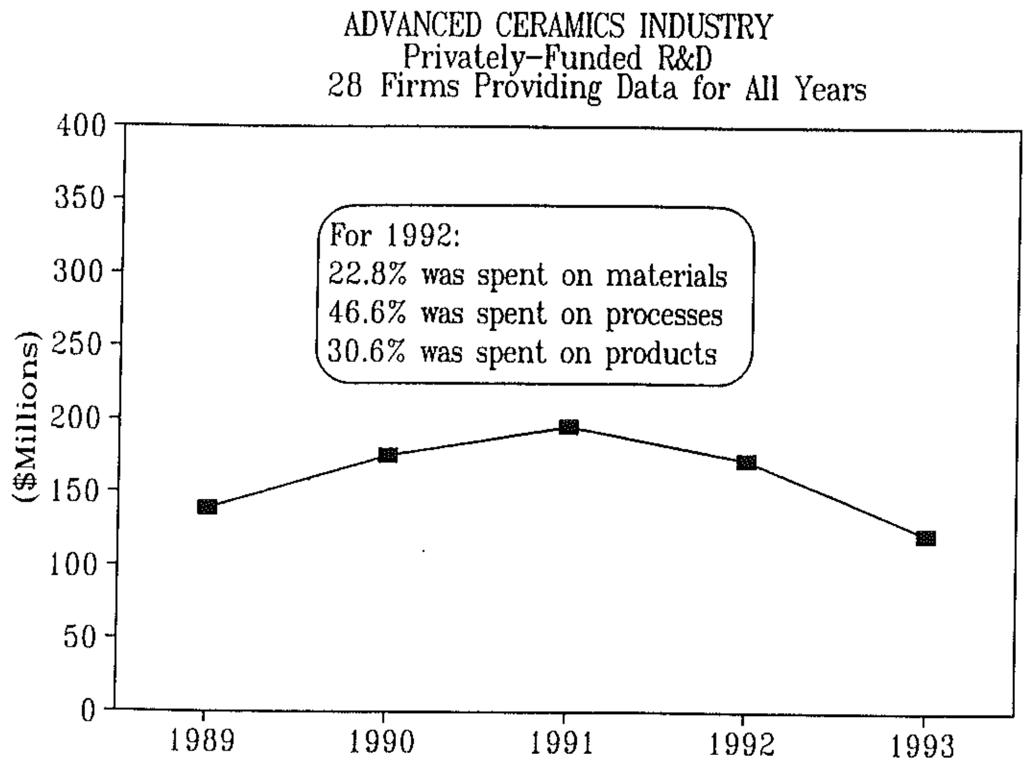
e = estimate
SOURCE: OIRA Survey

Table 13
Private Funding of Research and Development

	Private Funding (000s)		Funding Sources			
	Total	Average Per Co.	In-House	Domestic Customer	Foreign Customer	Domestic Joint Venture
1989	$147,248	$4,331	96%	2.0%	<1%	1.4%
1990	$188,922	$5,557	96%	1.6%	<1%	1.4%
1991	$213,679	$5,479	97%	1.7%	<1%	<1%
1992	$190,309	$5,437	97%	2.0%	<1%	<1%
1993e	$132,898	$4,430	94%	4.6%	<1%	<1%

e = estimate
SOURCE: OIRA Survey

The trend in the total column above shows a peak at 1991, then a drop to pre-1989 levels in 1993. Note that the calculated average per company shows a slightly different trend, with the peak for the period coming in 1990. The data for those 28 firms who responded for all years are shown in Graph 5 below.



SOURCE: OIRA Survey Data

The survey also asked firms how they allocated their research dollars. Using 1992 as an example, research on processes accounted for 46.6 percent of spending; research on products accounted for 30.6 percent; and materials research accounted for 22.8 percent of spending.

Table 14 below provides information on government support of R&D, as reported by our firms. As with investment, DOD and DOE shared primary responsibility for the funding.

Table 14
Government Funding of Research & Development

	Gov't.($000s)		Funding Sources				
	Total ($000)	Per Company	DOD	DOE	NSF	NIST	Other
1989	$8,188	$744	40%	59%	0	0	<1%
1990	8,656	721	25%	70%	0	0	5.2%
1991	15,626	1,041	32%	58%	<1%	0	8.9%
1992	20,099	1,256	38%	49%	<1%	<1%	12.2%
1993e	23,423	1,378	46%	39%	<1%	3.7%	11.6%

Note: Other government agencies listed as sources of R&D funding included NASA, the New York State Research and Development Authority, and Georgia Institute of Technology.
e = estimate
SOURCE: OIRA Survey

2. Research Relationships

Respondent firms also discussed any research relationships they have had with other firms, organizations, and universities. Twenty-three firms or divisions indicated that they had had at least one such relationship, totaling 79 relationships in all. Of these, 35 were with other firms, 33 with universities and U.S. or foreign institutes, and 11 with U.S. government entities. Work with other companies generally centered around the development of a particular product or process. Projects reported included tank armor, bearing components, engine applications, bearings, and electronic packaging. Interactions with universities ranged from consultation to fellowships to the contracting out of research and testing. Joint research topics included particulate coating research, ballistics testing for armor, development of

advanced dielectrics, abrasives testing, and aerosol powder processing. Respondents also mentioned research relationships with government organizations, particularly ARPA, DOE (Oak Ridge National Laboratory and Argonne National Laboratory), the Jet Propulsion Laboratory, and NASA-Lewis.

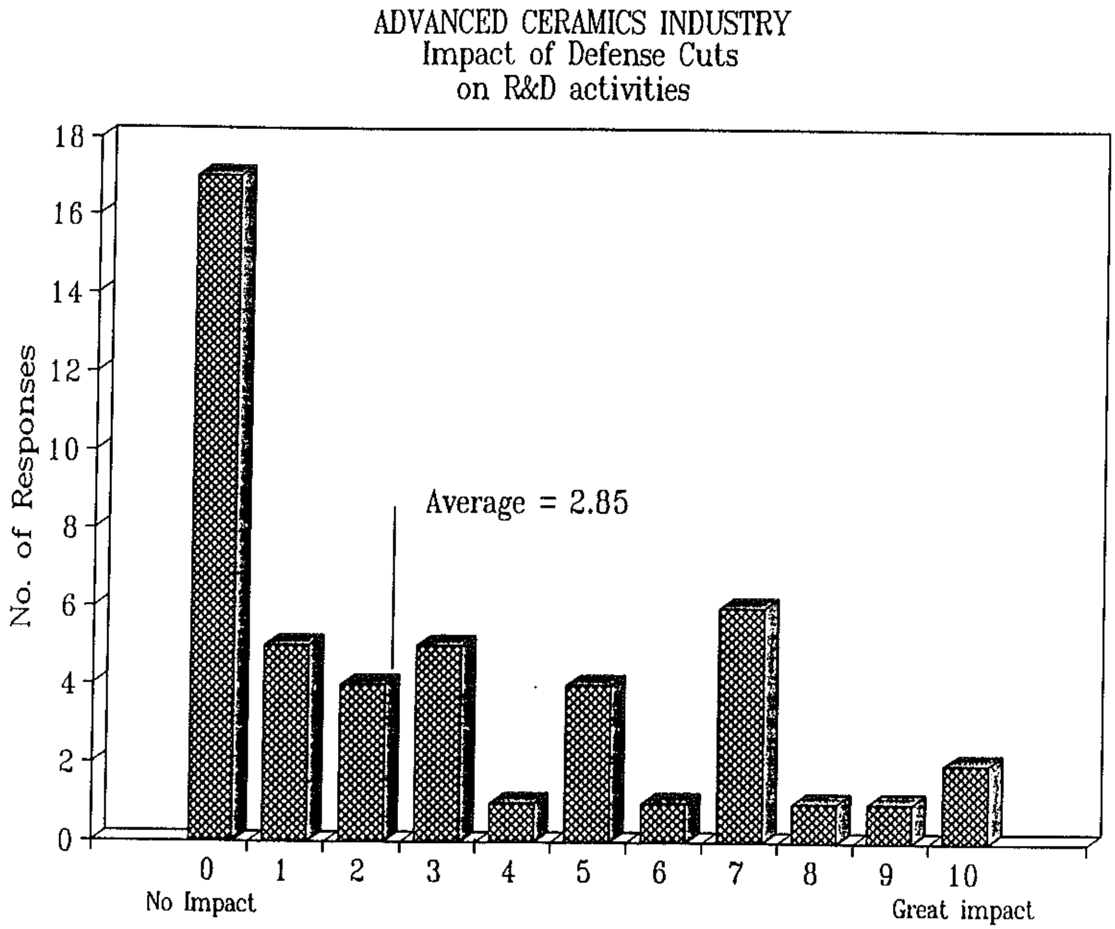
3. Government Programs Supporting Firms' Research & Development

The survey asked respondents which government programs, including Defense programs, supported their R&D efforts. Defense-related programs were most frequently mentioned; they included work with ARPA and the individual services - the Air Force, Navy and Army. The specific projects included the Ceramic Insertion Program, armor development, and ceramic bearings. Also frequently mentioned was the Department of Energy, in particular research on advanced technologies for turbine applications. The Department of Commerce's Advanced Technology Program was also mentioned, as was NASA and the National Science Foundation for studies in materials.

4. Impact of Defense Cuts on R&D Activities

Next, firms were asked to assess the impact of defense cuts on their R&D activities. The distribution of responses is shown in Graph 6 below. Respondents were asked to circle the appropriate point on a scale from 0 to 10, with 0 meaning no impact from defense cuts and 10 indicating that defense cuts would greatly impact research activities. A total of 48 firms responded; the average was 2.85, and the most frequently received response was 0, which seems to indicate that firms do not weigh defense spending heavily when determining R&D activity levels. However, many firms indicated that the loss of funding would indeed impact their R&D spending. In fact, in contrast to those who indicated that defense cuts would not impact their R&D activities, one firm indicated that it relies entirely on funding from DOD for research in one product area. The list of projects and products potentially affected included new applications and markets in avionics and electronics for aluminum nitride components; research on new silicon carbide products such as mirrors and severe environment components; ARPA projects, including armor/anti-armor and electronic packages; and research on radomes and advanced optics. Several firms alluded to an unfortunate cycle which results from reduced Defense support of R&D: with reduced

funding, firms decrease their R&D activities, which generally means laying off R&D personnel; then, when new contracts become available, the R&D capabilities are not available. Sales are lost, resources available for R&D and other areas decrease, and the cycle begins again.



SOURCE: OIRA Survey

5. Allocation of Research Funding

In order to better understand how firms use their R&D resources, firms were asked to allocate their spending to four different areas. The results are shown in Table 15 below. Forty-two respondents allocated 100 percent of their funding to these four categories.

Table 15
Allocation of R&D Funds

Focus of Research:	% of Funding
1. Support of Existing Business	43
2. New Business Projects Support	35
3. Directed Advanced Ceramics R&D	16
4. Directed Basic R&D	6
	100

SOURCE: OIRA Survey

Using the averages obscures the extremes. Three firms allocated no funding to the support of existing businesses; twenty-seven allocated nothing to directed basic R&D; twelve spent no funds on directed advanced ceramics R&D; and six spent nothing on new business project support. Still, firms focused their R&D spending predominantly on existing business, with substantial emphasis also given to new business support.

6. Materials and Products in Development

When asked to specify materials and products in development, respondents mentioned a wide array of items; projects included enhanced versions of current products as well as new products. Work with powders was most frequently mentioned; this highlights the overall importance to ceramics of quality powders. The list of materials covered, literally, everything from A to Z - from alumina-based ceramic powders to zirconia, including ferrites, gallium, lithium, magnesium, silicon carbide, and titania. Some firms are also experimenting with diamond. Goals mentioned for raw materials included lower cost, lower expansion, and lower thermal conductivity.

Firms also indicated several products that are under development or improvement. Structural products included armor, abrasives, bearings and other wear parts, engine components, and parts for pumps. Functional products mentioned included packages, substrates, multi-chip modules, and electrodes.

7. Application of New Technologies to the Production Process

Next, we asked firms in what areas of the production process they considered the application of new technologies to be most important. Once again, those related to the processing and preparation of powders were most frequently mentioned. Raw material technology and powder processing together received the most votes. Also listed were factors related to the manufacturing process as a whole. Process control, dimension control and yields were mentioned; advances in these areas would lead to improved product quality and consistency, as well as lower raw material losses. Automation was suggested by several respondents as an area for improvement through new technologies. And a wide range of the steps in the production process were listed. Areas other than powder preparation that were also mentioned include deposition, forming methods, sintering, firing, machining, and non-destructive evaluation and testing.

8. Substitution of Advanced Ceramics for Other Materials

Advanced ceramics are beginning to replace other materials, such as metals, in many applications. We asked our respondents if they had experienced any difficulties in marketing advanced ceramics as substitutes. Eight respondents indicated that they had experienced no problems. Of those who had encountered difficulties, a major problem was cost. Sellers found themselves having to justify ceramics' higher price, but said that it was difficult to demonstrate cost-effectiveness. This leads to another difficulty encountered by marketers: there is a lack of customer awareness and experience with these materials in relatively new applications. There is not enough non-qualitative performance data, so customers hesitate. They are unwilling to take the risk, and this makes dislodging existing technologies and materials difficult. Also, switching to ceramics would require new tooling and redesign; ceramics' relatively low toughness calls for new, rigid machining systems, and there are special design criteria for brittle materials.

E. Financial Performance

Firms were asked to provide financial information on a corporate basis and, if applicable, on a division-level basis as well. In 1987 and 1988, 21 firms provided corporate income statements; in 1989 and 1990, this number rose to 25, and in 1991, 44 of the 53 respondents provided corporate income statements. The results on key measures are shown below. As with the other data, financial information will be presented three way: as a total, for all companies reporting; on a per company basis; and as a total for those firms who responded each year.

Table 16
Firm-level Income Statement Data
(000s)

	1987	1988	1989	1990	1991
NET SALES					
All Companies	$65,335,789	$72,166,770	$100,414,210	$108,846,273	$106,800,609
Per company	$3,111,228	$3,436,513	$4,016,568	$4,353,851	$2,427,287
Firms (21) with data for all years	$65,335,789	$72,166,770	$88,329,018	$94,993,255	$89,420,972
NET INCOME					
All Companies	$5,487,401	$6,805,578	$6,130,178	$7,581,548	$3,314,448
Per Company	$288,811	$358,188	$266,530	$329,633	$80,840
Firms (19) with data for all years	$5,487,401	$6,805,578	$4,843,036	$6,329,040	$2,854,301
PROFIT MARGINS - Firms providing both net income and net sales within a given year					
Firm Average	8.43%	9.47%	6.13%	6.99%	3.11%

SOURCE: OIRA Survey

Using all three measures, net sales rose consistently through 1990 then fell in 1991; net income followed a different pattern, dropping 25 percent on a per company basis between 1988 and 1989, rising 24 percent in the next year, then falling a dramatic 75 percent between 1990 and 1991. The drop in net income on a per company basis in 1989 may be partially explained by the entry of firms in the market in the middle of the period who reported little

or no sales but also reported negative net income in accordance with the expenses incurred related to start-up activities, such as investment in land and equipment.

In fact, it is difficult to explain trends at the corporate level because the firms reporting include both those whose operations are devoted entirely to advanced ceramics and those firms for whom advanced ceramics is only one part of a diversified, sometimes multinational business. However, corporate performance is relevant here, to the extent that it indicates how well large firms are able to support their various businesses, including their advanced ceramics operations.

Given below are net sales and income for those divisions and one-division companies supplying information. The divisional net income information indicates that the divisions were in much worse financial condition than their corporate counterparts. At the division level, the per respondent sales data show a large increase between 1987 and 1988, then a drop to a level below that of 1987 in 1989. By this measure, firm net sales in 1991 were 34 percent lower than in 1987. However, because of the number of small firms reporting that year, it is to be expected that average sales would be lower. For the 17 firms reporting sales information for all years, sales grew steadily between 1987 and 1990, then fell slightly in 1991. Net income, by all measures, showed a different trend, peaking in 1988, then falling and showing a loss in 1990 and 1991.

Table 17
Division-Level Income Statement Data*
(000s)

	1987	1988	1989	1990	1991
NET SALES					
All Divisions	$1,686,085	$1,982,713	$2,098,439	$2,304,780	$2,287,155
Per division	$76,640	$104,353	$74,944	$76,826	$50,826
Div. (17) with data for all years	$1,655,736	$1,982,697	$2,010,888	$2,106,298	$1,998,918
NET INCOME					
All Divisions	$21,899	$51,967	$8,547	($55,979)	($66,601)
Per Division	$1,095	$3,057	$356	($2,239)	($1,586)
Div. (15) with data for all years	$22,149	$52,470	$7,224	($57,218)	($38,451)
PROFIT MARGINS - Divisions reporting both net sales and net income within a given year					
Division Average	2.77%	4.97%	2.42%	(.5%)	(.13%)

*Sales and net income information for firms with one division are included in these numbers. Negative figures are shown in brackets.
SOURCE: OIRA Survey

There are a number of commonly-used financial ratios available to judge the financial health of individual companies and industries. Table 18 below shows the results for two of these ratios as applied to divisions and corporations responding to our survey. The ratios are:

1. **Current Ratio** = Current Assets ÷ Current Liabilities
2. **Debt Ratio** = (Long term Debt + Short Term Debt) ÷ Total Assets

Averages were calculated by first determining the ratios for each division providing the information, then averaging the responses.

The *current ratio* is an indicator of a company's ability to pay its debts quickly, usually within one year. Usually, a 2:1 ratio indicates that the company can easily pay its expenses. From the averages shown below, it would appear that at both the corporate level and the

Table 18
Common Financial Ratios

	Current Ratio		Debt Ratio	
	Avg.	Range	Avg.	Range
Firm level	2.42	0.65 → 10.93	39%	0% → 231%
Division level	2.57	-3.87 → 10.93	40%	0% → 301%

SOURCE: OIRA Survey

division level, there is perhaps even an excess of cash and other easily convertible assets available. Our respondents performed better than the durable manufacturing sector, which displayed a current ratio in the third quarter of 1992 of 1.51. The *debt ratio* is a measure of the portion of assets financed through debt. Generally, lower is better. Here, both the corporate and division levels have a higher debt ratio than the durable sector as a whole, which had an average debt ratio of 25.8.

Overall, the income statement data and financial ratios given above portray an industry which has suffered, particularly in the later years of the period. With declining net incomes, negative profit margins, and relatively high debt ratios, it is difficult to imagine how this industry can afford to finance the research necessary for the development of future products. If it is unable to develop new products, the domestic industry will not be competitive in world markets. Further, it will not be able to afford to maintain its small but significant defense production capabilities; this will vary on a company by company basis.

As will be seen in the following section, survey respondents do not rate themselves or the domestic industry favorably relative to foreign competitors. Without the financial strength needed to support continued innovation in materials, processes, and products, the domestic industry likely will fall behind its foreign competitors.

IV. COMPETITIVENESS

This chapter summarizes responses to questions from the survey which asked respondents to give their perspective on their firm and the industry as a whole.

A. COMPETITIVE STANDING

Survey recipients were requested to evaluate the general competitive standing of their firm or establishment and that of the U.S. industry as a whole as compared to Pacific Rim producers and European producers. The firms/establishments were asked to rank their responses from 1 to 5, where 1 means they are far ahead of their competition, 2 means they are slightly ahead, 3 is even, 4 slightly behind, and 5 means far behind.

Data was aggregated for four subsets of the larger product code list: 1) wear components; 2) packages/substrates; 3) structural applications (not including wear components); and 4) functional applications (not including packages/substrates). For each of these subsets, competitive factors are grouped into three broad categories: technology; performance; and overall business environment. In each subset of the product code list, scores on the competitive factors were averaged and aggregated. The results are shown in the following series of tables.

1. Wear Components

From Table 19, it is evident that U.S. firms perceive that they have a slight technological lead (including materials, processes, application of R&D, overall technology) in comparison to their competitors in Europe, while domestic firms are relatively even with their Pacific Rim counterparts. When the general competitive standing of the U.S. industry is examined, once again, the domestic industry was rated even with Asian firms and slightly ahead (although not as great as for the individual firm ranking) of European companies.

Concerning service and product performance competitive factors (i.e., price, product quality, delivery and customer satisfaction) again, U.S. firms believe that they possess a slight lead over their European competitors, while maintaining a slimmer edge over their Asian rivals. When the U.S. industry as a whole is compared, the domestic industry is found to be on an even standing with Pacific Rim establishments and slightly ahead of European firms.

The last category of competitive factors - overall business environment (i.e., capital costs, access to risk capital, labor supply and government support) - illuminated the areas in which survey respondents viewed themselves and the U.S. industry at a disadvantage. Domestic firms rated themselves as being slightly behind their European competitors (the exception being labor supply, which was rated to be even). With regard to the Pacific Rim, U.S. firms viewed themselves as being on par in the areas of capital costs and labor supply, and slightly behind in access to risk capital and government support.

Table 19
General Competitive Standing - *Wear Components*

Competitive Factor		Pacific Rim	Europe
Materials	My firm is ...	2.6	2.4
	U.S. industry is ...	3.0	2.6
Processes	My firm is ...	3.2	2.6
	U.S. industry is ...	3.2	2.8
Product Quality	My firm is ...	2.6	2.3
	U.S. industry is ...	3.0	2.6
Application of R & D	My firm is ...	3.0	2.9
	U.S. industry is ...	3.7	3.0
Overall Technology	My firm is ...	3.0	2.5
	U.S. industry is ...	3.8	3.1
Price	My firm is ...	3.1	2.6
	U.S. industry is ...	3.5	2.8
Delivery	My firm is ...	2.2	2.1
	U.S. industry is ...	3.1	2.5
Customer Satisfaction	My firm is ...	2.7	2.1
	U.S. industry is ...	3.2	2.5
Capital Costs	My firm is ...	3.9	4.2
	U.S. industry is ...	3.3	3.9
Access To Risk Capital	My firm is ...	4.1	4.4
	U.S. industry is ...	3.2	3.9
Labor Supply	My firm is ...	3.3	3.3
	U.S. industry is ...	2.7	3.1
Government Support	My firm is ...	4.3	4.4
	U.S. industry is ...	3.8	4.0
1=Far Ahead 2=Slightly Ahead 3=Even 4=Slightly Behind 5=Far Behind			

SOURCE: OIRA Survey

2. Packages/Substrates

In terms of technological factors such as materials and processes, individual firms believe they have a substantial lead over their European competitors, and believe they are relatively on par with their European counterparts in the areas of R&D application and overall technology see Table 20). The competitive standing of the U.S. industry as a whole closely mirrors these standings, as U.S. industry possesses a significant edge over European firms in materials and processes, and is at or near parity for R&D application and technology.

When rating themselves against Pacific Rim competitors, the situation for both individual firms and U.S. firms as a whole is not as optimistic regarding technological factors. Overall, individual firms ranked their Pacific Rim competitors at or near parity for the technology-oriented competitive factors. The same is true for U.S. industry as a whole, except for application of R&D, in which case U.S. industry was rated as being slightly behind competitors in Pacific Rim nations.

In the category of performance competitive factors, individual U.S. firms ranked themselves and the U.S. industry as a whole as being on par with their European competition, with the exception of product quality and delivery, areas in which firms perceived having an extremely slim edge. The ratings for the Pacific Rim competitors were virtually identical to those of the European competition.

In the remaining category of competitive factors - overall business environment - firms for the most part rated themselves as being on par with their European and Pacific Rim competitors. The two exceptions were in access to risk capital and in government support. U.S. firms, both individually and collectively, viewed themselves as being slightly behind their European competitors in access to risk capital. In the area of government support, once again both individually and collectively, firms rated themselves slightly behind both their European and their Pacific Rim counterparts in this category.

Table 20
General Competitive Standing - *Packages/Substrates*

Competitive Factor		Pacific Rim	Europe
Materials	My firm is ...	2.6	1.6
	U.S. industry is ...	3.3	2.1
Processes	My firm is ...	3.1	2.3
	U.S. industry is ...	3.9	2.7
Product Quality	My firm is ...	2.8	2.6
	U.S. industry is ...	3.6	2.9
Application of R & D	My firm is ...	3.4	3.1
	U.S. industry is ...	4.2	3.8
Overall Technology	My firm is ...	3.4	3.0
	U.S. industry is ...	3.6	3.0
Price	My firm is ...	3.8	3.2
	U.S. industry is ...	3.9	3.4
Delivery	My firm is ...	3.0	2.8
	U.S. industry is ...	3.7	3.2
Customer Satisfaction	My firm is ...	2.9	3.0
	U.S. industry is ...	3.3	2.8
Capital Costs	My firm is ...	3.7	3.8
	U.S. industry is ...	3.3	3.5
Access To Risk Capital	My firm is ...	3.7	4.1
	U.S. industry is ...	3.6	4.2
Labor Supply	My firm is ...	3.6	3.6
	U.S. industry is ...	3.7	3.7
Government Support	My firm is ...	4.3	4.0
	U.S. industry is ...	4.5	4.8
1=Far Ahead 2=Slightly Ahead 3=Even 4=Slightly Behind 5=Far Behind			

SOURCE: OIRA Survey

3. Structural Applications

From Table 21, it is evident that U.S. firms perceive that they have a slight technological lead (including materials, processes, application of R&D, overall technology) over their competitors in Europe, while domestic firms are relatively even with their Pacific Rim counterparts. When the general competitive standing of the U.S. industry is examined, once again, the domestic industry was rated even with Asian firms and slightly ahead (although not as great as for the individual firm ranking) of European companies.

Concerning service and product performance competitive factors (i.e., price, product quality, delivery and customer satisfaction) again, U.S. firms believe that they possess a slight lead over their European competitors, while maintaining a slimmer edge over their Asian rivals. When the U.S. industry as a whole is compared, the domestic industry is found to be even with Pacific Rim establishments and slightly ahead of European firms.

In the last category of competitive factors - overall business environment (i.e., capital costs, access to risk capital, labor supply and government support) - survey respondents viewed themselves and the U.S. industry at a disadvantage. Domestic firms rated themselves as being slightly behind their European competitors (the exception being labor supply, which was rated to be even). With regard to the Pacific Rim, U.S. firms viewed themselves as being on par in the areas of capital costs and labor supply, and slightly behind in access to risk capital and government support.

Table 21
General Competitive Standing - *Structural Applications Except Wear Components*

Competitive Factor		Pacific Rim	Europe
Materials	My firm is ...	2.3	2.0
	U.S. industry is ...	3.2	2.6
Processes	My firm is ...	2.7	2.4
	U.S. industry is ...	3.2	2.7
Product Quality	My firm is ...	2.4	2.3
	U.S. industry is ...	3.1	2.6
Application of R & D	My firm is ...	2.7	2.3
	U.S. industry is ...	3.4	2.6
Overall Technology	My firm is ...	2.7	2.4
	U.S. industry is ...	3.3	2.8
Price	My firm is ...	2.9	2.8
	U.S. industry is ...	3.3	3.1
Delivery	My firm is ...	2.3	2.3
	U.S. industry is ...	3.1	3.0
Customer Satisfaction	My firm is ...	2.0	2.0
	U.S. industry is ...	2.8	2.4
Capital Costs	My firm is ...	3.4	3.1
	U.S. industry is ...	3.5	3.0
Access To Risk Capital	My firm is ...	3.6	3.3
	U.S. industry is ...	3.8	3.2
Labor Supply	My firm is ...	3.2	3.3
	U.S. industry is ...	3.5	3.4
Government Support	My firm is ...	4.3	3.6
	U.S. industry is ...	4.0	3.2
1=Far Ahead 2=Slightly Ahead 3=Even 4=Slightly Behind 5=Far Behind			

SOURCE: OIRA Survey

4. Functional Applications

For functional applications, U.S. firms perceive that they have a slight technological lead (including materials, processes, application of R&D, overall technology) in comparison to their competitors in Europe, while domestic firms are relatively even with their Pacific Rim counterparts (see Table 22). When the general competitive standing of the U.S. industry is examined, once again, the domestic industry was rated even with Asian firms and slightly ahead (although not as great as for the individual firm ranking) of European companies.

Concerning service and product performance competitive factors (i.e., price, product quality, delivery and customer satisfaction) again, U.S. firms believe that they possess a slight lead over their European competitors, while maintaining a slimmer edge over their Asian rivals. When the U.S. industry as a whole is compared, the domestic industry is found to be on an even standing with Pacific Rim establishments and slightly ahead of European firms.

In the last category, overall business environment (i.e., capital costs, access to risk capital, labor supply and government support), respondents viewed themselves and the U.S. industry at a disadvantage. Domestic firms rated themselves as being slightly behind their European competitors (the exception being labor supply, which was rated to be even). With regard to the Pacific Rim, U.S. firms viewed themselves as being on par in the areas of capital costs and labor supply, and slightly behind in access to risk capital and government support.

Table 22
General Competitive Standing - *Functional Applications Except Packages/Substrates*

Competitive Factor		Pacific Rim	Europe
Materials	My firm is ...	2.9	2.7
	U.S. industry is ...	3.4	2.8
Processes	My firm is ...	3.1	2.9
	U.S. industry is ...	3.0	2.8
Product Quality	My firm is ...	2.4	2.3
	U.S. industry is ...	2.7	2.4
Application of R & D	My firm is ...	3.0	2.5
	U.S. industry is ...	3.3	2.6
Overall Technology	My firm is ...	2.9	2.6
	U.S. industry is ...	2.9	2.4
Price	My firm is ...	3.1	3.0
	U.S. industry is ...	3.1	3.1
Delivery	My firm is ...	2.3	2.0
	U.S. industry is ...	2.7	2.6
Customer Satisfaction	My firm is ...	2.1	2.1
	U.S. industry is ...	2.8	2.6
Capital Costs	My firm is ...	3.1	2.6
	U.S. industry is ...	3.6	2.8
Access To Risk Capital	My firm is ...	3.4	3.1
	U.S. industry is ...	3.6	3.0
Labor Supply	My firm is ...	3.1	3.0
	U.S. industry is ...	2.9	2.7
Government Support	My firm is ...	3.8	3.6
	U.S. industry is ...	3.7	3.6
1=Far Ahead 2=Slightly Ahead 3=Even 4=Slightly Behind 5=Far Behind			

SOURCE: OIRA Survey

B. Other Emerging Competitors

Survey respondents were queried as to which countries/regions possess emerging advanced ceramic technologies and have the potential to become major international competitors in the future. Russia (the former Soviet Union) was the most frequently mentioned in this category, with 14 cites. Several respondents stressed that the former Soviet Union possessed good powder technology and was strong in the production of pumps (seals) and electronic sensors.

Eastern Europe (including the former German Democratic Republic) received 11 cites. In addition, the People's Republic of China also received 11 mentions. Many firms noted that China was an up-and-coming competitor in a number of product applications (i.e., pumps, heating components, engines, and wear components). Other Pacific Rim nations mentioned included: South Korea (seven mentions - heating components, engines/turbines, and wear components); Taiwan (three mentions); and Australia (two mentions - toughened zirconia).

India was mentioned by three respondents as a growing competitor. Other countries/regions named as emerging competitors were Brazil, with two mentions, and Africa, Israel, and Mexico which were each mentioned once by survey respondents.

C. Status of Eastern European and Former Soviet Facilities

Survey respondents were requested to provide any information on the state of development of the advanced ceramic industries of Eastern Europe and the former Soviet Union. The responses received were generally pessimistic in their assessments of the advanced ceramics industries in these countries.

The former Soviet Union was said to have sound capabilities in the areas of pyrolytic boron nitride, pyrolytic graphite, boron nitride, titanium diboride powder and resistance elements for vacuum metallizing, and in non-oxide ceramics. One firm responded that the Russians had performed notable work in the microwave ferrites field.

There was not a clear consensus by respondents concerning the state of advanced ceramics technology in either region. The answers offered ranged from "the Russian's manufacturing technology is weak", to "the technology is available, but production is low", to "they possess high technology, but have poor production rates and low product quality". Most respondents were in agreement on the fact that little or none of the advanced ceramics products have been commercialized.

Historically, the advancement of advanced ceramics in Eastern Europe and the former Soviet Union was financially supported by the defense sector. Given this setting, several respondents noted that Russian and East European advancements were limited to specific defense-related items. It was noted by more than one respondent that the former Soviet Union is probably well advanced in the development of advanced structural materials related to military applications. As with many industries in the former Soviet Union facing the conversion from defense related to consumer-related products, several respondents believed it would be a particularly difficult transition for the advanced ceramics industry.

Several mentions were made as to the plentiful and relatively well educated labor base available in the former Soviet Union. It was also noted that the glut of scientists (at comparatively low wages) was a real advantage for the former Soviet Union and Eastern Europe. In the area of research and development, several respondents mentioned that the former Soviet Union was strong in the field of basic research, and that R & D was active and widespread throughout the region.

D. Key Issues Impacting the Industry

Survey participants were asked to identify and discuss key issues which impact the U.S. advanced ceramic industry in the world market. The following discussion delineates the comments into four broad categories: company- and market- specific (i.e., financial, technological); legal, regulatory and other governmental; U.S. business environment (i.e., legal, regulatory); and the external environment. There is considerable overlap among these categories, as will be shown below.

- Company- and Market-Specific Factors

In this category, seventeen firms mentioned issues related to *cost, production volumes, delivery, quality, and reliability of products*. Specifically, the cost of labor, equipment, and R&D, the lack of materials science and process capabilities were mentioned, along with manufacturing efficiency and service. One mentioned the need for further refinement of cost and performance characteristics for certain products in order to better compete with products made from other materials. Eight firms cited issues related to the *research and development process*. Respondents mentioned a lack of investment in coordinated and long-range R&D efforts, and the difficulty of executing long-range research plans in light of relatively short business cycles. Also, firms mentioned difficulties both in determining which products will be commercially successful and bringing these products to market. Issues related to *investment policies and capital formation* were mentioned by eight firms. Firms expressed concerns about the availability of funds and the danger of short-term financial planning horizons. Eight respondents mentioned *slow customer acceptance* of new materials and innovative concepts as a major issues impacting the industry. Firms explained that customers do not have the knowledge to accept and adapt to new technologies. Four firms mentioned *raw material and resources cost and availability*. Finally, three respondents indicated that the *decline in markets and defense spending worldwide* significantly impacts their operations.

- Business Environment Factors

In this category, four firms mentioned the *lack of cooperation between suppliers, endusers, and the government*. One respondent decried the low level of commitment on the part of these parties to cooperating sufficiently to maintain the competitiveness of the industry. According to one firm, such collaboration on enabling technology and applications engineering is needed to protect and expand the industry's domestic and foreign business bases. Three firms indicated that the *cost of labor and the lack of an educated and trained labor force* impacted their business. Finally, three respondents mentioned the *lack of tax incentives* to spur long-term investment and research and development in the United States.

- Legal, Regulatory, and Other Governmental Factors

Here, the issue of compliance costs, was again popular. Six firms indicated that *environmental laws, clean-up costs, and OSHA laws* impact their operations. Three mentioned a general *lack of government support*, citing insufficient government funding for R&D and the absence of a national commitment to a purpose. Two respondents complained about *trade policy*; one stated that the government makes it difficult for domestic manufacturers to compete with foreign competitors because it is illegal for domestic manufacturers to use tactics that are used by foreign competitors, such as restricting access to distribution channels. In addition, two firms mentioned *export controls* and another indicated the government insurance for credit is feasible only on large orders. *Tax issues* were brought up by two firms; one mentioned taxes in general, and the other implied that the R&D tax credit is not as helpful as it could be, because it only applies to excess spending over the previous year. Finally, *customs duties* and the *patent situation* each were mentioned once.

- External Factors

The *lack of government support* for the U.S. advanced ceramics industry was mentioned by four respondents. According to one, the government support of advanced ceramics in foreign countries currently goes beyond U.S. government support of the U.S. industry. Another mentioned that it is difficult for U.S. companies to "sell against" the more-positive government/industry relationships in Asian and European countries. One firm referred to MITI's funding of advanced ceramic programs aimed at future commercial applications. Four respondents mentioned the *dominance of Japanese firms* in the industry. According to one, their technological lead and vast investment in ceramic technology will be hard to overcome. Three firms mentioned *trade practices*, indicating specifically that there is not equal access to U.S. and world markets. Competing against *low labor cost* was an issue brought up be two respondents, who referred to labor costs in the Pacific Rim in particular and mentioned the difficulty of maintaining a competitive posture in light of low labor costs elsewhere.Finally, the *lack of respect for patents* in Japan and Europe, *trade tariffs*, and *exchange rates* were each cited by one firm as key factors impacting their business.

E. Competitive Prospects

Survey participants were asked to forecast their firm's competitive prospects for the next five years. The results are shown in the table below. Overall, respondents were fairly optimistic about their competitive prospects for the near future (the next five years). More than 60 percent of the responding firms expected the competitiveness of their advanced ceramics products to improve greatly or somewhat over the next five years. Slightly over 20 percent of the firms expected no change in their competitive status over the next five years. A minority of respondents (less than 15 percent) anticipated the competitiveness of their advanced ceramics products to decline greatly or somewhat in the near term.

A variety of reasons were provided by firms for changes, positive or negative, in their competitiveness in the future. Among the responses on the positive side, many firms mentioned increased emphasis on cost of production and product quality, developing and

Table 23
Competitive Prospects for Advanced Ceramics Firms Over the Next Five Years

	# of Firms
Improve greatly	9
Improve somewhat	20
Stay the same	11
Decline somewhat	4
Decline greatly	2

SOURCE: OIRA Survey

broadening product lines, reducing costs through development of new production and process techniques as being instrumental to their future improved competitiveness. A number of respondents cited growth potential in new markets, planned acquisitions domestically and overseas, and increased investment in new equipment and facilities as another set of factors key to their future improved competitiveness. Other firms indicated potential benefits from using the vast, low cost, and highly-skilled workforce in Eastern Europe and the former

Soviet Union. Several firms mentioned the implementation of Total Quality Management (TQM) programs.

Others had more negative outlooks, citing a variety of reasons, including the presence of stronger and more numerous foreign competitors, with an increased domination of various product lines by Japanese and European firms. Markets are maturing and domestic and foreign competitors are battling to establish market share. Cutbacks in defense markets, the decline of aerospace market and slow economic recovery are combining to make competition even more fierce. Negative impact of government regulations (i.e., safety, health) were mentioned, as was a lack of funding for research and development.

F. Impact of Government Regulations/OSHA Standards

Survey respondents were queried as to what impact, if any, do government regulations, such as accounting rules, export licensing requirements, and OSHA and environmental standards have on their competitiveness. The table below contains their responses.

Table 24
Impact of Government Regulations On Competitiveness

Negative Impact	34 companies
No Impact	14 companies
Positive Impact	3 companies

SOURCE: OIRA Survey

About 67 percent of the respondents (34 companies) regarded government regulations as having a negative impact on their competitiveness. Among these companies, the most frequently mentioned complaint was the cost of compliance, expressed in terms of additional "non-productive" personnel requirements. Maintaining compliance with accounting rules, export licensing requirements, and OSHA and environmental regulations requires "significant internal resources," according to one firm. One respondent estimated that accounting rules increased the cost of doing business by 15 to 20 percent, due to the increased number of employees required to fill out forms and comply with regulations. Increases in costs lead to

rising prices, which decrease competitiveness. The resources required for compliance could be spent better R&D, investment, and process improvements - all of which would lower prices and increase competitiveness.

In addition to direct financial costs, several firms mentioned the costs in terms of time. Specifically, export licensing is perceived to lengthen lead times; this makes US firms less competitive with their foreign competitors and can make customers uncertain about the supplier's ability to deliver. Further, many companies stated that their foreign competitors are not burdened with OSHA and environmental standards, allowing these overseas firms to be more price competitive.

Approximately 27 percent of the companies viewed government regulations as having no impact. Only a few of these firms offered comments. One firm stated that, as a relatively new company, it did not have to undo, change, or correct old procedures. Another firms was unaffected by export licensing requirements because it did not export, and indicated that OSHA and environmental standards were consistent with efficient business practices in the industry.

A clear minority (6 percent or 3 companies) reported government regulations as having a positive impact on their competitiveness. These firms mentioned benefits gained from improved operations and from endmarket stimulus. One indicated that the regulations spur equipment upgrades; another stated that environmental regulations ultimately improve efficiency, and that foreign competitors would eventually be faced with similar regulations. Another spoke positively of OSHA regulations, saying that they protect the workforce, the firm's most valuable resource.

G. IMPACT OF MERGERS, ACQUISITIONS, AND TAKEOVERS

A large number of mergers and acquisitions impacting the advanced ceramics industry have occurred during the period covered by this study. These agreements have included mergers of domestic companies, acquisition of foreign firms by U.S. companies, and acquisitions of U.S. companies by foreign firms.

There are many possible motivations for companies deciding to merge with or acquire the operations of other companies. Basically, there are advantages to be gained from pooling resources; the synergy generated often means that the whole is greater than the sum of its parts. The complex technology requirements, the manufacturing expertise needed, and the competition for business combine to make mergers and acquisitions attractive in the advanced ceramics industry.[15]

In most cases, there are regulatory and policy hurdles to be overcome before such agreements can be finalized. In the United States, antitrust laws regulate any joining of companies that might create a monopoly in the market for a particular product. Although these laws have been adjusted in recent years to accommodate some beneficial forms of joint projects, they are still perceived as an impediment to these relationships. In addition, the U.S. government, through its Committee on Foreign Investment in the United States (CFIUS), investigates foreign acquisitions of domestic firms which threaten to impair national security. The existence of the Committee may deter some firms from considering mergers with foreign companies; however, CFIUS has blocked only one purchase after more than seven hundred cases.

Two of the largest and most-discussed acquisitions during the review period were foreign acquisitions of domestic producers. The first occurred in 1989 when Kyocera, a Japanese ceramics and electronics group, purchased AVX, the leading American producer of ceramic capacitors. According to press reports, AVX was attractive to Kyocera because of its European plants - two in Northern Ireland and one each in England, France, and Germany. With these plants, Kyocera would have a ready-made production base in Europe before 1992, and would be able to supply components to Japanese consumer electronics firms expanding into Europe.

The second took place in 1990, when a French firm, Compagnie de Saint-Gobain, purchased Norton for approximately $1.9 billion in a friendly takeover. This acquisition was

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[15] Abraham, Thomas. "The U.S. Advanced Ceramics Industry: The Growth Continues." JOM. The Minerals, Metals, and Materials Society. January 1992. pp. 6-7.

investigated by CFIUS, mainly because of Norton's classified contracts with the U.S. government, including the Departments of Defense and Energy. Eventually, the investigation showed that the merger would not present a threat to national security, and President Bush decided not to intervene in the acquisition. The fact that these cases were raised at all points out the growing significance of these two large foreign companies in the U.S. market.

Companies were asked whether they had been affected by mergers, acquisitions, and takeovers in the advanced ceramics industry. The following table contains the respondents' answers:

Table 25
Has Your Company Been Affected by Mergers, Acquisitions, and Takeovers?

Yes	25 companies
No	27 companies

SOURCE: OIRA Survey

Given the data, firms were almost evenly divided between those who had and had not been affected by mergers, acquisitions, and takeovers in the advanced ceramics industry. Of the 27 firms that reported having felt no impact from mergers, acquisitions, and takeovers, a few reported that the number of companies entering the advanced ceramics market was much fewer than the number leaving the industry.

The companies that reported being impacted by mergers, acquisitions, and takeovers offered a host of observations as how the advanced ceramics industry had been impacted. The past few years have seen a marked proliferation of foreign (Japanese and European) acquisitions of domestic suppliers, manufacturers, and vendors. Firms that had previously been small in size have grown larger as a result of their acquisitions. Several firms noted that the increase in acquisitions by larger firms has made it more difficult for smaller firms to compete. The merger, acquisition and takeover phenomena was credited for making access to R&D funding and promising technologies greater, as well as enhancing some firms' manufacturing and

technical capabilities. It was also noted that many firms gained greater access to markets (especially in Europe) due to mergers, acquisitions, and takeovers.

H. ANTITRUST LAWS

Questionnaire recipients were asked to provide their opinions and perceptions concerning U.S. antitrust laws and whether they were a barrier to strategic alliances. More specifically, firms were asked whether U.S. antitrust laws were a barrier to strategic alliances in the following arenas: 1) with other U.S. firms; 2.) with foreign firms; 3.) in horizontal relationships; and 4.) in vertical relationships. The table below contains the respondents' answers. In each topic category, a majority of firms did not view antitrust laws in a negative light.

Table 26
Are U.S. Antitrust Laws a Barrier to Strategic Alliances?

	Yes	No
With other U.S. firms	18	24
With foreign firms	13	24
In horizontal relationships	15	22
In vertical relationships	10	28

SOURCE: OIRA Survey

Survey recipients were also asked whether they had actual experiences in which U.S. antitrust laws have created a barrier to cooperation with other firms in either R&D partnerships or manufacturing partnerships. A resounding "no" was the response from 47 firms, while only 3 establishments reported any actual experiences in U.S. antitrust laws creating barriers. The table below contains the firms' responses.

Table 27 Has Your Company Had Actual Experiences in Which U.S. Antitrust Laws Have Created a Barrier to Cooperation?	
Yes	3 companies
No	47 companies

SOURCE: OIRA Survey

A large number (45) of firms indicated that they would consider forming vertical alliances with suppliers, manufacturers, or distributor firms in their fields. Only 3 firms reported that they would not consider forming vertical alliances with such entities.

Table 28 Would Your Company Consider Forming Vertical Alliances with Suppliers, Manufacturers, or Distributor Firms in Your Field?	
Yes	45 companies
No	3 companies

SOURCE: OIRA Survey

I. Tax Incentives

Survey respondents were asked whether foreign governments provided their competitors with tax incentives (i.e., R&D credits, investment credits) to invest in and develop new technologies. For those who answered in the affirmative, firms were requested to identify and explain these incentives. Several respondents identified the governments of Germany, Japan, and other Pacific Rim nations as providing their indigenous advanced ceramics firms with tax incentives to invest in and develop new technologies.

Germany - based on survey responses, the German government is said to: 1.) share R&D costs by grants from the Federal Ministry for Research and Technology; 2.) give investment tax credits; and 3.) grant attractive tax rebates to new plants built in the country.

Japan - based on survey responses, the Japanese government is said to: 1.) grant attractive tax rebates to new plants built in the country; 2.) (through MITI) help Japanese Advanced Ceramic firms extensively by providing funds, offering low capital interest rates, and capital purchased from R&D equipment with payback on successful commercialization, with the intended goal of future commercial applications.

Pacific Rim - based on survey responses, the governments of China and Taiwan are said to: 1.) share R&D costs; and 2.) subsidize capital costs at very low rates.

J. FOREIGN R&D AND INVESTMENT

Companies were asked to comment on what part of the R&D and investment in new technology and plant is performed by large, integrated foreign firms and how much is done by small, venture capital foreign firms.

Regarding R&D and investment by German firms, one respondent noted that small firms in Germany are seldom financed by venture capital but by bank loans. Another firm mentioned that the preponderance of R&D and investment is conducted by large integrated firms. One company estimated that of total expenditures for R&D by foreign firms, approximately 80 percent is performed by large, integrated foreign firms.

K. FOREIGN BANK INVOLVEMENT IN OWNERSHIP

Surveyed firms were asked to what extent foreign governments allow banks and other financial institutions to own a share of advanced ceramic manufacturers. Germany and Japan were both identified as foreign governments that permit such ownership. Based on survey responses, both Japanese and German advanced ceramic manufacturers are frequently part of vertically integrated corporations, and banks generally hold some stock. Small independent advanced ceramics manufacturers may or may not have banks as stockholders. According to our respondents, in Germany, banks routinely own 10 - 15 percent equity in major ceramic companies, and this percentage may be even higher for Japan. Consequently, access to major capital is virtually assured.

L. Foreign Government Assistance

Survey respondents were requested to comment on whether or not foreign governments provide any loans, loan guarantees, grants or other forms of financial assistance to underwrite the development of new technologies. The question elicited a variety of responses, but overall, respondents believed that the foreign industry does benefit from such assistance.

According to survey respondents, the Australian government has provided support in several cases for use within the country. Central and Eastern European governments also have money available for such assistance. In Europe, government grants to industry are quite common. National and local governments in Germany, Italy and Spain make loans or provide other forms of financial assistance to encourage new investment and build employment. Finally, according to our respondents, Japan's MITI funds research and development in advanced ceramic programs which are usually end-use specific, not just generic R&D. For example, MITI has provided a well-funded R&D program for ceramic gas turbines. The continuing close alliance between MITI and the industry strengthens that country's manufacturers. Several other research institutes in Japan conducted early research which has resulted in their sizeable technology and patent base.

M. Foreign Government Procurement Policies

Surveyed companies were queried as to whether foreign governments enter into procurement arrangements, such as supply contracts, or any other form of assistance to guarantee purchase of all or part of the product manufactured from a new technology. Several respondents identified the governments of France, Germany, and Japan as entering into such procurement arrangements.

One company stated that the French government enters into procurement arrangements (e.g., supply contracts) to guarantee purchases from new technologies. Another mentioned that the German government procures new products in critical technology areas, but leaves the choice of components to the entities at the top of the supply chain. Finally, a respondent noted that for certain Japanese products, the Japanese government encourages pre-competitive consortia

to make selected products and systematically removes regulatory and risk barriers for the top of the supply chain, and, like Germany, counts on the top to make a competitive selection of the rest of the chain.

V. THE INDUSTRY AROUND THE WORLD

BXA's Office of Foreign Availability prepared an assessment of the foreign advanced ceramics industry. The Executive Summary of that assessment is given here; the entire report is available for sale by contacting the National Technical Information Service at (703) 487-4650.

A. EXECUTIVE SUMMARY

Japan, the U.S., and Western Europe are the leading producers of advanced ceramics (in terms of sales), with estimated market shares of 59, 30, and 11 percent respectively in 1992, which match their market shares in 1987. Within Europe, Germany, France, and the United Kingdom are the leading producers. Taiwan will eventually become a leading producer.

Advanced ceramics are conventionally divided into the following four segments:

- **Structural ceramics:** This is an emerging technology with diverse potential commercial applications. No country has yet obtained a market edge in this segment.

- **Electronic ceramic:** This relatively mature technology (79 percent of the total market) is dominated by Japanese companies, particularly Kyocera. Other Asian countries with advanced electronics industries will also become significant producers.

- **Ceramic powders:** U.S. companies face their strongest competition in the production of zirconia and the nitrides, which comprise a relatively small portion of worldwide demand for powders.

- **Ceramic coatings:** Only about 9 percent of the total market, coatings are the fastest-growing segment. The U.S. enjoys a dominant position in this technology.

In terms of sales, five of the top ten performers in 1991 were Japanese companies. While U.S. companies also numbered among the leaders (10 out of the top 20), on average Japanese companies posted greater growth in 1991 relative to 1990. For U.S. companies,

1991 growth did not match the increase in U.S. domestic demand, due in part to intense competition in electronic ceramics.

Japanese companies dominate *U.S.* sales of electronic ceramics, particularly ceramic packaging for integrated circuits (ICs). Kyocera alone holds about 60 percent of the U.S. IC market. Another Japanese country, NTK Technical Ceramics, has 25 percent of this market.

Sixty percent of U.S.-based ceramic capacitor manufacturers are Japanese companies. This market dominance may reflect the Japanese companies' higher profit margins, which result from investments in labor-saving automation equipment. Japanese government polices reward such capital investments.

For the present, U.S. companies perform much better in the domestic market for structural ceramics. The top 4 U.S. companies share about 80 percent of the U.S. market. However, Kyocera was recently selected to participate in recent U.S. government-funded advanced ceramics programs by virtue of its unique production capabilities, which apparently exceeds any U.S. capability. The U.S. fares well in ceramic coatings and powders.

In recent years, foreign acquisitions of U.S. companies, foreign mergers and joint ventures have eroded the share of U.S. companies in the domestic market. Along with foreign competition, U.S. companies also are concerned by changing markets, environmental standards, labor cost, and health and safety standards.

U.S. government-funded research in advanced ceramics has increased dramatically in recent years, partly through the Advanced Materials and Processing Program. The U.S. Department of Energy is the lead agency for this program.

Market forecasts predict steady growth until the year 2000 for all segments of the U.S. advanced ceramics industry. In recent years, the growth of the industry has been slowed by

the poor performance of the U.S. automotive and electronics industries, which are prime consumers of ceramics.

Japanese companies supply about 80 percent of the worldwide market for electronic ceramics. Within this segment, they hold about 35 percent of the market for integrated circuit packages, 50 percent of the ceramic capacitors, and 70 percent of the piezoelectrics. The leading firms are Kyocera, Murata, Sumitomo, NGK Insulator, and Sony. The Japanese government invests heavily in all phases of ceramics research.

German industry is strong in certain niche markets for ceramic powders. Leading companies are Hoechst CeramTec, Siemens, and Cerasiv. German government involvement in technological development is most significant in its support for applied research and development, technology transfer, and worker training.

France is strong in the production of ceramic coatings for aerospace applications and electronic ceramics. The French government is extensively involved in several key aspects of technology policy. French government ownership of a percentage of leading ceramics companies gives the government additional incentive and leverage to direct industrial policy in this area. Leading companies are St. Gobain and Pechiney.

The United Kingdom and the Netherlands also possess well-developed advanced ceramics industries and extensive government-funded research. The leading companies are Morgan Crucible (U.K.) and Philips (Netherlands).

Taiwan's growing consumer electronics industry has spurred electronic ceramic sales of over $450 million in 1991, by over 100 medium and small-size Taiwan companies. Taiwan production increased by 17.3 percent in 1991, almost double U.S. and Japanese annual growth rates. The key products of the Taiwan industry are ceramic capacitors.

B. CONCLUSIONS

All of the leading foreign advanced ceramics companies benefit directly or indirectly from national technology policies that are designed to promote their commercial competitiveness. For advocates of a U.S. technology policy, publications by the U.S. National Academy of Sciences (NAS) and the National Science Board (NSB) present thought-provoking recommendations. A comparison of the foreign government policies presented in Appendices A through G and the recommendations of the NAS and NSB may prove beneficial for U.S. policy makers.

The U.S. and Japan are at parity in terms of pure technology, yet Japan holds a decided edge in commercial success, probably due to business practices driven by "demand articulation."

In the more "mature" segment of electronic ceramics, Japanese commercial successes are greatest in the low-tech end of the spectrum; U.S. commercial success is greatest at the higher end. In general, Japanese success is due more to competitive pricing, strict quality control, and adherence to delivery timetables than to fast commercialization of R&D.

OFA concludes that, in the near term, growing competition from Taiwan will drive down market prices of certain electronic ceramic products, namely ceramic capacitors. Competition from Taiwan will spur greater Japanese production and finish off the almost moribund U.S. industry. Japan may thereafter shift production to threaten other U.S. advanced ceramics markets.

For both Asian and U.S. producers, slimmer profits are increasingly forcing off-shore production schemes and R&D efforts focusing on cost reductions.

However, Japanese integration of R&D and production processes places them at an advantage in the emerging technology of structural ceramics. In this field, **one key to future success is mastery of the ceramic-shaping processes** rather than the quality of the ceramic material itself. Japan holds a clear edge in the "enabling" technologies of flexible manufacturing and

robotics. Japanese companies are also adept at cooperative research which may, for example, "team" a leading ceramics company with a leading materials-processing company in order to devise efficient ceramic fabrication equipment or processes.

APPENDIX I

SURVEY COVER PAGE AND TABLE OF CONTENTS

U.S. Department of Commerce
Bureau of Export Administration

OMB Control # 0694-0071
Expires 12/31/92

CRITICAL TECHNOLOGY ASSESSMENT: ADVANCED CERAMICS

PURPOSE OF THIS ASSESSMENT

This critical technology assessment was initiated under Section 825 of the Defense Authorization Act of 1991. Section 825 requires the Department of Defense and the Department of Commerce to submit an annual report to the Armed Services Committees of the Senate and the House of Representatives on the financial and production status of the industries supporting the Department of Defense's (DOD's) list of critical technologies. This report will also be released to the public.

The objective of this assessment is to provide government policymakers and industry planners with needed information and analysis on the advanced ceramics industry, a sector which DOD has deemed essential to the development of the next generation of weapon systems needed to ensure our national security. In completing this survey your firm will assist the U.S. Government in understanding the consequences of DOD spending cutbacks for your sector as well as the opportunities for defense conversion activities.

MANDATE

This information is being collected to carry out Department of Commerce emergency preparedness responsibilities under Presidential Executive Order 12656 of November 18, 1988. One of these responsibilities is to "perform industry analyses to assess capabilities of the commercial industrial base to support the national defense, and develop policy alternatives to improve the international competitiveness of specific domestic industries and their abilities to meet defense program needs." [Authority: Defense Production Act (50 U.S.C. App. 2155); Department of Commerce Act (15 U.S.C. 1516).] Information furnished herewith is deemed confidential and will not be disclosed except in accordance with applicable law. Where appropriate, information and material submitted should be designated "BUSINESS CONFIDENTIAL" as provided for in Section 705.6 of the U.S. Department of Commerce Regulations, 15 C.F.R. 705.

No business proprietary information will be released under a Freedom of Information Act request.

If, during 1989-1991, your firm did not produce advanced ceramics or advanced ceramic products, you are not required to complete this form, but please provide the information requested below and return this page:

______________________	______________________
Signature of Authorized Official	Date
______________________	______________________
Name of Official - Please Print	Phone

PLEASE COMPLETE AND RETURN THIS QUESTIONNAIRE BY AUGUST 31, 1992

BURDEN ESTIMATE AND REQUEST FOR COMMENT

Public reporting burden for this collection of information is estimated to average from 6 to 15 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to BXA Reports Clearance Officer, Room 4513, Bureau of Export Administration, U.S. Department of Commerce, Washington, DC 20230, and to the Office of Management and Budget, Paperwork Reduction Project (0694-0071), Washington, DC 20503.

GENERAL INSTRUCTIONS

1. Please complete the questionnaire in its entirety as it applies to your firm. The survey is divided into six parts, as outlined in the Table of Contents. Sales entities should complete only Part I and question 1 of Part III. Research entities should complete applicable portions of Parts I and IV.

Please use the codes on the attached "List of Product Codes" to identify items in Parts II and III.

2. **SMALL FIRM EXEMPTION:** Firms with fewer than 50 employees are only required to complete the following:
   PART I: All
   PART II: All; for question 1, respond for your best-selling product only.
   PART III: All; report data for question 1 for 1991 only.
   PART IV: For investment (section A, question 1) and employment (section B, question 1), provide 1991 data only. Please respond to the remaining questions in this part.
   PART V: All
   PART VI: 1991 data only.

3. We do not want to impose an unreasonable burden on any respondent. If the information is not available from your records in exactly the form requested, please provide estimates and label them with the letter "E".

4. Report calendar year data, unless otherwise specified in a particular question. Please complete the following questions separately for each of your establishments that manufacture advanced ceramics or advanced ceramic products in the United States:

   Part IV - Sections A and B　　　Part V　　　Part VI - Questions 1B and 2B

   Please photocopy the forms if additional copies are needed. For the other questions, firms operating more than one establishment may combine the data for all establishments into one report.

5. Be sure to sign the certification found at the end of the questionnaire and give the name and phone number of the person to contact at your firm in case we have any questions about your response.

6. If you have any questions related to the questionnaire, you can contact Margaret Cahill, Trade and Industry Analyst, at (202) 377-3795, or Eric McDonald, Trade and Industry Analyst, at (202) 377-3984, both of the Department of Commerce.

7. Thank you for your assistance. Please return the completed questionnaire by **August 31, 1992** to:

   Brad Botwin
   Director, Strategic Analysis Division
   Ref: Advanced Ceramics
   U.S. Department of Commerce
   HCHB 3878
   Washington, DC 20230

TABLE OF CONTENTS - QUESTIONNAIRE
ADVANCED CERAMICS

APPENDIX II

PRODUCT CODE LIST

CRITICAL TECHNOLOGY ASSESSMENT: ADVANCED CERAMICS
LIST OF PRODUCT CODES FOR USE IN COMPLETING PARTS II, III AND IV

A. STRUCTURAL APPLICATIONS

A.1. ENGINES: INTERNAL COMBUSTION/DIESEL
- A.1.a. Turbochargers
- A.1.b. Exhaust port liners
- A.1.c. Exhaust catalytic converters
- A.1.d. Thermal protection shields
- A.1.e. Cylinder liners
- A.1.f. Piston crowns
- A.1.g. Valves
- A.1.h. Valve sleeves
- A.1.i. Cam followers
- A.1.j. Wear components
- A.1.k. Other (specify):

A.2. ENGINES: AUTOMOTIVE, AIRCRAFT AND STATIONARY TURBINES
- A.2.a. Rotors
- A.2.b. Stators
- A.2.c. Recuperators
- A.2.d. Heat exchangers
- A.2.e. Thermal protection shrouds
- A.2.f. Bearings/wear components
- A.2.g. Other (specify):

A.3. PUMPS
- A.3.a. Seals
- A.3.b. Pump liners/components
- A.3.c. Valves
- A.3.d. Bearings
- A.3.e. Other (specify):

A.4. CUTTING TOOLS
- A.4.a. Tool bit inserts
- A.4.b. Wheels
- A.4.c. Abrasives
- A.4.d. Other (specify):

A.5. HEAT EXCHANGERS
- A.5.a. Preheaters
- A.5.b. Recuperators
- A.5.c. Other (specify):

A.6. ARMOR
- A.6.a. Vehicle
- A.6.b. Personnel
- A.6.c. Other (specify):

A.7. WEAR COMPONENTS

A.8. CORROSION RESISTANT COMPONENTS

A.9. "SEVERE ENVIRONMENT" COMPONENTS

A.10. OTHER

B. FUNCTIONAL APPLICATIONS

B.1. PACKAGES/SUBSTRATES

B.2. CAPACITORS

B.3. MAGNETS

B.4. FUEL CELLS

B.5. MICROWAVE

B.6. VARISTORS

B.7. TRANSDUCORS

B.8. ACTUATORS

B.9. SENSORS
- B.9.a. Optical
- B.9.b. Electronic
- B.9.c. Other (specify):

B.10. INSULATORS

B.11. WINDOWS
- B.11.a. Radar
- B.11.b. Infrared
- B.11.c. Ultraviolet
- B.11.d. Optical
- B.11.e. Radomes
- B.11.f. Other (specify):

B.12. NUCLEAR
- B.12.a. Elements
- B.12.b. Shielding
- B.12.c. Cladding
- B.12.d. Controlling
- B.12.e. Other (specify):

B.13. HEATING COMPONENTS
- B.13.a. Ignitors
- B.13.b. Heater elements
- B.13.c. Muffle components
- B.13.d. Setter hardware
- B.13.e. Other (specify):

B.14. POWER TUBES

B.15. VACUUM INTERRUPTERS

B.16. ADVANCED GLASSES
- B.16.a. Fluoride
- B.16.b. Laser host
- B.16.c. Other (specify):

B.17. OTHER

C. COATINGS

C.1. ALUMINUM OXIDE
C.2. SILICON NITRIDE
C.3. TUNGSTEN CARBIDE
C.4. ZIRCONIA
C.5. OTHER (specify):
C.6. OTHER (specify):
C.7. OTHER (specify):

D. RAW MATERIALS

D.1. ALUMINUM OXIDE
D.2. ALUMINUM NITRIDE
D.3. ALUMINUM TITANATE
D.4. BORON CARBIDE
D.5. CERMET
D.6. DIAMOND
D.7. DOPANTS, OTHER SINTERING AIDS
D.8. FERRITES
D.9. NIOBATES
D.10. ORGANIC PRECURSORS (specify):

D.10. SILICATES
D.11. SILICON CARBIDE
D.12. SILICON NITRIDE
D.13. TITANATE
D.14. TUNGSTEN CARBIDE
D.15. ZIRCONIA
D.16. OTHER (specify):

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