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BASELINE INDUSTRY ANALYSIS

ADVANCED CERAMICS INDUSTRY

John J. Erb
Lieutenant Colonel, US Army

ABSTRACT

The U.S. Advanced Ceramics Industry is identified as a critical technology by the Department of Commerce, Department of Defense, and the National Critical Technologies Panel. Advanced Ceramics, which include ceramic matrix composites, are found in every major weapons system in the U.S. inventory. Like many of our subtier technologies, the U.S. has long maintained the lead in research and development of new applications while most production has moved overseas. This paper reviews the current status of the industry. In light of a decreasing DOD budget for both R&D and production, it offers a series of policy recommendations to help ensure the industry stays responsive to the needs of this country.

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Executive Research Project
DIS1

Baseline Industry Analysis Advanced Ceramics Industry

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DISCLAIMER

THE ADVANCED CERAMICS INDUSTRY

INTRODUCTION

The advanced ceramics industry is frequently referred to by other names, depending on the region or country of origin - advanced ceramics can also be called industrial ceramics, engineered ceramics, fine ceramics or enhanced ceramics. Regardless of the name, the advanced ceramics industry is comprised of firms involved in the process of developing non-ferrous based products for a wide field of applications. These structural materials, called "advanced" because they have to be designed to have the properties required by a given application, offer superior properties to the more traditional metals or metal alloys.

The advanced ceramics industry becomes even more broadly defined when considering composite ceramics (or CMCs) - advanced ceramics formulas that are reinforced by various compositions of fibers, whiskers or particles (see PROCESS). For the purpose of this paper, the CMC industry will be included as part of the advanced ceramics industry.

Although the properties of advanced ceramic products vary by design, they generally are of higher temperature strength, greater friction wear resistance, greater chemical resistance, lower thermal conductivity and lower thermal expansion than conventional products.

The importance of these properties to both the commercial and governmental sectors of the economy are evidenced by the advanced ceramics and materials industry being identified as a National Critical Technology, Commerce Emerging Technology, and Defense Critical Technology.[1]

There is no one specific SIC code for the industry, because the codes are assigned to types of end products, not processes. A review was made of twenty firms that are members of the US Advanced Ceramics Association, a Washington D.C.-based trade association. These firms, though only a small percentage of the total industry, had products classified in over sixty SIC codes.[2]

APPLICATIONS

Advanced ceramic applications can be divided into five broad categories: structural ceramics, electrical ceramics, capacitors/substrates/packages, ceramic coatings, and optical fibers. In the commercial sector, products include wear parts, cutting tools, bearings, bio-ceramics (ranging from artificial joints to dentures), electro-chemical devises, heat transfer parts, ceramic filters, fiber optics, and sporting goods.

Products for the governmental sector include most of the commercial applications, plus gun liners, ceramic armor, various missile and modern ammunition parts, and space shuttle cones and tiles.

IMPACT ON NATIONAL SECURITY

Advanced ceramics are found in every major weapons system in the U.S. arsenal; and are increasing in importance. Ceramic packages alone constitute almost two percent of the total procurement cost in advanced systems, and as much as ten percent of the electronics portion of those weapons. Ceramic capacitors are almost as plentiful.[3]

Structural ceramics can be found as heat exchange parts, bearings, and as components in our vehicles, ships, aircraft and missiles. They are also the foundation for most of our advanced armor protection. Bio-ceramics are routinely used in our hospitals and dental clinics.

The impact of ceramics is not limited to the military element of our national power. Its impact on our space industry (to include our commercial space technology) cannot be understated. Advanced ceramics are as plentiful in the commercial sector as they are in the military.

Ceramic's potential impact on our national power is as great as its impact to date. Current national forecasts indicate our reliance on oil for transportation will increase over the next decade, even if oil prices rise by fifty percent.[4] The development and acceptance of a ceramic engine would avoid this increased dependency; and enable alternative fuels to further cut into our reliance on oil. It would also greatly assist our military in meeting its principle sustainment constraint for deployed forces. In his March 1992 keynote address to the

National Technology Initiative Conference, the President of Coors Ceramics Company alluded to the economic impact of this effort.

> "If the U.S. were to gain a technological and production advantage in advanced ceramic-based engines, domestic automakers would have a competitive advantage in world motor vehicle markets. According to an Argonne National Laboratory study:
>
> - 164 Million ceramic engine parts will be needed in the United States by the year 2000, and 558 million parts by 2010;
> - The value of these parts in 1986 dollars will increase from more than $1 billion in 2000 to more than $3.6 billion in 2010;
> - If U.S. manufacturers lead in the development of advanced ceramics, the U.S. GNP could expand by $11 billion;
> - However, if foreign producers lead, the U.S. GNP could decrease by $26 billion;
> - As a consequence, U.S. employment could also expand by 100,000 jobs if the U.S. leads, or decline by 200,000 under foreign leadership."[5]

Fiber Optics will continue to push the information infrastructure. Ceramic packages and coatings will extend the life of our machinery and electronics; and CMCs will continue to play a major role in our space program.

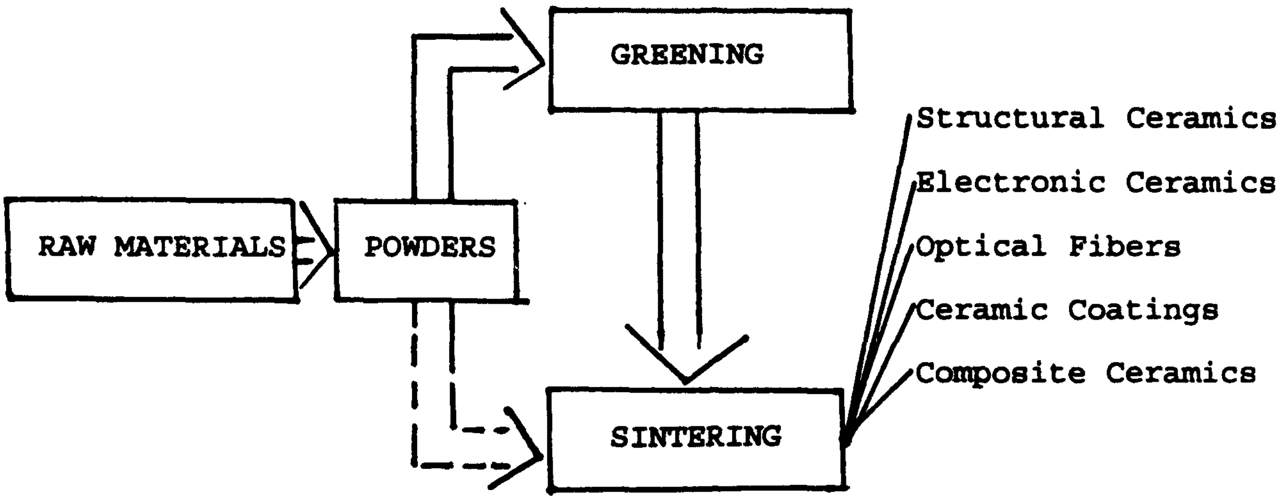
If we assume that advanced ceramics will continue to be essential to this country, the next question should be of our ability to ensure adequate supply. This is a complicated area as ceramics firms tend to be in the lower tiers of supply, often the third tier or lower. This makes it difficult to directly correlate the "health" of a firm to its impact on national security.

In November of last year, Coors Electronic Package Company and Ceramic Process Systems Corporation filed a petition under section 232 of the Trade Expansion Act of 1962, regarding integrated circuit ceramic packages. In its petition, Coors and CPS alleged that "The defense industrial base is experiencing serious and potentially fatal problems within the semiconductor and semiconductor components industry, industries which have been weakened by the activities of their foreign counterparts...whose actions include importation, targeting by ... government, and price underselling."[6]

This petition followed a March 1992 Department of Commerce report on three U.S. Navy weapons systems. The report showed a significant foreign dependence (Japan) for ceramic packages in these three systems. Even more disturbing was that foreign higher tier manufacturers routinely used foreign lower tier components, without looking for a U.S. manufacturer.[7]

Coors' and CPS's petition has caused an unusually high interest throughout the ceramic electronic packaging industry, and in its downstream industries. As of mid-February 1993, over twenty independent letters have been received by the DOC, about equally split in support. The respondents universally indicate the U.S. industry is in trouble, though various reasons are cited. Almost as universal is the concern that the President not restrict trade, but rather assist the U.S. industry in becoming competitive. DOC will forward its recommendations to the President in late Summer.

PROCESS



Not all advanced ceramics are processed in the same manner, but there are several basic processes most advanced ceramics undergo. The American Ceramic Society Bulletin's Annual on Minerals lists over 35 minerals that are used in advanced ceramics, usually in some mixture with silica. Fortunately, many of these raw materials are available from U.S. or Canadian mines. Those raw materials not available in North America are of sufficient quantity in numerous other locations in the world as to not be a strategic problem.

During processing, many of these minerals are enhanced to oxides, nitrites or carbides. These raw materials are ground into fine powders, that can be mixed and prepared for forming. New techniques are emerging for the production of ultra-pure and highly fine powders, to meet the demands of downstream users.

Greening, or green forming, is a method of ceramic forming without using heat. The most common forming methods are die pressing, slip casting, injection molding, and sol-gel molding. The latter methods are usually associated with the more sophisticated structural ceramics, as they require less grinding or finishing than the cruder methods. Some ceramic products do not require greening at all, and proceed directly from the mixed powder to the sintering process.

Sintering is the process of applying heat, with or without pressure, to affect a change in the chemical composition of the ceramic. The product is then ready for the finishing steps of grinding, polishing or drilling, if necessary. Recent articles discuss the insertion of a chemical reaction, rather than direct heat, to complete this sintering process.

The process for composite ceramics is similar to that described above. The application of reinforcements usually occurs in the green forming stage. The most common reinforcements include discrete materials in the shape of particles, whiskers, or short fibers; or continuous length reinforcements. The discrete reinforcements are dispersed into a slurry of matrix ceramic particles; while continuous yarns or fibers are impregnated with a slurry of the powder matrix to form "green tapes". The green products are then sintered, the same as the monolithic ceramics.[8]

It is during the sintering or finishing steps that the largest drawback to universal acceptance of advanced ceramics occurs. These steps can result in microscopic cracks that can cause complete (or "catastrophic") failure of the product. A great deal of research has gone into the ceramic process for the purpose of preventing formation of these cracks; and many changes have been applied to the process.

PRICE AND COMPETITION

The price of advanced ceramics products varies with the usual factors of quantity produced, investment of R&D dollars, process start-up costs, commonality of the product (leading to competition), etc.. The price of green formed ceramics ranges from a few dollars/kilogram for the crudest types, to several thousand dollars/kilogram for the most advanced ceramics.[9]

Competition remains high in most ceramic markets. In addition to competition between companies, there is also competition from other types of advanced materials and from the more conventional products. One example is the recent increase in the use of plastic (or PMC) semiconductor packages, as a substitute for ceramic packages. The cost of production of advanced ceramics reduces its acceptability in the end product markets, especially during periods of recession.

THE U.S. INDUSTRY

The U.S. advanced ceramics industry can be characterized as one of little growth of new firms; increasing reliance on mergers and partnerships; increasing multinational scope; and an increasing dedication to the commercial application of its products, with a cautious optimism for the future.

Sales figures for U.S. firms were estimated at $3.79 billion in 1990, and $3.91 billion in 1991. Sales are projected to increase at an average annual rate of ten percent (nominal dollars), to over $9 billion by the year 2000. Annex A shows the percentage of 1991 international sales, by broad category of product. Forecasts indicate that structural ceramics sales will grow at an annual rate as high as 18 percent per year, with engines and wear parts perhaps exceeding 20 percent. The growth in other advanced ceramic applications should remain a constant 8 to 9 percent, per year. Composite ceramics are expected to grow at an annual rate of approximately 14.6 percent.[10]

The top ten U.S. advanced ceramic firms, and their 1991 sales, are listed below. The top four firms account for 52 percent of the U.S. industry's sales, while the top ten firms account for 74 percent. The U.S. industry accounted for 67 percent of the number of top 100 international firms, and 25.5 percent of the sales. It must be noted that the 1991 growth projections were also for a 8 to 10 percent increase. Although total US sales increased by 3.1 percent (real dollars), seven of the top ten firms experienced either no growth or a decline in their 1991 sales. Most firms attributed this to the sluggish economy.[11]

Several ceramic production firms have evolved from firms that originally specialized in ceramics technology R&D; but they have tended to be focused in only a small range of applications. There have also been instances of ceramic product users expanding upstream to ceramic production- the most noticeable addition being IBM.[12]

Entry of new firms is extremely cost prohibitive, especially in today's international competitive environment. The creation of new American firms, specializing in only one major product line (eg. electronic ceramics) could easily cost in the hundreds of millions of dollars. One source estimates the capital cost of a U.S. advanced materials firm at $92,000 per employee, compared to an international average of $42,000 per employee. Although not discussed, this dispersion may include a combination of factors to include a higer cost of machinery and a more productive ratio of machinery to employee.[13] In addition to the high start-up costs, there are significant costs in qualifying a process. The Semiconductor Industry Association estimates a semiconductor company must invest an average of between $50,000 to $75,000 to qualify a new ceramic package supplier for just one package - and most semiconductor firms require a multitude of packages.[14]

Labor costs, while not a primary inhibitor to the start-up of new firms, does play a role in maintaining a competitive edge in the international industry. The U.S. advanced ceramics industry is a mix of union and nonunion shops where labor costs can often exceed $15.00 per hour. Japanese labor costs average under $10.00 per hour, while the labor costs in the non-industrialized nations are much lower.[15]

Most of the top U.S. firms are multinational in scope, with examples including Kyocera America, Inc., NGK Ceramics, USA, Cooper Industry plants in Europe, and Coors facilities in Brazil. Additionally, there has been a noticeable increase in partnerships in the East Asian region.

Table 1 - Top 10 U.S. Firms
(with 1991 ceramics sales)

FIRM	US Ranking	INT'L Ranking	Sales (m)
Corning, Inc.	1	4	$1000.4
Cooper Industries	2	7	456.0
General Motors	3	10	308.0
GTE Corp.	4	12	275.3
Allied-Signal	5	16	212.5
Adolph Coors, Co	6	17	180.2
Kemet Electronics	7	19	146.0
CTS Corp.	8	20	112.6
Dover Technologies	9	21	105.0
Keystone Carbon	10	22	100.0

Source: "10th Annual Giants in Ceramics", Ceramic Industry, (August 1992: pp 28-29).

INTERNATIONAL CERAMICS INDUSTRY

Table 2 compares 1991 sales between the U.S., Japanese and EC industries. Some of the data are questionable, because the source relies on input from individual firms. For example, the third ranked international firm for 1991 did not even appear on the 1990 list. The world figures track closely with like statistics from other sources.

The top six Japanese firms are all in the top ten international sales. The EC figures are skewed by including the number one international firm, Phillips Electronics N.V. with 1991 sales of over $3.2 billion. The United States (8), Japan (6) and the EC (6) make up all top twenty international firms The highest ranked firm that is not included in one of these categories, is ICI Australia Ltd., with 1991 sales of $34.0 million. Competition between international firms is tremendous, especially when most larger firms have partnerships or subsidiaries in the US, Europe, and East Asia (not Japan).

When responding to the 1991 "Giants in Ceramics" survey, international firms were asked to rank the three most critical issues facing their company. Of those responding, 45 percent viewed "changing markets" as the top issue facing them. "Meeting environmental standards" and "controlling labor costs" tied for second place (38%), while "meeting health and safety standards" were viewed as the number three issue (33%).[16]

Table 2 - INTERNATIONAL SALES
(nominal dollars - millions)

	1990	1991	2000 (proj)
World Sales	$13,600	$15,342	$29,900
United States Firms	$3,790	$3,911	$9,202
% of world total	27.9%	25.5%	30.8%
Japanese Firms	$4,527	$6,685	na
% of world total	33.3%	43.6%	na
EC Firms	$5,423	$4,627	na
% of world total	39.9%	30.2%	na

Source: "10th Annual Giants in Ceramics", Ceramic Industry, Aug, 1992, p. 28.

RESEARCH AND DEVELOPMENT

The U.S. industry has always enjoyed a healthy cooperation with government, especially in the area of research and development (see next topic). Government funding for R&D has been fairly stable, at around 125-150 million per year. While projections for the next two years do not reflect a dramatic change in the level of funding, a reduction in DOD funding is expected by 1995. The Department of Defense currently provides around 55 percent of the total government funding, including classified and unclassified projects, with the Department of Energy accounting for another 30 percent.

Based on this sustained R&D support, the US is recognized as the leading nation in the development of defense and space applications, However, the U.S. industry lags behind the Japanese industry, and not far ahead of the European Community, in the development of commercial applications. On the average, the U.S. industry contributes 1.2 dollars to every government dollar for R&D - in comparison with the Japanese industry who spends 4 dollars to every dollar of government support. Table 3 shows the comparative competitive advantage between the US, Japanese and EC industries.

Table 3 - Comparative Competitive Advantage

in High-Performance Ceramics*

High-performance Ceramic	US	Japan	EC
Structure			
Bio-ceramics	M	m	
Catalyst	m	m	M
Engine Parts		M	
High Temperature	m	M	m
Pump and Valve Components	m		M
Tool and die	M	m	m
Wear Resistant	M	m	m
Electronic			
Capacitors	m	M	m
Packages/substrates		M	
Piezoelectrics	m	M	m
Superconductors	m	M	
Powders			
Carbides/Nitrites		M	
Oxides	M		

* Advantage code: M is major and m is minor.
Source: William Wellock and Bruce Deckman, "Global Competitiveness and Its Impact on High-Performance Ceramics", American Ceramic Society Bulletin, Jan, 1992: p 103.

GOVERNMENT-INDUSTRY INTERFACE

There are a myriad of government agencies that interface with the advanced ceramics industry. These agencies range from congressional subcommittees, to science councils, to technological institutes, to trade administrators, to federal laboratories, to one of the numerous university-level government-funded research programs. Among these federal activities we are most familiar with are NASA, the Office of Science and Technology, the National Science Foundation, the National Critical Materials Council, the Departments of Defense, Commerce, Energy, Health and Interior, and the National Academy of Science.

The Legislative Branch activities include the Office of Technology Assessment as well as standing committees in both houses on science and technology, the armed services, and energy.[17]

These agencies have varying interests in the industry, ranging from pure research of ceramic formulas to process tooling. Yet across the spectrum, there is an increasing awareness on the part of federal agencies that a competitive commercial industry is vital to our national interests. A very brief description of several major agencies' interaction with the ceramics industry is described below.

o Department of Defense. DOD allocates funding support through the Army, Navy and Air Force, and the Defense Advanced Research Projects Agency (DARPA). Projects are approved and coordinated through the Under Secretary of Defense for Research and Development. The Air Force manages approximately 49 percent of the unclassified materials programs; the Army 25 percent; the Navy, 18 percent; and DARPA, 8 percent. This funding is spread between in-house laboratories, universities, industrial laboratories, and non-profit laboratories. Each of the services has its own laboratories, well-equipped for most aspects of materials research.

The Army programs range from the manufacturing of high strength ceramics and CMCs, to reduction of gun barrel erosion and kinetic energy projectiles. The Army, in cooperation with DARPA, pioneered ceramic bearing research. Many of the properties of advanced ceramics, including its low heat rejection (designed to reduce the infrared signature) and high resistance to the affects of chemical agents, continue to keep the Army interested in ceramic applications. One example of a recent Army contract is with the Norton Company, to develop ceramic material for applications in heat engines, requiring resistance to high temperature, wear and corrosion.[18]

The Navy program is designed to support the needs of its air, sea and undersea components. Like the Army and Air Force, the Navy is very interested in ceramic propulsion parts, for both its lack of infrared signature and its improved fuel consumption. Corrosion is of special concern to the Navy, especially the affects of salt water, and ceramic coatings have proven valuable. The Navy has been involved in the application of ceramic packages to protect its critical sensitive electronics in its missiles, aircraft and torpedoes. A recent example of a Navy contract is with Ceramic Process Systems Corporation, to produce lightweight composite packages for advanced microwave systems.[19]

Air Force programs have been significant in their support of weapons, aircraft and spacecraft. Many of the Air Force programs have resulted in the development of new ceramic applications for the other military services and the aerospace industry. The Air Force has been the leader in the development of ceramic parts for turbine engines, and for optic systems. Among its many sponsorships, the Air Force has teamed up with NASA to sponsor an Integrated High Performance Turbine Engine Technology (IHPTET) initiative, with a goal to double propulsion capability by the year 2005.[20]

DARPA's efforts are habitually concentrated in a few areas with long-term but high payoff for military systems. DARPA's projects that interact with the ceramics industry include: composites for advanced aircraft engines, photo optics, and high-temperature super conductors. DARPA's Ceramic Insertion Program, for the development of structural ceramics for use in military systems, has been cited as a model program for industry/government interaction.[21]

o Department of Energy. DOE's involvement with the ceramics industry has been particularly noteworthy in their efforts to reduce both energy consumption and energy pollutants, affecting both the government and private sectors. Accounting for only the unclassified programs, DOE has the largest share of funding for materials science and technology.

Within DOE, the Energy Materials Coordinating Committee coordinates the broad-encompassing research programs under DOE's purview. Under the auspices of the Office of Conservation and Renewable Energy, R&D is conducted to promote the synthesis and process of materials to recover energy from industrial waste heat, and to promote higher fuel economy. It is also involved in R&D for the development of high-temperature structural ceramics for industrial heat exchangers and thermal insulators. In the Office of Transportation Technologies, research continues on the need for more efficient propulsion systems; focusing on ceramics technology and friction, wear and lubrication research for advanced systems. It also sponsors R&D programs on vehicular systems materials and materials for alternative fuels production and utilization, all with applications for the ceramics industry. Still other DOE efforts are involved in corrosion control and high-temperature structural ceramics and CMCs.

DOE's understanding of the need to move technology from the laboratory to the marketplace is evident in several successful programs. One model program is its Continuous Fiber Ceramic Composite (CFCC) Program - a cooperative effort among DOE, industry, universities and materials laboratories to develop a stronger ceramic material that is less prone to brittleness. Another program is the Advanced Materials Development Program Ceramic Technology Project (CTP), a cooperative program between DOE, Oak Ridge National Laboratory , and private firms. CTP utilizes the Oak Ridge National Laboratory's High Temperature Materials Laboratory, a research and user facility that specializes in high-temperature ceramic research.

Although the formation of Cooperative Research and Development Agreements (CRADAs) between government and industry are not limited to DOE, it has been a leader in the initiation of these types of agreements with the ceramics industry. As part of a five-year DOE program for Cost-Effective Machining of Ceramics, one of the first ceramics industry CRADAs was signed in February 1992 between Coors Ceramics Company and the Oak Ridge Laboratory.

"The 3-year $3.6 million agreement supports the development of better ways to produce advanced ceramics for commercial use, specifically in the precision machining area, and is being 50% funded by DOE. Oak Ridge will work on manufacturing, inspection and characterization methods, whereas Coors will provide parts and equipment, as well as final inspection and performance evaluations. The ultimate goal is to establish and optimize a prototype production line after processes are developed."[22]

Funding for the overall five-year DOE program is estimated at $48.6 million.

DOE's proposed FY93 AMPP enhancements include even more cooperative efforts with the ceramic industry. Among those enhancements include: Synthesis and Processing of Material for Ceramic Environments, Advanced Techniques for Near-Net-Shape Processing of Bulk Ceramics, Synthesis and Processing of Polymeric and Organic Super Conducting Materials, Basic Research on Tribology (friction), High-Temperature Load-Bearing Structural CMCs, and Ceramics Manufacturing.[23]

o Department of Commerce. "The DOC's National Institute of Standards and Technology (NIST) plays a leading role in Federal efforts to improve the use of technology in the competition for global markets." Approximately 80 percent of NIST materials R&D is carried out in the Materials Science and Engineering Laboratory, which has five technical divisions including a Ceramics Division.

"The Ceramics Division focuses on advanced ceramics and advanced processing of ceramics, both for structural applications, such as heat engines and heat exchangers, and for functional applications, such as optical and electronic devises. Areas of emphasis include processing science, powder characterization, tribology, and ceramic matrix composites."[24]

This division, with both DOE and the U.S. Navy's Manufacturing Technology Program as co-sponsors, has established a consortium of ten manufacturers and users of ceramic components, plus the University of Maryland, to develop marketing data and guidelines to improve grinding processes for structural ceramics.

A point must be made that the DOC is far more involved with the ceramics industry than just its R&D efforts. DOC's office of International Trade Administration provides economic data and analysis on materials markets in the U.S. Within DOC's Bureau of Export Trade Administration, the Strategic Analysis Division is currently evaluating the results of a major survey of the U.S. advanced ceramics industry, which will serve as a point of reference in government response to the industry in the future. This same division is also responsible for administration of Section 232 of the Trade Expansion Act of 1962 (as amended), and the cases that are initiated under that section. The Patent and Trademark Office serves the industry by both providing exclusive rights to technological inventions and (through its library system) is a source of information on general research developments.

o <u>Department of the Interior</u>. Although only funded for $3.0 million (FY 93) in ceramics and composites, the DOI plays an important role in the development of ceramic materials. Through its Bureau of Mines, DOI conducts new materials studies to meet three objectives: (1) Obtain/disseminate information on new materials needed by the Federal government and industry; (2) Determine the role of new materials as substitutes for conventional materials; and (3) Analyze the effects of this substitution on the economy and national policies. Among the research topics involved with the ceramics industry are the microwave processing of ceramics, and ceramic materials for high-temperature applications.[25]

o Department of Health and Human Services. HHS devotes over 65 percent of its $80 million R&D budget on synthesis and process. Bio-ceramic materials have been well received by the health profession, in various applications. Proposed FY 93 enhancements include programs of excellence in Orthopedic Biomaterials, and the development of an advanced biomaterials laboratory.

o National Air and Space Administration. NASA, either alone or in co-sponsorship with DOE or DOD, has enjoyed a long relationship with the composite ceramics industry.

> "Ceramics research is aimed at developing tough, reliable, high-temperature ceramic composites for turbine engines. Ceramic and metallic coatings are being developed to protect heat engine components in high-temperature corrosive and erosive environments. Lubrication experiments are enhancing our understanding of the behavior of interfaces (e.g. solid-to-solid contact) in heat engines, aircraft components, and space mechanisms."

Proposed FY 93 enhancements include research on enabling propulsion materials, to include CMCs that can operate effectively at temperatures up to 1650 degrees (C).[26]

o <u>National Science Foundation</u>. The NSF is a non-cabinet agency whose director is appointed by the President. Its mission is to increase the country's scientific and engineering base, to strengthen U.S. capability to conduct research, to help promote science education, and to promote international cooperation in the sciences. The NSF has recently initiated a program to enhance research in materials synthesis and process. Of its proposed FY 93 budget, $19.5 million was targeted for ceramics, $129 million for all composites, and $19.5 million for super conducting materials. The NSF sponsors a broad range of materials research laboratories, science and technology centers, national user facilities, and superconductor facilities that provide both equipment and a link to the academic world in the research of possible ceramic applications.

It has long been recognized that the U.S. governmental R&D effort is both massive <u>and</u> disjointed. In 1991, the U.S. Advanced Materials and Processing Program (AMPP) was organized as a means of synchronizing the numerous R&D programs of the Executive Branch. The Federal agencies discussed above, as well as the Department of Transportation , the Environmental Protection Agency, and the Department of Agriculture participate in the AMPP.

While the various agencies of the Executive Branch have the mission of executing R&D programs, the Legislative Branch is responsible for authorizing them and allocating the various funding programs. In addition to the many congressional committees, subcommittees and panels, there are four key legislative offices that influence the support to the ceramics industry: the Office of Technology Assessment, the General Accounting Office, the Congressional Budget Office, and the Congressional Research Service.

INDUSTRY COOPERATION

There are several associations for advanced ceramics firms, where non-proprietary information can be exchanged. Within the United States, the American Ceramic Society and the United States Advanced Ceramics Association are two of the most visible organizations. Both sponsor numerous regional and national symposiums on aspects of the industry. While these associations include the major ceramics firms in America, there are still many firms that are members of neither. International ceramics and materials societies are also found, on a regional basis. U.S. firms' involvement in regional international symposia has increased during the past several years, especially in the Pacific Rim and European Community regions. Most international exchanges are limited to scientific and environmental issues.

Partnerships are another way firms can pass information, to include proprietary information. Many of the larger ceramic firms have partnerships with other U.S. firms, or with foreign firms. Two recent examples are the W.R. Grace and Company / Coors Electronic Packaging Company partnership for the development of electronic packages; and the Corning, Inc. joint research agreement with the Institute for Silicate Chemistry and Institute of Optical Materials, located in St. Petersburg, Russia.[27]

RECOMMENDATIONS

At the same time DOC reports and the Coors/CPS 232 petition indicate a least part of the U.S. advanced ceramics industry is in trouble, other authors point to the decreasing DOD budget and express concerns about the survivability of major DOD contractors and their sub-tier suppliers. If we feel the advanced ceramics industry is critical (see page 2), then there are certain measures we should take to assure its survival. Regardless of the methods chosen, the goal must be to improve U.S. ceramic firm competitiveness in the marketplace.

o **Make the R&D Effort More Efficient**

The first actions should be taken to improve the current R&D effort. There are dozens of U.S. governmental agencies, panels and committees directly involved in the awarding of R&D contracts. There are a dozen more governmental research centers standing by to assist. And there are still several dozen more universities with government contracts related to the ceramics industry. All this at a time when both DOD and non-DOD governmental budgets are under scrutiny. The current AMPP is a start - but is not enough. A thorough review of all ceramics and composites Federal R&D programs needs to be undertaken to improve the efficiency of the annual $150+ million ceramics and $200+ million composites R&D effort.

The Office of Science and Technology (home of the AMPP) is the most likely candidate to oversee this review. It has no pet projects of its own, and no R&D money to spend. It also would be in an excellent position to advise the President on congressional "pork barrel" R&D programs.

Concurrently, DOD and DOE need to review their defense-related classified ceramics projects. Here DARPA (now ARPA) seems the most likely "honest broker".

These two reviews do not necessitate an overall reduction of R&D funds. Sophisticated research equipment is expensive - and necessary. The industry (and U.S. government) would be better served to have fewer, more capable research facilities. Parallel research is not inherently mismanagement; but as the President looks for ways to trim the federal budget, parallel research must at least be managed - I suspect it currently is not.

Cooperative Research and Development Agreements (CRADAs) should be the R&D contract of choice. It focuses on national laboratories for technical improvements; but also calls for industry R&D investment to formulate the commercial process. CRADAs have another advantage - they help ensure the proprietary technology of the participants.

> "Under the legislation that authorized the CRADA, each party owns the technology it brings to the arrangement. Any jointly owned developed technology is owned by the organization that developed the technology and an inexpensive license will be provided to the other partner. With regards to trade secrets, which has in

the past been a real road block with partnership in business, we can now keep our proprietary secrets from ever being published and keep jointly developed technology secret for five years."[28]

o **Provide a Technology Information Service**

Hand-in-hand with the effort to make R&D more efficient, there is an overwhelming need for a capable technology information service that can provide non-proprietary information on current technology as well as current research programs. This information service should be made available, without cost, to all DOC-certified U.S. ceramics firms (to include foreign owned). The intent of this system is to improve the competitiveness of U.S. firms, so process should be an integral part of the data base. Too often, the smaller advanced ceramics firms are left out of any type of R&D or cooperative venture. Information from international symposiums should also feed this system.

o **Re-focus on Ceramic Engine Applications**

As part of the overall R&D effort, a more focused approach must be made on the development of ceramic engines for commercial vehicles. This effort must include a fleet demonstration, with a goal of 1996. Assuming its success, the government should then be prepared to assist in the initial investment of engine assembly plants (see investment suggestions) and interface with U.S. automobile firms to initiate new vehicle sales by the year 2000. The Japanese are currently ahead on this project; but there is no reason the U.S. can't regain the lead. DOE should head this effort.

o **Make Process Capital "Cheaper"**

The next inhibitor to competition is the cost of capital for ceramics processes. Again, the larger firms are at a distinct advantage; but they also find investment costs prohibitive in an industry where the capital requirements are twice those of traditional fabrication and assembly functions of the prime integrators.[29] Advanced ceramic processes should receive special consideration due to their status as a critical technology!

One approach would be to apply a special investment tax credit for firms in this industry. A short term (3 years?) credit of twenty-five percent would ensure a rapid investment in the critically needed process improvements.

Another method of improving both commercial process and surge capability for DOD would be to give added benefits to parallel process equipment - that equipment that can be used for both applications. In this case, a short term investment tax credit of perhaps fifty percent would provide the stimulus. An alternative to the investment tax credit would be an accelerated depreciation program; but would tend to favor the larger firms who had more capital in the first place.

o **Ensure Availability of Critical Components**

The next area is ensuring the availability of critical ceramic components for DOD systems. The first step must be to determine which components are really critical. A major electronics system may have over a hundred different packages. Of those, a certain percentage are probably over-engineered (based on DOD specs), and could be replaced by commercial ceramic or plastic packages. The balance of the packages should be reviewed as to source. If they are no longer available through North American sources, but are available through sufficient foreign sources as to ensure delivery despite any one region's objections, then that should be sufficient.

Under those circumstances where our source is strictly overseas, in one country, we still have options. For critical packages, DOD could certify U.S. firms, and require a U.S. manufactured package. Another option would be for DOD to purchase them outright, and provide them as "government furnished equipment". This option ensures the suppliers a set delivery contract. A third option is to procure the number of critical components for the life cycle of the weapons system and store them until needed. This would preclude concerns over availability at critical times, and allow for the most competitive procurement.

CONCLUSIONS

The advanced ceramics industry has good reason to be optimistic for the future. As the U.S. economy continues its recovery, monolithic and composite ceramics will again be competitive with the more traditional materials. Many firms are investing a higher percentage of their profits into their own R&D programs - an indication they have learned they must develop a commercial process along with the product - and will gain on the current Japanese domination of the marketplace. The future of the advanced ceramics industry is dependent on the industry's ability to develop commercial applications, then be competitive in marketing those applications.

The possibilities for ceramics are excellent. Imagine a ceramic engine capable of producing greater power at up to 30 percent less fuel, with a major reduction in nitrous oxide emissions. Government and industry need to place top priority on the development of this engine, then work with U.S. auto manufacturers to market the engine.[30]

Part of the U.S. industry may be in trouble, specifically the electronic packaging industry. Despite the complaints of several U.S. manufacturers, it appears that much of the loss in competition may be the result of actions on the part of the U.S. firms, and not due to unfair practices by the Japanese firms. Regardless, DOD has to be concerned with a guaranteed supply of critical ceramic packages.

The full potential of U.S. firms will not be realized under the present circumstances. The governmental R&D effort needs to become more efficient. More ceramic firms need to become involved in the R&D process. The transfer of non-proprietary technical information is essential to the growth of the industry. Finally, the industry needs to invest the capital in the process to gain a competitive advantage.

ENDNOTES

1. As defined in the National Critical Technologies Panel Report to the President, March 22, 1991; US Department of Commerce, "Emerging Technologies: A Survey of Technical and Economic Opportunities", Spring, 1990; and US Department of Defense, "Critical Technologies Plan", 15 March 1990.

2. Estimates of the number of advanced ceramics firms, even in the U.S., varies between a hundred and a thousand. For the purpose of this report, industry projections will be based on those firm with sales of advanced ceramics of US$2 million in 1991, as listed in "10th Annual Giants in Ceramics", Ceramic Industry, August, 1992: pp. 23-31.

3. W. Grover Coors, "Ceramic Packages - the Issue of Foreign Dependency", Speech before the OSD Advisory Group on Electronic Devises. 2 March 1992.

4. D.E. Gushee, "Reducing Gasoline and Diesel Use in Transportation", Congressional Research Service Review, Mar-Apr 1991, p. 16.

5. *Joseph Coors, Jr., speech* before the National Technology Initiative Conference, Orlando, FL. 24 March 1992.

6. Gilbert B. Kaplin and Giovanni M. Cinelli, petitioners for Coors Electronic Packaging Company and Ceramic Process Systems Corporation, Petition Under Section 232 of the Trade Expansion Act of 1962, Regarding Integrated Circuit Ceramic Packages (Public Version). 10 Nov 92, p. 57.

7. U.S. Department of Commerce Bureau of Export Administration, National Security Assessment of the Domestic and Foreign Subcontractor Base: A Status of Three U.S. Navy Weapons Systems, March, 1992, p. 87.

8. An excellent, more detailed description of the process is S.B. Bhoduri and F.H. Froes, "The Science and Technology of Advanced Structural Ceramics", JOM, May, 1991: pp 16-21.

9. Thomas Abraham, "The US Ceramic-Matrix Composites Market in the 1990s", JOM, June, 1992: p 44.

10. Thomas Abraham, "The US Advanced Ceramics Industry", JOM, Jan., 1992, p 7.

11. "10th Annual Giants in Ceramics", p 28-29.

12. M.J. Attardo, Office of the IBM Vice President , General Manager, Technology Products, Letter to the U.S. Department of Commerce regarding the effects on the national security of the United States of imports of integrated circuit ceramic packages. 15 Jan 93.

13. Laurel M. Sheppard, ed., "Legislative and Policy Bases of Technology", American Ceramic Society Bulletin, April, 1992, p. 634.

14. Alan W. Wolff, Counsel to the Semiconductor Industry Association, Letter to the U.S. Department of Commerce regarding Petition under Section 232 of the Trade Expansion Act of 1962 regarding Integrated Circuit Ceramic Packages. 1 Feb 93.

15. Randolph J. Stayin, Counsel for Kyocera Corporation, Letter to the U.S. Department of Commerce regarding Investigation of Imports of Integrated Circuit Ceramic Packages under paragraph 232 of the Trade Expansion Act of 1962. 1 Feb 93.

16. It is not possible to separate the responses of U.S. firms from those of the international industry. The current Department of Commerce survey of the U.S. advanced ceramics industry will shed more light on the specific problems facing U.S. firms. The report on this survey is scheduled for release in April (1993).

17. The most detailed descriptions of government agency interest in the advanced ceramics industry can be found in two publications: Volume 1 of The New Materials Society, written by the Bureau of Mines; and the Office of Science and Technology Policy's Fiscal Year 1993 Advanced Materials and Processing Program. Unless otherwise cited, the condensed description of select activities have been taken from these two publications.

18. ACSB Staff Report, "Industry News", American Ceramic Society Bulletin, August, 1992, p. 1175.

19. "Industry News", August, 1992, P. 1176.

20. "Industry News", August, 1992, p. 1176.

21. ACSB Staff Report, "Industry News", American Ceramic Society Bulletin, July, 1992, p. 1053.

22. ACSB Staff Report, "Cooperative Research to Improve Economics Machining", American Ceramic Society Bulletin, November, 1992, p. 1602.

23. Office of Science and Technology Policy, Advanced Materials and Processing: Fiscal Year 1993 Program, April, 1992, pp. 78-89.

24. AMPP: The Fiscal Year 1993 Program, p. 39.

25. The New Materials Society, Volume 1, p. 3.10.

26. AMPP: The FY 93 Program, p. 149.

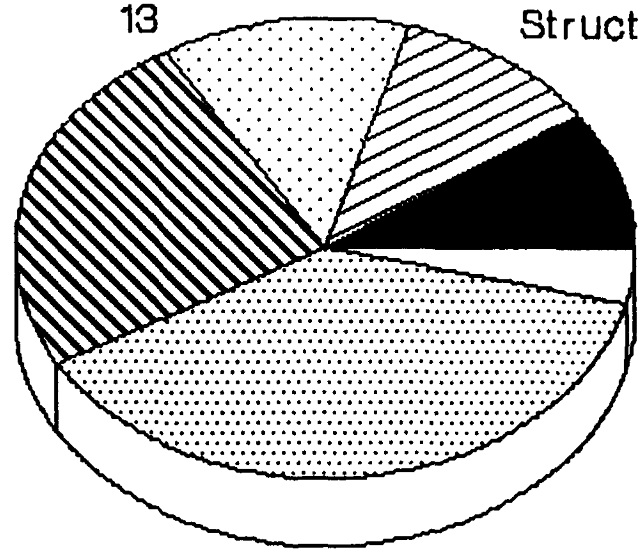
27. "Industry News", August, 1992, p. 1174.

28. Joseph Coors, Jr. speech, March 24, 1992.

29. United States Advanced Ceramics Association, Bridging the Gap, October, 1992, p. 11.

30. Dana Gardner, "Ceramics Drive Turbine Technology", Design News, March 11, 1991, pp. 80-83.

Advanced Ceramics Sales (%)
(1991- Total: $15,342 million)



SOURCE: 10th Annual Giants in Ceramics

ANNEX A

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